Improving Infrared Sensor Temperature Readings by Machine Analysis of Emissivity

by
Timothy M. Johnson

Submitted in partial fulfillment
of the requirements for the degree of
Doctor of Professional Studies
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We hereby certify that this dissertation, submitted by Timothy M. Johnson, satisfies the dissertation requirements for the degree of *Doctor of Professional Studies in Computing* and has been approved.

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Abstract

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Temperature is an important and first step in determining the health of individuals. Using an infrared temperature sensor is easy to do, quick, and does not involve touching a patient. Current devices are useful but technological advances in electronics have brought new capabilities to infrared temperature readings. One advance has narrowed the field of view and thereby increased the distance range of infrared thermometers. This feature would allow health care personnel to avoid exposure to a contagious zone surrounding a patient. A second feature allows users to include the emissivity of infrared readings for humans. Neither of these advances can be exploited by current infrared thermometers leaving a void in the practical application of this new breed of infrared sensors. A 2014 report by the Canadian Agency for Drugs and in Health (CADTH) questioned the accuracy of infrared thermometers and called for more research.

This dissertation explores the parameters of the basic physics underlying infrared sensors. A methodology is developed to conduct various testing regimes using C++ or Python software programming and two surveys of students were conducted using a modern sensor. The evaluation of the results determined the accuracy and range of infrared sensor temperature readings were improved with the inclusion of the emissivity parameter using machine analysis of emissivity.

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Chapter 1

Introduction

1.1 Overview

Modern medicine has come to rely on infrared sensor thermometers for home, office visits, and hospital use as a medical instrument for detecting the temperature of patients. Within the last decade improvements in sensor technology has enhanced infrared sensor with increased accuracy. This allows new approaches to taking temperatures from a longer distance than current technology and retain their medical accuracy. The distance becomes important when we consider the contagious zone around a patient. This zone is a three-foot area around a patient that exhaled breathe collects. If the patient has a contagious disease that is spread by air-borne pathogens, health care workers would be exposed when taking a temperature using either a contact thermometer or a non-contact thermometer that is distance limited to 6 inches. Currently, health care workers simply take their chances by time-limiting their exposure within this contagious zone. This practice is tolerated as they are unaware that their standards and practices have been influenced by older, bulkier, and slower technology that limits users to near-field devices.

There are two parameters that affect the accuracy of the infrared temperature sensors: distance and emissivity. For the purposes of this dissertation, the distance parameter will be examined so any errors attributed to distance will be known. When we examine emissivity, the distance will be considered fixed so that errors introduced by emissivity can be known and addressed. Currently, non-contact thermometers do not consider emissivity as their distance is minimal and the resolution of their readings is larger than changes in emissivity.

1.2 Problem Statement

Infrared thermometers have had a spotty record of acceptance by the medical community due to erratic readings and old technology. Improved technology of infrared sensor technology has allowed new capabilities of utilizing infrared sensor at greater distances than ever before; yet retain and improve their medical accuracy. This dissertation will examine the key parameters for infrared sensors: distance and emissivity.

The assumptions for examining the emissivity parameter are: 1) the distance is fixed, 2) the source temperature is known or can be detected, and 3) humans have an emissivity factor determined by their skin-tone. Our solution methods include known physical laws, computer analysis of testing results, display of graphs, and interpretation of statistical results. The results will be challenged, tested, and compared with theoretical expectations to discover practical limits. Prototypes will be built for testing an experimental infrared sensor and software written to extract pertinent data for examination. The data and their equations will be analyzed using Excel software for presentation in graphs, tables, or both. Software will be written to collect the output of hardware. Analysis of testing results will challenge the test setups requiring hardware and/or software modifications. Means will be developed to determine if problems are hardware or software in origin.

1.3 Solution Methodology

- Stefan-Boltzmann Law examined for temperature's sensitivity to emissivity.
- Beer-Lambert Law examined for temperature's sensitivity to distance.
- Calculation of object temperature using Beer-Lambert Law with Excel software.
- Prototypes tested using a calibrated black body temperature generator.
- Temperature surveys with students using prototype thermometers.
- Emissivity testing with sample pigment colors to discover characteristic behavior.
- Emissivity testing using humans to detect emissivity's characteristic behavior.
- Machine testing for emissivity using grayscale photos.

1.4 Expected Achievements

- Delta *e* values from Stefan-Boltzmann Law.
- Delta k values from Beer-Lambert Law.
- Offset calculation based on distance for use with prototypes.
- Emissivity offset based on analysis of temperature surveys.
- Statistical improvement shown with the inclusion of emissivity corrections.
- Development of an emissivity guide for humans.
- Python computer code for automatic emissivity control.

1.5 Dissertation Roadmap

A literature search will be conducted to determine the state of the art for infrared thermometers. An examination will be undertaken to explore the variable parameters of the basic physics underlying infrared sensors and what the sensitivity of the infrared thermometers is to these parameters. A methodology will be developed to conduct testing to isolate the emissivity parameter from the distance parameter using behavioral analysis. An evaluation of an emissivity survey results to determine what the infrared temperature readings revealed about emissivity. Analysis of skin-tone photos to discover what they reveal about emissivity. This dissertation will develop experimental prototypes to test a modern infrared sensor's capabilities, explore its limitations, and how improvements could help improve temperature readings. Recommendation for further technology improvements will be suggested. This dissertation will not consider thermal imagining systems due to their low accuracy nor variations in temperature due to circadian rhythms.

Chapter 2

Review of Literature

2.1 Overview

Since the nineteen sixties, various studies of emissivity and temperature for humans produced contradictory results or results so broadly interpreted that they provided little guidance. This review will discuss what emissivity is, survey various findings, the effectiveness of various types of thermometers, and look at outcomes from this conundrum. The reason emissivity is a focus is because commonly used infrared thermometers do not make allowance for this variable.

2.2 Emissivity

2.2.1 Motivation

The reason that this dissertation was under taken is out of concern for the safety of health care personnel. There are infrared thermometers that work from 6 inches away as does the experimental thermometer. This leaves little space between a patient and the healthcare worker. Distance is critical because it establishes a buffer zone for the exhaled breath of a patient. According to a 2005 article by Kathy Dix in *Infection Control Today: Clinical Update*, Dr. William Schaffner, professor and chair of the Department of Preventive Medicine at Vanderbilt University Medical Center in Nashville, explains, "In droplet spread, infectious agents are spread from the respiratory tract and usually spread only within three feet of an individual...

"…so most of the risk to those of us who care for patients comes in that immediate environment, where you get into the breathing zone of the patient…

"…and the more time you spend in that zone, the more likely transmission is to occur [14]."

The article provides a list of the following infectious diseases that can be spread by breath:

- Active pulmonary Mycobacterium tuberculosis (TB)
- Active Varicella (chickenpox)
- Disseminated Herpes zoster (Varicella)
- Localized Herpes zoster with potential to disseminate in an immunocompromised/ immune suppressed host
- Active Rubella (measles): Susceptible persons who have been recently exposed to measles (rubeola) and/or chickenpox (varicella) and may potentially be contagious
- Smallpox
- Monkeypox
- Severe Acute Respiratory Syndrome (SARS)/coronavirus infection.
- Avian influenza

The article goes on to paint a grim picture of hospital infection control with a discussion between airborne versus droplet spread of infections. Pertussis is the most common infection exceeding needlesticks and tuberculosis that occupational health services contend with Dr. Schaffer declares.

Allowing caregivers, the option to take a patient's temperature from outside of 3 feet can protect the caregiver’s health and help stop the spread of infections. If the temperature of a patient can be taken from 3 feet of a patient, it would limit the exposure of health care workers to disease, save lives, and help stop the spread of disease. These aspects would be an important contribution to improving the health of society.

A secondary purpose was for data collection and recording of a patient’s temperature for HIPPA records. A study published in 2015 by a student at Newcastle University (UK) suggested a temperature monitoring system to improve patient care. Their system did not include an infrared sensor with distance capabilities. It was a contact thermometer attached to the arm to record and communicated by a wireless network the patient’s temperature data as part of their vital statistics [9]. Their reasons for their study were in essence the same as ours. Two problems not considered in this study were: the health care worker was exposed to a contagious disease while attaching the axillary (armpit) device and the continuous wearing of the device which was uncomfortable. The main benefit of this system was the elimination of one chore performed by nurses: taking temperatures and recording them on patient records. The student’s expectation was that this would free up nurses to perform other duties. What they didn’t realize was the recording of the data takes the pencil out of the nurse’s hands and eliminates human recording errors.

2.2.2 What is Infrared Radiation?

Infrared radiation is commonly identified as heat and the feelings that come when warm or cold. Heat is a phonon or vibration that resonates along the longitudinal or transverse axis of the molecular constituent of the source. There are two types of phonons, acoustical and optical. It is observed that both phonons are mechanical waves generated by atoms either moving toward adjacent atoms omnidirectionally (optical) or moving together like an ocean wave (acoustical) [5] [61].

When the heat from a source is radiated into a medium an absorption mechanism occurs. In an elastic medium (a way of describing air), when molecules are struck by a vibrating force they will transmit that vibration around it absorbing resonate frequencies. This behavior is an acoustical radiation and one of the mechanism by which heat is transferred in a gas (air). The frequency of the radiation will be diminished in strength, but the wavelength doesn't change. This corresponds to an easily noticed characteristic of heat: the further away you are from heat the less warmth is felt and the ambient temperature begins to dominate [13] [26] [42].

2.2.3 How Does an Infrared Sensor Work?

An infrared sensor is designed to respond to the infrared energy (heat) that enters the device from a source when the sensor package is turned to point at the heat source. With a direct access thermometer, there is a portal on the device that allows the sensor within to access the heat source for sampling purposes. This heat source is the residue from the surface temperature of the object. For human, the heat generated from the body core leaves by radiation from the skin surface. This is called the skin surface temperature (SST). The sensor detects (feels) the residue of that vibration and begins to vibrate at the frequency that is detected and permitted by the physical dimensions of the atoms that make up the sensor material.

Deep inside an infrared thermometer are layers of material sensitive to heat that lays exposed to the heat coming through the sensor package opening called a transducer. The transducer's task is to convert mechanical energy into electrical energy. The transducer, in this case a thermopile, is made up of thin layers of two different materials that resonate at the infrared frequency[1] of the incoming energy. The heat energy from the source causes the material's nominal electron state to rise and oscillate at the radiant energy frequency [60]. As the material heats up from the external vibration source, the molecules that make up this material generate (releases) a free electron. Alternating with the layers of material that release an electron are layers of a different material that absorb the electron (Seebeck principle) [53]. These layers of material constitute a transducer called a thermopile which acts much like a diode: when a potential (bias) across the two materials is exceeded it causes current to flow across the junction of the two materials at a known rate proportional to the heat absorbed in the transducer's layers. The thermopile changes heat energy into electrical energy which is easily measured by using analog to digital converters. Further processing in smart sensors convert the current flow into a digital number representing the heat that is created within the thermopile and attributable to the source, the skin surface temperature [16] [24] [50] [70].

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[11] Infrared wavelengths are longer than visible light and have a heat component called radiant energy.

2.2.4 FDA Standards for Infrared Thermometers

The Food and Drug Administration in the United States regulates thermometers and other medical devices [20]. For infrared thermometers, there are numerous standards but as concerns this dissertation, the FDA relies upon the American Society for Testing and Materials (ASTM), founded 1898, to set performance standards for infrared thermometers sold for medical purposes. The specific standard is ASTM E1965-98(2016), *Standard Specifications for Infrared Thermometers for Intermittent Determination of Patient Temperature.* This standard requires, within the range of 37 °C to 39 °C, accuracy of ±0.2 ° [4]. The experimental sensor used in this dissertation has a published accuracy of ±0.1 °C within a specific range of ambient and observed temperatures [35]. A thermometer of this sensitivity cannot be bought at Home Depo or local drug stores.

2.2.5 How Emissivity is Used in Infrared Temperature Sensors

The formula, Equation 1, seen below is known as the Stefan-Boltzmann Law. It describes how the radiated heat seen by the sensor (P_{rad}) is calculated for a receiver unit:

$$\mathbf{P_{rad} = \sigma \mathit{e} A T^4}$$

Equation 1 Stephan Boltzmann Law

In this formula sigma, σ, is the Stefan-Boltzmann constant, $5.6704 \cdot 10^{-8} W/m^2 \cdot K^4$, *e* is the emissivity, A is the area of the thermopile in the sensor, and T is the temperature (in Kelvins) which we seek. P_{rad} is the amount of energy per unit of time (joules) corresponding to the energy transfer seen by the thermopile. This formula works equally well as a source where you go from internal temperature to radiated heat energy [5] [27] [66]. A change in emissivity causes a direct change (inverse) in the radiated heat.

2.2.6 What is Emissivity?

Simply stated emissivity is the ratio of the heat radiated by an object compared to the actual heat of the object. A perfect radiator is called a "black body" because it emits the same amount of heat as contained within the object. A black body emissivity is 1.0. Other objects have lesser values because not all the heat within the body is released by the object. Emissivity is a function of the wavelengths of the heat emitted by the object that may include visible light and infrared radiation. Visible light is observable to the human eye as surface color and infrared radiation is not visible to the human eye. In formulas, italics *e* is the symbol for emissivity. Emissivity could be considered a color filter for heat [32][57].

2.2.7 What is the Sensitivity of Temperature to Emissivity?

Given that…

$$P_{rad} = \sigma e A T^4$$

Let's remove the 4th power of T to see how much effect *e* has on temperature:

Isolating temperature and emissivity: $P_{rad}/\sigma A = eT^4$

Resolving the right side of the equation first: $(eT^4)^{1/4} = e^{1/4} T^{4/4} = e^{1/4} T^1 = e^{1/4} T$

The left side of the equation equal $(P_{rad})(\sigma A)^{-1}$

Then take the root to the 4th power, $[(P_{rad})(\sigma A)^{-1}]^{1/4} = (P_{rad})^{1/4} (\sigma A)^{-1/4}$

Taken together:

$$(P_{rad})^{1/4}(\sigma A)^{-1/4} = e^{1/4} T \Rightarrow (P_{rad})^{1/4} \sigma^{-1/4} A^{-1/4} = e^{1/4} T$$

$$e^{1/4}\,T$$

Equation 2 Emissivity: cofactor of Temperature

From the above analysis, it can be seen that *e* direct changes T by $e^{1/4}$.

Emissivity is a factor that represents a percentage of T making the value of T emitted smaller. For example, if *e* is set to 1.0, then Equation 2 becomes:

$(P_{rad})^{1/4}\sigma^{-1/4}A^{-1/4} = e^{-1/4}\,T \Rightarrow [(P_{rad})^{1/4}\sigma^{-1/4}A^{-1/4}] = 1*T$

Thus $(P_{rad})^{1/4}\sigma^{-1/4}A^{-1/4} = T\,|_{\text{when } e = 1}$

Since σ and A are unalterable constants, and if we allow P_{rad} to be whatever value needed to make T equal to 37 °C, call it P_{rad37}, then at *e* = 1, Equation 2 becomes:

$(P_{rad37})^{1/4}\sigma^{-1/4}A^{-1/4} = 37\ °C$

The sensitivity of temperature to emissivity changes is revealed in temperature centigrade by holding the power constant and changing e incrementally subtracting that resulting temperature from what it should be at e equal 1.

$T - T*e^{1/4}$

In Table 1, ΔT is what the measured temperature would vary **if** $(P_{rad})^{1/4}\sigma^{-1/4}A^{-1/4}$ the source was 37.0 °C and *e* was varied. The table is created by holding P_{rad} constant and varying *e* from 1.0 to .96 then evaluating the equation:

$$\Delta T = T - T*e^{1/4}$$

Equation 3 Temperature sensitivity to Emissivity

Table 1 Temperature Sensitivity to Emissivity

	emissivity	e factor	ΔT= T-Te¼
T	e	e ¼	ΔT
37	1	1	0
37	0.99	0.997491	0.0928489
37	0.98	0.994962	0.1864039
37	0.97	0.992414	0.2806777
37	0.96	0.989846	0.3756832

The sensitivity of temperature is ~ 0.093 °C per -0.01 change in *e* in the normal human temperature range.

2.2.8 What is the Emissivity Value for Humans?

This is a good question and one this dissertation hopes to uncover. It turns out that there are popular sources that ordinary people and even college students would visit to obtain a value for emissivity (for a human) to solve problems. Then there are other sources from journals and papers prepared by scholars that no one takes notice [32] [33]. The problem is this scholarly information isn't found and used as much as the popular sources.

Based on the emissivity from Table 1 in the previous subsection, should an infrared thermometer have a default emissivity of 1.0 and a subject with a skin-tone[2] close to white (0.97) has their temperature read, it will be off by as much as 0.75 °F (0.38 °C). This error exceeds the FDA standard of ±0.4 °F (±0.2 °C) and should not be used to measure human temperatures. If a statistical average of 0.98 is used for emissivity, then the error could be ±0.25 °F. This would keep the reading within the FDA standard guidelines. Unfortunately,

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[2] Skin-tone is caused by a biological polymer found in the epidermis of humans called melanin.

there are numerous sources that state the emissivity of humans is 1.0 and one scholarly source that says it is 0.97 [32]. In medical thermography (a technique of using a matrix of sensor to graphically represent temperature) states "…human skin is almost a perfect emitter, or black body, with an emissivity that is approximately 0.98 [44]."

An Australian study published in September of 2013, in their Journal for General practice psychiatry while using an infrared thermometer that can be adjusted, set their instrument at the "recommended" value of .98 to detect and diagnosis skin infections [38]. Hopefully this dissertation will help shed some light on this problem of using an average emissivity by establishing a tie between skin-tone and temperature with the emissivity setting.

2.3 Temperature

2.3.1 What is a Normal/Fever Temperature?

The discussion on normal/fever temperature should start with a discussion on how the temperature is measured. We use a comparison study conducted in 2016 conducted in the intensive care ward of Imam Ali Hospital of Kermanshan, Iran. Probably the most controversial aspect of taking a temperature is its accuracy. This study uses four common different non-invasive peripheral methods: oral, axillary (armpit), tympanic (ear canal), and an infrared forehead scanner. All four methods were taken at the same time were compare with a central nasopharyngeal temperature taken immediately afterward. The nasal method involves inserting a sensor through the nose 5 cm to the posterior of the pharynx, so it lay between the nose and ears. This bring up an aspect of testing: what is the (gold) standard to which a sample temperature should be compared against. Not selected in this study was the esophagus, rectum or bladder temperature standard due to the non-invasive requirement of the study [29].

The Mayo Clinic treat fever as a first aid classification. Their website simply states that the normal temperature is an average temperature equal to 98.6 °F (37 °C) that can range from between 97 °F (36.1 °C) to 99 °F (37.2 °C) or more. They don't say how the temperature was taken. For a fever, they state the oral temperature would read 100 °F (37.8 °C) or higher. By deduction then the upper range for a normal temperature would be 99.9 °F assuming the normal temperature reading was for an oral thermometer [34].

WebMD, a popular website, treats temperature under its first aid classification as the Mayo Clinic does. The website defines of the normal temperature as an average of normal body temperature of 98.6 °F allowing a range of 1 °F above or below. A fever is 100.4 °F which differs from the Mayo Clinic definition by 0.4 °F. These two sources offer different temperatures for a fever effecting the upper range for a normal temperature [54]. By WebMD definitions, the normal range extends down to 97.7 °F but a treatable symptom of hyperthermia upper range is 95 °F. For this dissertation a low temperature is less than 95.0°F when medical treatment/observation is required.

The National Institute of Health article in the Journal Paediatrics & Child Health, *Temperature measurement in paediatrics*, acknowledged 98.6 °F as the normal body temperature according to traditional teaching [31].

A graphic from a market survey of all the thermometers sold in the UK in 2005 by the Device Evaluation Service of the MHRA at the University Hospital of Wales is shown below [12].

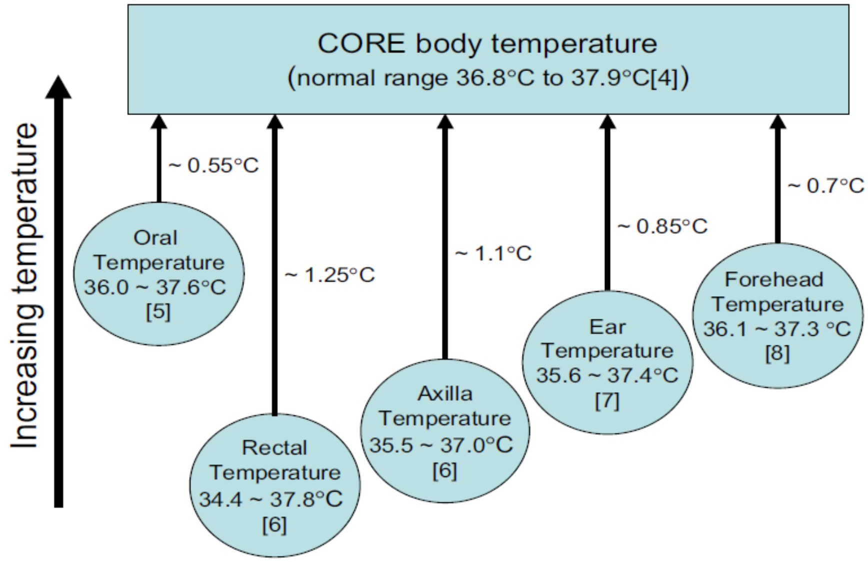

Figure 1 Classification of thermometer types and variation of readings with offsets

Figure 1 is the Rosetta Stone of thermometers because it allows comparison between not only the normal range of the various types of thermometers (seen within the circles) but also the physiological offsets used to estimate the core body temperature for each type.[3] The report also states that the difference seen between body sites are only approximations due to the limited nature of the clinical studies of their sources.

What is not shown are non-contact infrared thermometers because their offsets are unique to their manufacturers. Figure 1 illustrates the extent approximations are used in the normal temperature range for human and the various body locations have different normal temperatures. Each thermometer type could read the same person's temperature slightly differently and resolve to a different value but still be normal. Some thermometers offer

[3] The citation indicators [ ] seen within the circles for the types of thermometers in Figure 1 are for citations within the report.

conversions to the oral temperature by formulas derived from the above offsets. The oral temperature has the least offset for determining the core temperature.

A small but directed criticism of the 98.6 ° F standard determined in 1868 by Dr. Carl Wunderlich was published in 1992 by Philip Mackowiak, MD, and others. Dr. Wunderlich analyzed over a million-axillary reading (armpit) from 25,000 patients published in 1868. Dr. Mackowiak's recommendation was to set the normal temperature for adults to be 98.2 ° F based on 700 readings from 148 patients [33]. Dr. Mackowiak's study referenced over 10 other studies some of which found common cause with his study.

In June of 2011, the author of this dissertation was part of an interdisciplinary team from Wentworth Institute of Technology to present a paper on an infrared sensor and possible applications using the same sensor as used with this study, in Vancouver, Canada [29]. No effort was made to determine a normal temperature in this paper as the paper presented a system for detection using Texas Instrument equipment.

Lena Wong published on a website called the Physics Factbook, a comprehensive study of 20 different papers including historical references in 1997. Of these papers, 7 studies recommended different normal temperatures [68].

This dissertation takes no position on the issue of what is the best normal temperature but simply points out the wide range of opinions and the length of time over which this debate has extended. A discourse on emissivity for thermometers could be just as wide ranging.

2.3.2 What other External Variables Can Affect Temperature Readings?

The UK Medicines and Healthcare (products) Regulatory Agency (MHRA) cites in their 2005 market report that the normal temperature can be affected by a diurnal variation with higher temperature toward the afternoon. The temperature varies with the extremes of age with lower temperatures for the elderly. Gender is another factor based on ovulation. This report also cautions that because a device displays its reading and may or may not include the offset, that this functionality of the device can lead to errors [12].

The diurnal variation is confirmed in the Jan Rustemeyer 2007 study at the Department of Cranio-Maxillofacial Surgery, Bremen, Germany [46]. Here, 26 subjects underwent a 24 hour test of 32 fixed measuring sites that recorded their skin surface temperature (SST) using a contact thermograph called Eidatherm [39]. The mean temperature differences (between subjects high and low temperature readings) was 0.7 °C were observed.

2.3.3 Can Thermometers Register False Negatives/Positives?

In a study of 72 critically ill adults in 2000 by K.K. Giuliano published in the American Journal of Critical Care, the variability between two tympanic and one oral electronic thermometer was undertaken. The readings were compared with a pulmonary artery catheter thermometer with all reading concluding within a one-minute window. Upon comparison, it was evident that one of the tympanic thermometers was at variance with not only the pulmonary artery catheter thermometer but the second tympanic thermometer and the oral thermometer as well. The oral thermometer was the most stable when compared with the pulmonary thermometer. The study concludes with the variances seen in both tympanic thermometers ruling out their use and the suggestion that the oral electronic thermometer be used with critical care patients [22].

In a paper published in 2001 by Neal Latham and others on the accuracy and reliability of new devices of this period found “All the test instruments significantly underestimated higher temperatures and overestimated lower temperatures." This paper was published around the time new technology was coming available and these researchers were not at all enthralled with the prospects of a new age in temperature measurement [30]. In this dissertation, we will find the above description of the errors to be exactly what emissivity corrects.

A review of surveys published in 2002 by J. Craig in Lancet covering nearly 6000 children in 44 studies found that the tympanic thermometer in "rectum mode" when compared to actual rectum readings were inadequate to be used as a device where precision[4] was needed [11].

In 2006, a survey of studies was published by J. Dodd in the Journal of Clinical Epidemiology with findings of poor sensitivity using tympanic infrared thermometer. While the survey had difficulty in establishing a threshold for ear thermometer mode, their finding was that between 30% to 40% of children with a fever would not be detected using an ear thermometer [15].

In a systematic search of numerous medical databases for clinical trials published in the Journal of Australasian Academy of Critical Care Medicine by S. Jefferies and others undertaken in 2011 concerning accuracy of peripheral thermometers (temperatures taken by external devices within a body cavity) in critically ill patients, three studies were found. The critically ill patients were defined as having a temperature > 37.5 °C. The studies

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[4] Precision is repeatability (gets the same number each time) while accuracy is closeness to a known value. It is assumed that the study's summary used an incorrect term.

compared tympanic, oral and rectal thermometers to a pulmonary artery catheter (a sensor inserted into the main heart artery to take the core temperature reading directly). The study found 5 of 7 tympanic thermometers and one oral thermometer read within the ±0.2 °C ASTM standard for accuracy. While citing failures in all the studies it pronounced the studied devices as acceptable. The study also noted that all three rectal thermometers studied were out of bounds [28].

The references cited in this subsection all found errors and low standards in different types of thermometers. These finding are considered clinical studies and definitive. The answer to our inquiry about false negatives/positives would be yes, false positives and negatives are certainly possible.

In November of 2014 the Canadian Agency for Drug and Technologies in Health, CADTH, released a report on *Non-Contact Thermometers for Detecting Fever: A Review of Clinical Effectiveness* [7]. This study identified 523 citations in its literature search of which 20 met the inclusion criteria for their study. Four were systematic reviews and sixteen were non-randomized studies. The systematic reviews' participants ranged from 9 to over 72 thousand participants while the non-randomized studies ranged from 21 to 2000. Since this was a review, the years of publication for the included studies were 2009 to 2014. Ages of the participants ranged from 1 month to 80 years old with most of the studies equally divided between male and female. Methods for comparison with gold standards included: oral, axillary, tympanic, rectal, pulmonary artery catheter, and nasopharyngeal thermometers (devices used varied between the different papers).

While the Canadian survey included a huge number of participants, methodologies, and a variety of conclusions presented, the one key finding from this study that pertains to this dissertation was, “Evidence for the accuracy of infrared skin thermometers is equivocal and requires more research.”

The results of the Canadian survey of non-contact infrared thermometers support the literature search in this dissertation. Additionally, this author believes this dissertation answers the call by the Canadian agency for more research.

Chapter 3

Accuracy and Distance When Using an Infrared Sensor

3.1 Overview

When using an infrared sensor to take temperature, two aspects are important: distance from the target and resolution of the temperature. The distance is a crucial factor in sensing because if you are too far away from the target the sensor doesn’t see the temperature you desire to measure. Distance information is often conveyed to the user in spot sizes, the diameter of the circle that the spot encircles or in field of view (FOV) degrees, the angle measured at the sensor that intercepts the spot diameter at the target.

The resolution tells the user how small an increased in temperature can be detected by the sensor. The accuracy is how faithfully the sensor can interpret the heat that it is detecting. This information is usually found in the manufacture’s data sheets which involves searching for documents. The easy way to find this information out is to look at the display. The resolution is related to how many digits are available to display the temperature's value and whether the digits are whole numbers or decimal numbers. Some sensors are accurate to 5 degrees, meaning the smallest digit in the display will increment by one when the sensor detects a five degree rise in the temperature. Others are much more sensitive and can detect temperature increments in the hundredths of a degree. The Fahrenheit temperature scale can inherently display a smaller unit of heat than Centigrade.

3.2 Published Manufacturer Information on Accuracy

The sensor used for this dissertation is the Melexis MLX90614DCI. Melexis is the name of the company that manufactures the 90614 family of sensors. MLX is the manufacturers designation used by the parts industry. Within the family of products for infrared sensors the designation "DCI" distinguishes a sensor that has medical accuracy, (D), a thermopile that is gradient compensated, (C), and a field of view of 5º, (I) [35].

In Figure 2 the manufacture graphically displays their published results for accuracy in their data sheet.

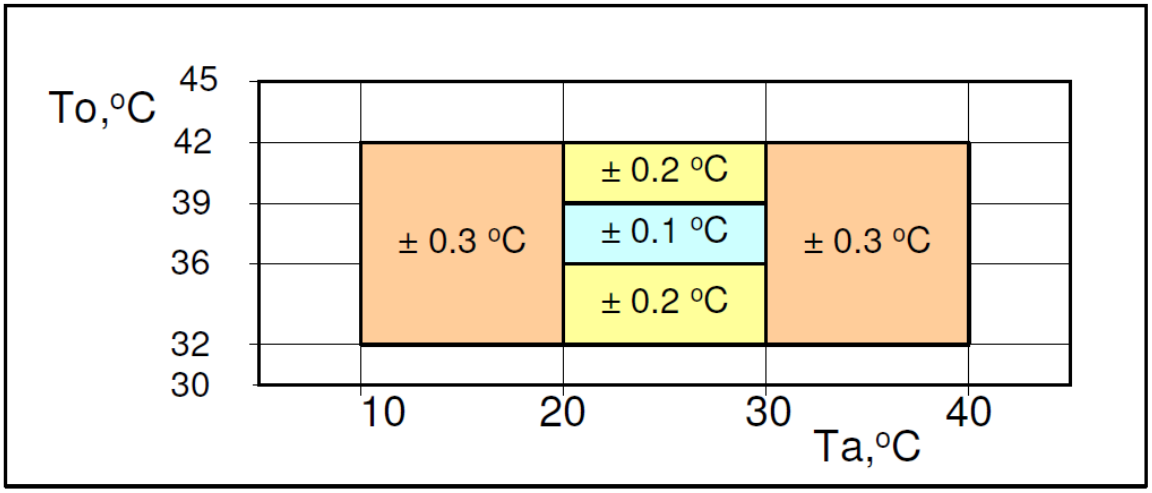


Figure 2 Melexis data sheet accuracy chart

The vertical axis is the observed infrared temperature, To, evaluated by the sensor. The horizontal axis is the ambient temperature, Ta, as measured by the ASIC circuit within the sensor. These two variables define 3 regions of accuracy. The blue interior region has the highest accuracy of ±0.1 °C and above and below in yellow the accuracy is ±0.2 °C. Any observed temperature that falls within either of these colors meets the FDA standard for medical accuracy [4]. The temperature range is from a high of 42 °C to down to 32 °C (107.6 °F to 89.6 °F). If the ambient temperature is outside the range of 30 °C to 20 °C (86.0 °F to 68 °F) shown as the orange color region, no matter what the observed temperature read is the accuracy drops to ±0.3 °C. The key to getting medically accurate temperature reading is to observe the ambient temperature limits.

Once the observed temperature and the ambient temperature is read from the sensor memory, a nested IF statement will reveal the accuracy or possible error of the reading. Here is an example from software written by the author to test the sensor:

```
IF((Ta<20.0) OR (Ta>30.0)){
        accuracy= 0.3;
```

```
    }
    ELSE IF((To>39.0) AND (To<36.0)){
      accuracy= 0.2;
     }
      ELSE{
        accuracy= 0.1;
        }
  PRINT(" Sensor accuracy is %5.3F \r\n", accuracy);
```

3.3 Determining the Accuracy of the Experimental Sensor

A test can be used to verify the accuracy of the sensor by using a calibrated black body. The black body used for this test is the Palmer-Wald Surface Hot Plate, model CBB14KC-1. This instrument can generate and maintaining a consistent temperature with an accuracy of 0.1 degrees [40]. A Certificate of Conformance to ISO9001:2008 by Palmer Wahl is dated 2/8/2016. The calibration was performed by instruments traceable to NIST.

The test for the experimental sensor would be conducted by fixing the sensor to the portal of the recessed tunnel from which a calibrated temperature is emitted. Begin the test by setting the source at any temperature (37.0º C, for example) then wait for the source to stabilized before continuing. During the test, the source is incremented by one tenth of a degree, its degree of calibration, 0.1º C, and having the sensor capture all the temperature differences as the source changes to a higher number. The test ends when the source reaches the new temperature and stabilizes. Examining the results in Figure 3 and Figure 4 following will reveal just how accurate the sensor can measure, how fast the source can change its set point, and the difficulty in conducting the test.

Note should be made of the ambient temperature and the room air should be still. Any sensor readings will be difference due to the placement of the sensor at the portal opening which is 2" from the source. While the source is set at 37.0º Centigrade, the sensor reported readings that vary from that number (see Figure 3). The amount that the device readings vary from the source reveals the extent that the ambient temperature is mixed with the heat source and the actual distance placement of the sensor. Once the sensor is placed in a fixed position the readings represent the temperature values seen by the sensor. The next subsection covers the results of two tests conduction to observe the accuracy of the experimental sensor.

3.3.1 Results of the Accuracy Test of the Sensor

Here is an example of the first 40 reads in a 200 read run while the portal was "open" to ambient room air. Data was recorded left column down then the right column down.

temp is 36.07 degrees C	temp is 36.13 degrees C
temp is 35.99 degrees C	temp is 36.07 degrees C
temp is 36.01 degrees C	temp is 36.07 degrees C
temp is 36.03 degrees C	temp is 36.03 degrees C
temp is 36.07 degrees C	temp is 36.03 degrees C
temp is 36.05 degrees C	temp is 36.09 degrees C
temp is 36.03 degrees C	temp is 36.03 degrees C
temp is 36.07 degrees C	temp is 36.07 degrees C
temp is 36.07 degrees C	temp is 36.03 degrees C
temp is 36.07 degrees C	temp is 36.03 degrees C
temp is 36.11 degrees C	temp is 36.07 degrees C
temp is 36.11 degrees C	temp is 36.09 degrees C
temp is 36.03 degrees C	temp is 36.09 degrees C
temp is 36.07 degrees C	temp is 36.07 degrees C
temp is 36.11 degrees C	temp is 36.05 degrees C
temp is 36.15 degrees C	temp is 36.09 degrees C
temp is 36.09 degrees C	temp is 36.11 degrees C
temp is 36.09 degrees C	temp is 36.11 degrees C
temp is 36.03 degrees C	temp is 36.07 degrees C
temp is 36.11 degrees C	temp is 36.07 degrees C

Figure 3 Sensitivity of sensor with portal "open" to ambient air flow.

In Figure 3, the temperature varied from 35.99ºC to 36.13 ºC which for a source device that only guarantees accuracy to 0.1 °C isn't too bad except the device was set for 37.0 °C. Since the portal of the heat source was open to the ambient temperature, what we are seeing is a cooling effect of almost 1 °C. While hundredths of degrees were seen recorded, the range of 1.14 °C varied too much from the set point. Something was affecting the data.

A modification of the test to correct for the problem described above was found: a circular piece of cardboard paper was taped over the portal to close off the ambient air with a small hole poked thru so that just the sensor could look inside. This in effect stopped the ambient air mixing allowing the heating/cooling of the air trapped within the portal to be observed. With the ambient air flow muted and a new set point of 36.3 ºC, an attempt was made to read the source temperature of the. This information is recorded in Figure 4.

```
Observation                                 Heater
Number              Temperature             On Off

# 0 temperature is 36.31 Centigrade            Off
# 1 temperature is 36.31 Centigrade         On
# 2 temperature is 36.31 Centigrade         On
# 3 temperature is 36.31 Centigrade         On
# 4 temperature is 36.31 Centigrade         On
# 5 temperature is 36.35 Centigrade         On
# 6 temperature is 36.35 Centigrade            Off
# 7 temperature is 36.35 Centigrade            Off
# 8 temperature is 36.31 Centigrade         On
# 9 temperature is 36.31 Centigrade         On
# 10 temperature is 36.31 Centigrade On
# 11 temperature is 36.35 Centigrade    Off
# 12 temperature is 36.35 Centigrade    Off
# 13 temperature is 36.35 Centigrade    Off
# 14 temperature is 36.37 Centigrade    Off
# 15 temperature is 36.37 Centigrade    Off
# 16 temperature is 36.37 Centigrade    Off
# 17 temperature is 36.31 Centigrade    Off
# 18 temperature is 36.31 Centigrade    Off
# 19 temperature is 36.31 Centigrade    Off
# 20 temperature is 36.31 Centigrade    Off
# 21 temperature is 36.31 Centigrade    Off
# 22 temperature is 36.31 Centigrade    Off
# 23 temperature is 36.29 Centigrade On
# 24 temperature is 36.29 Centigrade On
# 25 temperature is 36.29 Centigrade On
# 26 temperature is 36.29 Centigrade On
# 27 temperature is 36.33 Centigrade    Off
# 28 temperature is 36.33 Centigrade    Off
# 29 temperature is 36.33 Centigrade    Off
# 30 temperature is 36.31 Centigrade    Off
# 31 temperature is 36.31 Centigrade    Off
# 32 temperature is 36.31 Centigrade    Off
# 33 temperature is 36.31 Centigrade    Off
# 34 temperature is 36.31 Centigrade    Off
# 35 temperature is 36.31 Centigrade    Off
# 36 temperature is 36.27 Centigrade On
# 37 temperature is 36.27 Centigrade On
# 38 temperature is 36.27 Centigrade On
# 39 temperature is 36.31 Centigrade    Off
# 40 temperature is 36.31 Centigrade    Off
# 41 temperature is 36.31 Centigrade    Off
# 42 temperature is 36.29 Centigrade On
# 43 temperature is 36.29 Centigrade On
# 44 temperature is 36.29 Centigrade On
# 45 temperature is 36.29 Centigrade On
# 46 temperature is 36.29 Centigrade On
# 47 temperature is 36.29 Centigrade On
# 48 temperature is 36.23 Centigrade On
# 49 temperature is 36.23 Centigrade On
# 50 temperature is 36.23 Centigrade On

Observation                                 Heater
Number              Temperature             On Off

# 51 temperature is 36.29 Centigrade On
# 52 temperature is 36.29 Centigrade On
# 53 temperature is 36.29 Centigrade On
# 54 temperature is 36.33 Centigrade    Off
# 55 temperature is 36.33 Centigrade    Off
# 56 temperature is 36.33 Centigrade    Off
# 57 temperature is 36.33 Centigrade    Off
# 58 temperature is 36.33 Centigrade    Off
# 59 temperature is 36.33 Centigrade    Off
# 60 temperature is 36.33 Centigrade    Off
# 61 temperature is 36.33 Centigrade    Off
# 62 temperature is 36.33 Centigrade    Off
# 63 temperature is 36.31 Centigrade    Off
# 64 temperature is 36.31 Centigrade    Off
# 65 temperature is 36.31 Centigrade    Off
# 66 temperature is 36.29 Centigrade    Off
# 67 temperature is 36.29 Centigrade On
# 68 temperature is 36.29 Centigrade On
# 69 temperature is 36.27 Centigrade On
# 70 temperature is 36.27 Centigrade On
# 71 temperature is 36.27 Centigrade On
# 72 temperature is 36.29 Centigrade On
# 73 temperature is 36.29 Centigrade On
# 74 temperature is 36.29 Centigrade On
# 76 temperature is 36.31 Centigrade    Off
# 77 temperature is 36.31 Centigrade    Off
# 78 temperature is 36.31 Centigrade    Off
# 79 temperature is 36.31 Centigrade    Off
# 80 temperature is 36.31 Centigrade    Off
# 81 temperature is 36.31 Centigrade    Off
# 82 temperature is 36.29 Centigrade    Off
# 83 temperature is 36.29 Centigrade On
# 84 temperature is 36.29 Centigrade On
# 85 temperature is 36.29 Centigrade On
# 86 temperature is 36.29 Centigrade On
# 87 temperature is 36.29 Centigrade On
# 88 temperature is 36.29 Centigrade On
# 89 temperature is 36.29 Centigrade On
# 90 temperature is 36.29 Centigrade On
# 91 temperature is 36.31 Centigrade    Off
# 92 temperature is 36.31 Centigrade    Off
# 93 temperature is 36.31 Centigrade    Off
# 94 temperature is 36.27 Centigrade On
# 95 temperature is 36.27 Centigrade On
# 96 temperature is 36.27 Centigrade On
# 97 temperature is 36.27 Centigrade On
# 98 temperature is 36.27 Centigrade On
# 99 temperature is 36.27 Centigrade On
```

Figure 4 Sensitivity of sensor with portal "closed" to ambient air flow.

The data shows that the sensor does record data down to the hundreds as the temperature source changed from heating to a cooling phase by shutting off the heating element to allow the ambient air to cool the air trapped inside the portal. The range was from 36.23 °C to

36.37 °C. The air temperature range was 0.14 °C as the source maintained the set point temperature within ±0.07 °C. This is better and confirms the advertised accuracy of the Palmer-Wald Surface Hot Plate temperature generator to within 0.1 °C. It also demonstrates the capabilities of the sensor to read changes in temperature down to 0.01 °C.

This improvement came about by controlling the ambient air flows. This type of problem with the ambient air will surface again when the sensor is moved 36” away from the heat source with three feet of ambient air flow between the sensor and the target. A different method was employed to solve this distance problem, but it is not discussed in this dissertation as the focus is on emissivity.

Also, observable in Figure 4 is the readings consist of only odd numbers. While the claim that the sensor is accurate down to 1/100 of a degree centigrade is valid, not all values for the hundredth position are seen. This seems incorrect that as the source changes its temperature, the sensor never captured an even number in the hundredth position.

3.3.2 Odd Number Problem.

The question that needs to be asked: is it the software or the hardware (the sensor itself) that is causing the problem of missing values in the hundredth position [63]?

The datasheet for the sensor sheds some revealing light on this problem [35]. The manufacturer says the sensor has a resolution down to 0.01 °C but the I2C bus limits the sensor to reporting to 0.02 °C resolution. The I2C bus sends 3 bytes reporting the temperature to the microcontroller in hexadecimal format. The manufacturer provides software algorithm for changing the data in hexadecimal into a decimal value. The I2cC buss uses two bytes for the data giving us a 16-bit data word and the third byte is a CRC error correction code. The information seen in Figure 4 is correct based on having two bytes of data coming off the I2C bus. The sigma-delta ADC on board the smart sensor calculates 17 bits and the memory holds 17 bits. The least significate bit is dropped during processing for the I2C bus communication parameters. Since this is a consideration during design manufacturing, one could presume that the decision was made to only send 2 bytes of data as opposed to 3 bytes needed for all 17 bits [35]. The sending of the extra bit could create a choke point in the communication link if speed was a factor in the design process over accuracy. The answer to the question for this subsection is the firmware in the sensor processing the I2C data is the source of the odd number reporting.

3.3.3 What is the Effect of Distance upon Accuracy?

What is the effect of distance upon the accuracy of infrared temperature readings? One method to determine this would be to detect the difference between a normal temperature and a fever temperature as the distance is increased. A test was conducted on May 16, 2016 using two different temperatures level with the Palmer-Wald Surface Hot Plate source. The normal temperature was set at 98.6 ºF (37.0ºC) and the fever temperature was set at 101.4 ºF (38.5 ºC). The following table shows the reading where distance is a criterion:

Table 2 Normal vs. Fever readings with distance parameter

Temperature reading in Centigade				
Dist inches	Normal	Fever	difference	
2	36.91	38.41	1.5	
6	36.71	38.11	1.4	
12	35.81	37.39	1.58	
18	35.05	36.29	1.24	
24	33.91	34.57	0.66	
30	31.45	32.43	0.98	
36	29.05	29.85	0.8	
42	27.05	28.05	1	
			0.997955	correlation

The correlation factor of 99.7% relates to the extent the normal and fever curves match each other. If two data sets had the exact same numbers, the correlation would be 100%. What this value says is despite the obvious differences (in the difference column for each row) the line bends and flexes nearly perfectly as the source temperatures roll off from their initial high points [17]. The only effect apparent is the lower temperature detected by the infrared sensor.

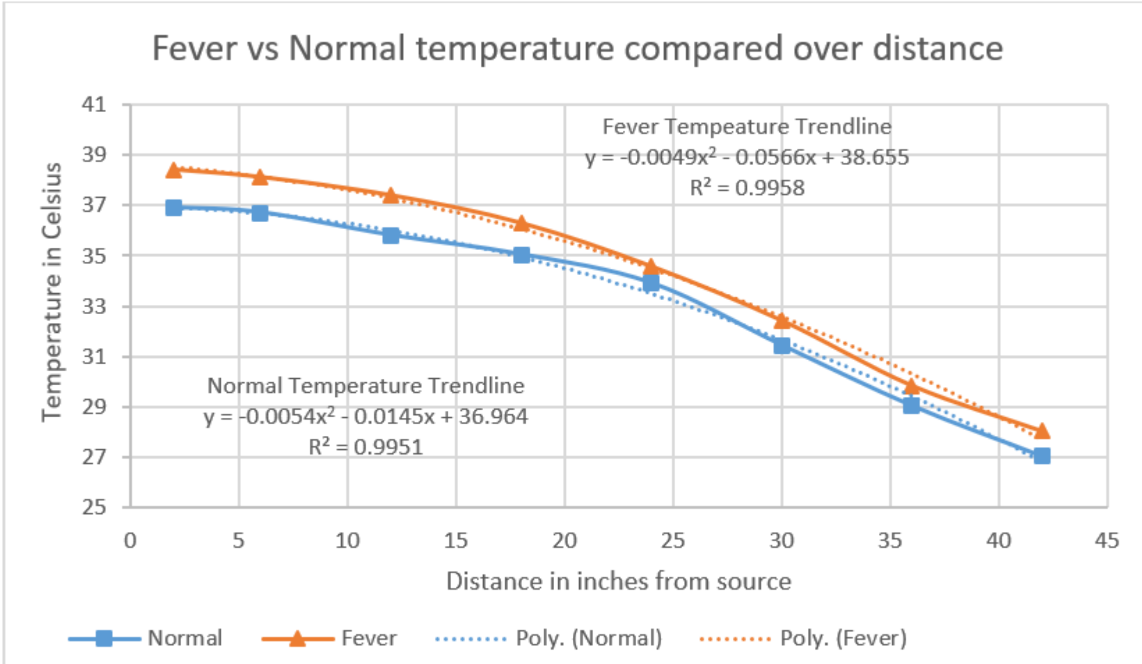


Figure 5 Fever vs. Normal Temperature over Distance

This graph of the data collected from Table 2 demonstrates the effect of distance (horizontal axis in inches) on temperature (vertical axis in degrees Celsius). The source temperature is at zero inches The gradually increasing slope is called roll-off. As the distance increases, the temperature decreases due to the negative slope. This graph shows the roll-off with distance out to 42”. The correlation between the two curves’ trendlines was in the high 99th percentile. The representative equation of the curves, called trendlines in Excel, allow a dotted line to be laid in over the curve that can be useful for interpolation. Equation 4 and 5 below are those equations. If a distance is entered as x into one of these equations, the expected temperature will be returned. An additional value, R^2, called the coefficient of determination. This value gives the expected degree of accuracy for a model based on observed data.

Figure 6 Testing setup

The source for the heat was the Palmer-Wald Surface Hot Plate seen above in Figure 6. The data for this graph was collected using an mbed microprocessor [36] connected to the Melexis infrared temperature sensor, MLX90614, set with an emissivity of 1.0 displayed on a terminal monitor for recording purposes [35]. This basic prototype was used in all sensor readings for this dissertation.

The temperatures for this experiment were collected to determine if at a range of 36" the normal temperature could still be distinguished from a fever temperature. This graph shows that both heat temperature signals were unique.

The normal temperature roll-off equation is temperature (y) is determined by a polynomial for distance (x):

$$y = -0.0054x^2 - 0.0245x + 36.964$$

Equation 4 Trendline for Normal Temperatures

and the fever temperature formula is:

y = -0.0049x2 -0.0566x + 38.655

Equation 5 Trendline for Fever temperature

These equations fit a line/curve to the data and calculates the R^2 value. This information is seen in the graph as dotted lines visible when the trendline differs from the smoothed curve representing the actual data (otherwise the curve and the trendline overlap one another obscuring the dotted line). As an observation, the trendlines found the y-axis zero crossing (when x = 0) to within 0.036 °C for the normal temperature curve and within 0.155 °C for the fever curve.

3.3.4 Comments:

Figure 5's overlay of temperature curves shows two temperatures curves with different starting points whose data points were collected in increments of six inches. During the data collection the temperature source was held to a normal temperature of 37.0 °C (98.6 °F) until all distance being considered were measured then the temperature source was changed to a fever temperature of 38.5 ºC (101.4 °F). A family of curves exist unique for each source temperature that is detectible out to 42". The temperatures were detectible by the Melexis MLX90614 infrared temperature sensor [35]. Another observation from this testing is the sensor should to be able to detect a change in emissivity at 36" because of the separation of temperatures.

Additionally, in the collection of the data, the sensor was first "zeroed out" so that it was exactly in the center of the 3" diameter round emitter portal. The sensor was located at a distance of 2" where the heat exited the source portal. The heat travels 2" along a tube with a 3" inner diameter. The data was collected by increasing the distance of the sensor from the source in multiples of six inches. The MLX90614 infrared sensor found the hottest temperatures closest to the source. As the distance increased, the decline of the temperature readings was evident. Evidence of the heat signal rising through the ambient air and some effect from the Coriolis forces as it left the source portal was found [41].

3.4 Heat Transport Through the Air Medium

An experimental test was conducted on October 18, 2017 to determine the heat loss through the air medium using the MLX90614DCI sensor. The setup is similar to that seen in Figure 6 except the reading were taken at 2”, 6”, 12”, 24”, and 36” then analyzed. The experiment goal was to determine what happens to the source heat as it radiates out from the source up to 36” away. The test setup is similar to that shown in Figure 6 below. The software written for this experiment in C++ program that reads and writes 200 readings logging the results on a terminal software program called TeraTerm running on a computer. The goal is to identify different temperature readings collected as the sensor moves horizontally across the plane of the source portal during the test.

3.4.1 Results

At 2” the collection had 30 regimes, 14 different temperatures, and regime lengths that varied from 20 similar readings to short regimes of 4 or 5 reading. The range of temperature reading varied from a high of 36.97 °C to 36.75 °C. The sensor was not moved at this location. Since this distance is located at the portal exit for the heat source from the Palmer-Wald Surface Hot Plate source where the surface plate is recessed 2”, we are observing the instrument’s tracking control of the temperature.

The only information to be learned at this distance for subsequent distances is the source temperature can vary by the same amount or more because the accuracy of the Palmer-

Wald Surface Hot Plate is ±0.1 °C. This location appeared to only capture one side of the temperature range as our sensor didn't see any reading greater than 37 °C. The two inches transmission loss could account for that being the case. When taking human temperatures there is no such issue as the human temperature has a much longer time base for control.

At 6" the sensor was not moved and only a cursory examination showed temperature regimes similar to 2" but had a wider temperature range. There were 34 regimes. The range varied between 36.29 °C to 36.45 °C. A number of regimes of extended length >10 at the same temperature. It seems some of the longer regimes from 2" had split up.

At 12" the sensor is moved across the source portal for the first time. There were 36 sets of temperatures of length 5 or more. The range was from a low of 35.11 °C to 35.31 °C with 12 regimes of the same temperature. It appears that the core temperature had fractured again but the length of the path of the sensor as it moved through each of the regimes was shorter.

At 24" a new development occurred. The regimes were experiencing jumps of 1 whole degree Celsius or more between them. Some regimes had 4 degrees Celsius of separation. There were 24 jumps of this magnitude. There were 36 sets of regimes with 5 or more with the same temperature readings in that regime. The temperature range of the regimes ranged from 21.13 °C (ambient) to 32.47 °C. The range of for 24" was 11.34 degrees Celsius wide.

At 36" the same behavior was seen with some regimes at ambient temperature and others at elevated levels. There were 37 regimes. There was one region where the temperature jumps only moved about 0.50 away from their neighbors for a total of 21 jumps in temperature.

3.4.2 Discussion of Results

Each reading is a temperature observed within the *cone of interest*: a conical shape between the sensor at the apex of the cone and the source portal at the base with a variable distance between of 2”, 6”, 12”, 24”, and 36”. What is of interest as the sensor is moved is: 1) the number of different regimes, 2) the number of readings in each regime (length), and 3) the temperature range. All the temperature readings are dependent on the speed and pattern of the movement because the data collection is being done manually. Each distance this test is conducted at is time separated from the previous and generates a collection of readings. As the distance becomes larger, the temperature between the different sets drops lower as expected.

The different temperatures reading occur across a region in space the heat passes through and is sequentially recorded in the data. Since the thermometer is moving, different temperatures indicate different regimes are dominant at that location in space.

This behavior illustrated how the temperature from a human through radiation mixes with the ambient temperature. More ambient readings were being seen the further away from the heat source as the sensor was passed across the 3” diameter portal of the Palmer-Wald and that similar temperatures stay together even as they cool off. The groupings get smaller as you move further away but at 36” they are still detectable. Beyond this distance and detection becomes difficult. This leads to a general rule that as the object temperature drops, drawing closer to the ambient temperature, detection becomes impossible as the object temperature becomes merged with the ambient temperature. The larger the difference between the two, the further away from the source temperature this will occur.

3.5 What is the Attenuation of Temperature at Distance?

In planning for a temperature survey of volunteers, assuming all the subjects are at the same distance from the sensor eliminates any variation due to distance but in practice some variation is inevitable. This section examines how this variation can be quantified. An understanding of the attenuation that distance has upon temperature is essential in taking a good temperature reading.

The Beer-Lambert Law seen in Equation 6, could be used as the theoretical basis to solve for the intensity of the heat at the origin based on the intensity values at known locations:

$$\mathbf{Log_{10}\ (Io/I) = \alpha CL}$$

Equation 6 Beer-Lambert Law

where L is the distance in meters, C is the concentration of the absorber, I and Io is the intensity at the distant location and at the origin, and α is the absorption coefficient [8]. This formula is useful not only for chemical analysis of attenuation but for electromagnetic waves consisting of photons attenuation through atmosphere [25]. Another reference from Wikipedia [56] covers a deeper explanation of this law but is not necessary for this dissertation.

The formula calls for *intensity* at the origin and at the sensor location; however, the only measurements taken were infrared temperatures readings. What is needed is a conversion to change *intensity* into temperature. Intensity is radiant flux which is the radiant energy transmitted or received. Radiant energy is measured in joules [64]. Fortunately, there is a formula that converts joules into temperature: 1 calorie or 4.184 joule of heat energy is equivalent to the temperature change to raise 1 gram of water 1.0 °C [51]. The absorption coefficient α and C are both look-up constants and won't change for this consideration and while they represent different aspects of attenuation, for our consideration we could call them "k" for absorption. D could represent the distance in inches but for calculation purposes joules and meters are used; so, we will have conversions applied to Equation 6. Change the symbols in Equation 6 to represent a revised formula. The I's become T's, the distance is changed to D for clarity, and add the constant "k" for attenuation to represent the concentration and density (αC). We have changed the formula into:

$$\log_{10} (To/T) = kD$$

Equation 7 Beer-Lambert Law Rearranged

Since we have the all the data necessary to solve this formula for "k".

$$[\log_{10} (To/T)]/D = k$$

Equation 8 Temperature's Sensitivity to Distance: k

From Table 2 we will build and graph the values of k in the table below (Column H). Information from Table 2 is included in the three left hand columns in a slightly different order to calculate the value of k. Intensity is calculated as specified above. A dummy distance value of 0.001 was entered for graphing purposes.

Table 3 Calculating attenuation coefficient k based on distance

	A	B	C	D	E	F	G	H	I
1	Temperature in C			Intensity Calculations					
2	Dist "	Source T	local T	Io	I	meter dist	Dist "	k	k trend
3	0.001	38.6	38.6	161.5024	161.5024	0.0000254	0.001	0	0.0080
4	6	38.6	38.11	161.5024	159.4522	0.1524	6	0.036407	0.0260
5	12	38.6	37.39	161.5024	156.4398	0.3048	12	0.04538	0.0440
6	18	38.6	36.29	161.5024	151.8374	0.4572	18	0.058618	0.0620
7	24	38.6	34.57	161.5024	144.6409	0.6096	24	0.078556	0.0800
8	30	38.6	32.43	161.5024	135.6871	0.762	30	0.099266	0.0980
9	36	38.6	29.85	161.5024	124.8924	0.9144	36	0.122094	0.1160
10	42	38.6	28.05	161.5024	117.3612	1.0668	42	0.129972	0.1340
11						correlation columns H & I			0.9913

We next graph the values for k:

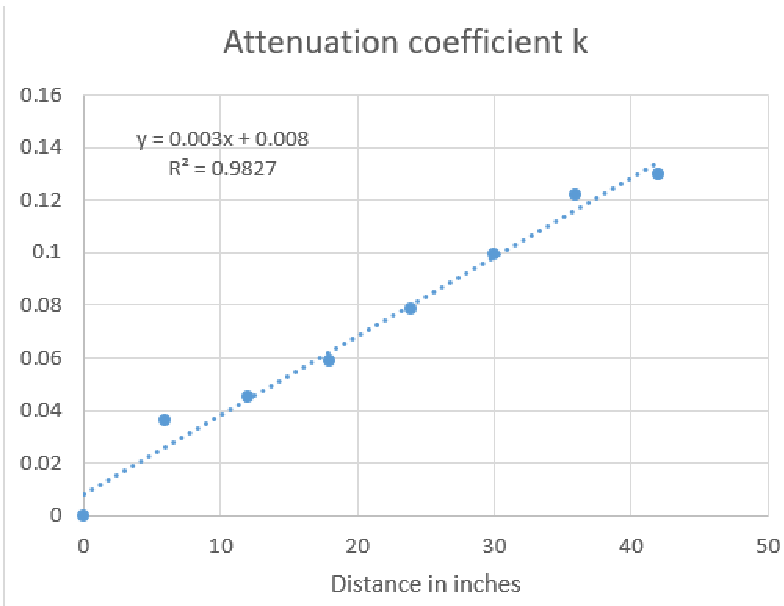


Figure 7 Graph of values derived for k

In Figure 7, the vertical axis are the values for the coefficient k in degrees centigrade. Obviously, k is not constant. This could be caused by errors in the SST readings taken by the experimental sensor as the range of k varies from 0.0 to 0.134 °C per inch. The linearized formula to calculate **k** based on distances **x** shows a high value for the coefficient of determination (R^2): 0.9827. This is slightly different from the correlation of the calculated input data, column G, with the trendline calculation of Figure 7 in column I of: k = 0.003D-0.008 seen in Table 3 which is .9913 seen in cell I11.

What do we have? A graphical method to solve for the source temperature if all we know is distance (L) and the local temperature reading (T) at 36" or any other distance. The temperature (T) and the distance (L) are "tied" together by attenuation factor k in a one to one relationship**.** The trendline formula seen in Figure 7 allows you to use distance to determine k. Once you have k you can compute the source intensity: Io from which you can determine the source Temperature which is the point of taking a temperature.

3.6 Calculating Source Temperature using Distance and SST as Inputs

This is a way to determine the source temperature (To) of a patient without using an offset value. A formula can be derived from the Beer-Lambert Law. The following is Equation 7 as we have changed it in the last section:

$$\mathrm{Log}_{10}\,(To/T) = kD$$

We will further change the equation using logarithmic rules:

$$\log_{10}\,(To) - \log_{10}\,(T) = kD$$

move the $\log_{10}$ (T) term:

$$\log_{10}\,(To) = \log_{10}(T) + kD$$

This modifcation shows that the $\log_{10}$ (T) (the SST reading of the sensor) plus the attenuation times distance can sum together to give us the $\log_{10}$ (To).

Removing "$\log_{10}$" is accomplish using an exponential rule by raising both sides of the equation by the power of 10, for example: $10^{\log(To)} = To$.

$$\mathbf{To = T + 10^{kD}}$$

Equation 9 Solving for Source Temperature, To

This solution has been automated this on an Excel spreadsheet including substituting in the trendline equation value for k. Below is an example of the automatic solution using D = 42" showing no error because I am using Table 3 data for k (cell C8).

	A	B	C	D	E	F
1		Solution for Io if I and D are known				
2		The equation ==>	log (Io/I) = kD			
3		Temp local	28.05	Centigrade		
4		distance "	42	1.0668	" ==> m	
5		T → Intensity conv	4.184			
6		local Intensity (I)	117.3612			
7		Log(I) ==>	2.0695			
8		k=	0.12997	from table or trenline formula cell J4		
9		kD =	0.138651996			
10		log (Io/I)=	0.138651996			
11		log (Io)-log (I)=	0.138651996			
12		therefore Log(Io)=sum of kD (C9) & Log(I) (C7)				
13		Log(Io)=	2.208			
14		10^(C13)=Io ==>		161.5015		
15		Io divided by 4.184 ==>		38.60		
16			Known source Temperature	38.6		
17			difference	0.00		

Figure 8 Automatic calculation of To knowing Distance, T_{local} and k.

Automatic insertion of k calculation from the trendline formula from the entry of distance data can occur by linking several Excel cells together appropriate for this data calculation.

The trendline equation of Figure 7 is seen in Figure 9 with solution for k using D in cell J4, followed by Figure 10 showing those results entered into the automatic solution for To.

I	J	K	L
Solution for k if D is known by trendline equation			
	k=-.003*Dist"+.008		
Distance "	42	from C4	
k resolved	0.134		

Figure 9 Automatic k calculation from trendline equation

The same temperature and distance is entered below as in Figure 8.

	A	B	C	D	E	F
1		Solution for Io if I and D are known				
2		The equation ==>	log (Io/I) = kD			
3		Temp local	28.05	Centigrade		
4		distance "	42	1.0668	" ==> m	
5		T → Intensity conv	4.184			
6		local Intensity (I)	117.3612			
7		Log(I) ==>	2.0695			
8		k=	0.134	from table or trenline formula cell J4		
9		kD =	0.1429512			
10		log (Io/I)=	0.1429512			
11		log (Io)-log (I)=	0.1429512			
12		therefore Log(Io)=sum of kD (C9) & Log(I) (C7)				
13		Log(Io)=	2.212			
14		10^(C13)=Io ==>		163.1082		
15		Io divided by 4.184 ==>		38.98		
16			Known source Temperature	38.6		
17			difference	0.38		

Figure 10 Calculating To from data using k calculated by trendline equation

An error using the Trendline formula is 0.38 °C. This is at the extreme end of the sensors range, 42”. Here are the ranges for this To solution spreadsheet using Trendline data from 6” to 42” and an error correct followed by an offset:

	low	high	total range
no correct	-0.14	0.38	0.52
correction	-0.07	0.04	0.11
with error correction of -D4*C5/2 included			
-2.02886	161.0793		
0.14	38.64	+ offset	
	38.6		
	0.04	difference error (+ is high, - is lower)	

Figure 11 Automatic To calculation error ranges with correction for D=42”

The trendline error can be seen in Figure 10 since the calculated k value of 0.134 differs from the k value of 0.12997 from Figure 8 which was calculated from real data at distance 42” in Table 3. This error was noticed while building the automated solution of To using the Excel Trendline formula even with the high value of correlation shown. The trendline error is a result of the fit of the trendline on the data points from real data collected during testing at the extreme ends.

Summary

Being able to project the source temperature based on the local reading is very handy. What is not handy is the errors introduced by solutions based on predetermined and generalized values of the attenuation value k.

Looking beyond that issue, the solution gives you the heat emitted by the source after the emissivity factor is removed. It is the skin surface temperature (SST) on the surface of the patient and not the oral or core temperature. An offset is needed to correct from SST to other modes of common temperature readings which is addressed in section 4.6.

3.7 Calculating the Sensitivity of Temperature to Distance from Data

Sensitivity can be calculated from slope between known points. Because the temperature roll-off is not linear, sensitivity has more than one value depending upon the distance.

Table 4 Sensitivity of Temperature to Distance

using normal curve data				3 slope		
To	T	distance	slope/inch	ranges	temp range	distance
37	37	0.001	0			
37	36.91	2	-0.045	<.05	37-36	0 to 6"
37	36.71	6	-0.04833	<.05	37-36	0 to 6"
37	35.81	12	-0.09917	<.15	36-32	12" to 26"
37	35.05	18	-0.10833	<.15	36-32	12" to 26"
37	33.91	24	-0.12875	<.15	36-32	12" to 26"
37	31.45	30	-0.185	<.25	32-27	26" to 42"
37	29.05	36	-0.22083	<.25	32-27	26" to 42"
37	27.05	42	-0.2369	<.25	32-27	26" to 42"

The data above in Table 4 again has the three columns from Table 2 reproduced in the left-hand columns in a slightly different format. These columns are used to develop the middle column: slope/inch. The read temperature intensity column label "T" is divided the column "To" which is the source temperature (which was the same for all the rows). This ratio which is the fractional value for percent of roll-off at that distance specified by the row. This value is then divided by the distance in inches from column "distance" and recorded in the "slope/inch" column.

The data derived is then placed in a graph such as Figure 5 for display but here we are isolating on the slope to indicate the possible errors at various distance that can occur if a pre-determined distance is used for calculation of the temperature. The following graph shows the plot with slope indications for 3 linearized regions.

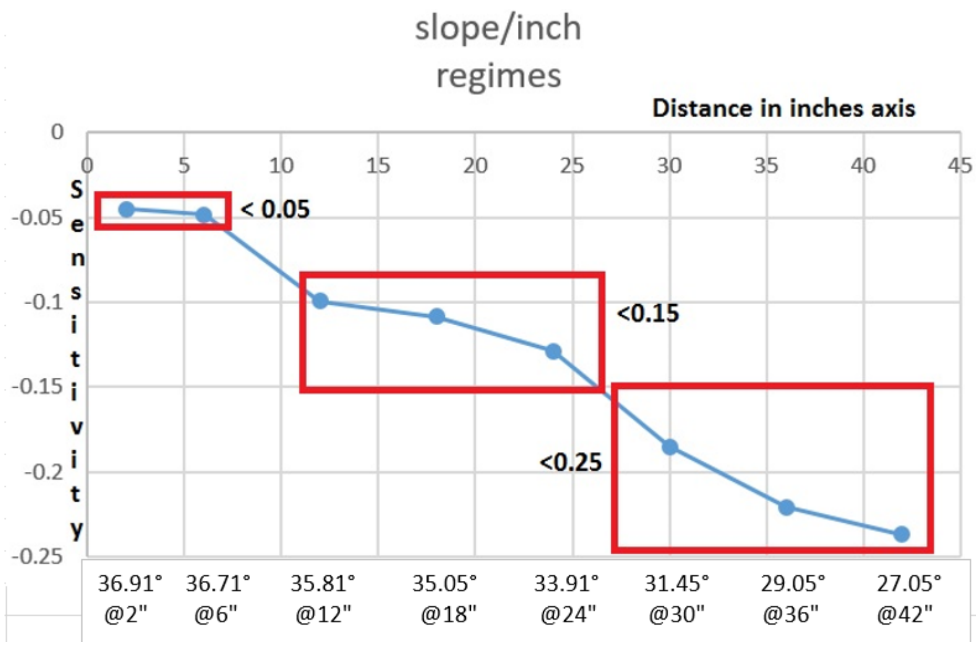


Figure 12 Temperature sensitivity to distance

In Figure 12 above, the upper left-hand corner has two zero points. The sensitivity is along the vertical axis starting at zero and increases in negative values as the plot for the data points falls. The top horizontal axis is distance marked off in increments of five inches. The values for distance increase from the source at the zero point out to 45 inches on the right. The bottom horizontal axis is the distance the sensor was "@" from the source temperature and shows the SST temperatures in Celsius read for each data point.

This graph shows the possible error in the temperature reading for unaccounted variations in the distance. The values in Table 4, column "slope/inch" is the amount of variance you could expect at a distance when the subject or your sensor moves while taking a reading. The error for one inch can be plus or minus *X* amount of degrees of temperature depending on the distance you are taking the temperature from. The modeling of the sensitivity curve requires a 2nd order equation for modeling but when it is graphed three regions are distinct from each other and somewhat linear. These regions can be grouped as being in one regime or another. The midrange is the "safest" for a one-inch error in distance will account for a reading error of either ± 0.15 °C or less. The regime where the distance sensitivity error is largest is when the temperature reading without an offset is below 32 °C. In this regime, errors are approaching ±0.25 when you are short one inch or long by one inch from 36".

However, from the temperature survey discussed in Chapter 4, the temperature for humans at 36" averaged out to around 33 °C, see Table 35, cell F42. This put us into the middle regime of Figure 12 with less error when distance varies. This is an indication of the difference between theory and practice. According to the Palmer-Wald Surface Hot Plate readings that Figure 5 shows for the same distance (36") we should be reading temperatures as low as 29 °C. The results from the temperature survey in Chapter 4 are in a different part of the curve than the data developed for Figure 5 using the Palmer-Wald black body. It is also an indication of the difference between a 3" diameter heat source and the whole face temperature.

The face is generating an estimated 4 degrees Celsius more than the calibrated heat source at 36". How can this be? Is there any theoretical basis for this difference? It turns out that yes there is a basis in theory. The size of the heat source has changed; and in the Stefan-Boltzmann Law, area (A) of the source/receiver is a parameter that is directly proportional to P_{rad}.

Until a survey is done measuring humans on an incremental basis, using as a worse-case scenario, the roll-off curve from Figure 5, the sensitivity of temperature to distance is ~0.25 °C or less at 36”. We could consider this the upper limit. On the lower limit, by using a straight-line roll-off gives a slope of -0.068 °C per inch. This means that at the lower limit, reading errors from the infrared sensor are more sensitivity to emissivity by 36% at 36" for each hundredth unit of emissivity (using .093 °C as the emissivity increment) than distance. At the upper limit, the distance error can overwhelm the emissivity correction by 2½ times. If the distance error were as small as the sensor’s accuracy, the sensitivity problem for distance goes away. The goal of this dissertation is to improve infrared sensor temperature readings and a significant problem is distance accuracy.

3.8 A System Level Model for Infrared Temperature Sensors

Taking everything into consideration presented thus far, we can develop a system model for infrared temperature sensors:

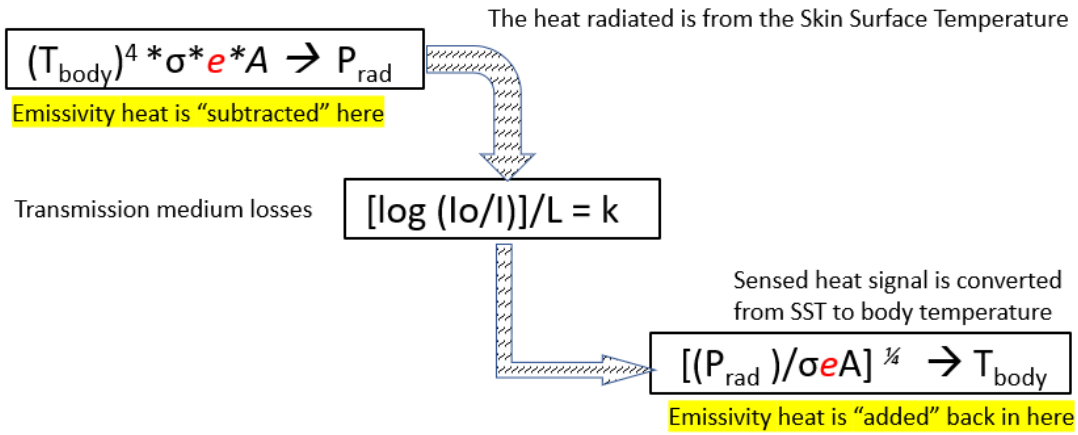


Figure 13 System Model for Infrared Temperature Sensors

This model shows the versality of the Stefan-Boltzmann Law. Here it is used as the source for the radiation in the upper left block then as the rule for measuring the source heat in the lower right. The loss through the air transmission connects the two blocks which are separated by distance modeled on the Beers Lambert Law. The role of emissivity is highlighted in text underneath the two blocks. At the source, you subtract the emissivity heat value and at the observation sensor it is added back in. The variable A (area) is different in both locations: at the source A represents the *area subtended by the observation sensor's field of view of the source* and at the sensor A is the much smaller area for the thermopile used (smaller than the size of a small pepper flake).

Chapter 4

Experimental Validation

4.1 Overview

In this chapter a temperature survey was undertaken to compare the experimental sensor with 3 commercially available thermometers.

4.2 Whole Face Temperature Readings

One caution that needs to be expressed here in Chapter 4 is the difference between methods, techniques, and data used in Chapter 3. The source of the heat signal in Chapter 3 was a Palmer-Wald Surface Hot Plate, a clinical instrument calibrated traceable to NIST [40]. For humans, no such ability to limit or set the temperature is possible and since the whole face can be used to collect the temperature signal, it has a much larger signal area than the Palmer-Wald Surface Hot Plate. Because the diameter of the calibrated portal is 3” and the source temperature can be adjusted in steps of 0.1 °C, it is a clinical tool useful for testing infrared thermometers. In chapter 4, the whole human face is observed, the skin surface area is easily twice that of the calibrated source. Obviously, the various parts of the human face do not generate heat at the same temperature as noted in the Rustemeyer study [46]. From that study the following graphs and charts summarize their finding on this point.

Temperatures on the face and neck were collect by nickel ring probes of 2.5mm radius from 32 sites as seen below in Figure 14 with the “Eidatherm” electronic dermal contacts [39]. The ambient temperature in this experiment was 22º C and 6 readings for each participant were taken over a 24-hour period, every 4 hours. Reading were collected after attaching the leads to the computer within one minute for each subject.

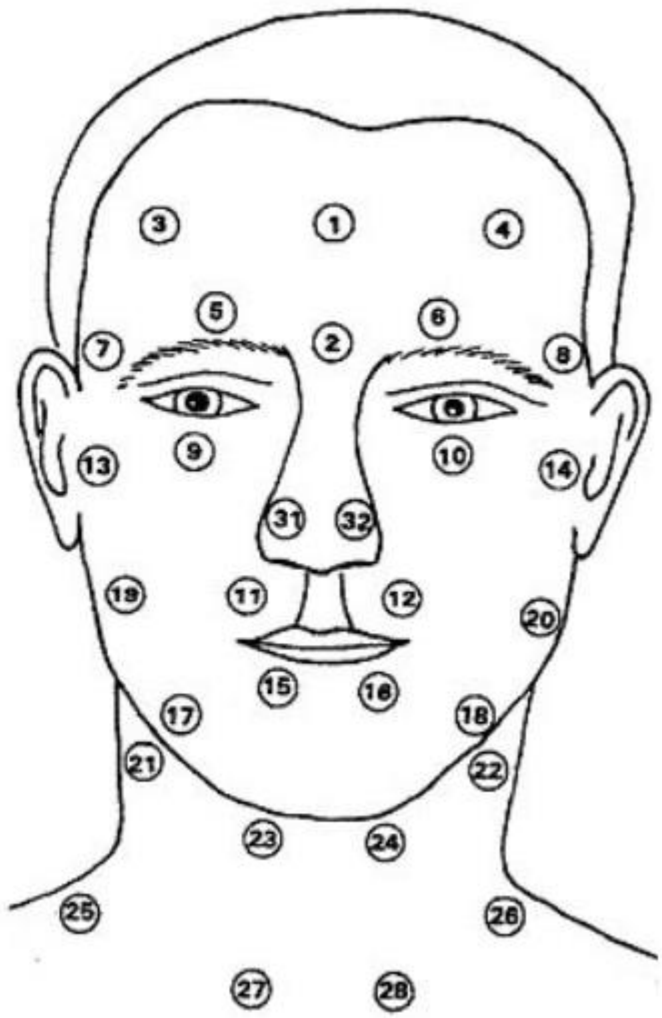


Figure 14 Location of dermal contacts

The locations 1 and 2, the Glabella and root of the nose are considered the “hottest” locations of face followed by the temporal regions 7 and 8. Most near field infrared thermometers seek to capture the temperature of a subject from either of these regions. In our case, we utilize the heat being generated by the face as one number from all locations.

Below is shown a data intensive graph from the Rustemeyer study. The 32 locations were grouped into 4 regions sharing the same facial nerve source. The face is divided between a right and left side. A note was made that the mean of the left side was 0.1 °C lower than the right side.

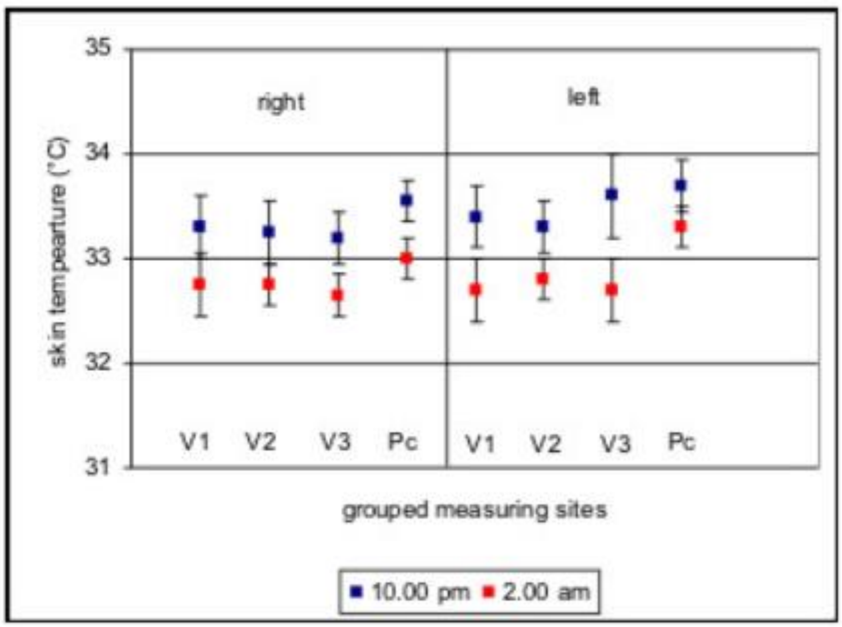


Figure 15 Nerve bundles data and ranges of data point at 2am and 10pm.

In Figure 15, the temperature is along the left side with the horizontal line representing the skin surface temperature. The vertical line above each of the 4 groups (V1, V2, V3, Pc) on each side of the face represent the range of temperatures each nerve group experience at the two time periods shown, the lines have bars across them indicating the end of the range but in some cases, there is some overlap. What is most evident here is the circadian rhythm which the authors point out. Figure 15 shows the temperature for the entire body moving up and down together with some asymmetry. This tells us that the body could be considered one heat engine with one source that is distributed throughout the body. If the face raises or lowers in temperature, every part of the body shares this heat source and rises or fall in synchronized fashion. This means that a temperature in one part of the body without hindrance can likewise reveal the body's temperature. Once the skin surface temperature is known at any location, an offset for that location can be developed to reveal the oral or core temperature. An example of this using infrared thermography was published on Academia.edu in 2012 [21].

While the whole face approach uses radiated heat that does not fit within the field of view of the sensor, this larger area has a different effect: the heat signal from the face stays together longer as the heat radiates away from the face into the ambient temperature. In an illuminative example, the stability of an ocean current such as the Gulf Stream passing through still waters is disrupted along the edges due to the differences in velocity creating eddies by friction. The flow can be modeled using a residue scheme for the water velocity which compares to a skew diffusion and certain skew flux schemes [69]. The same can be said of heat radiating from a person's face.

4.3 Temperature Survey

A temperature survey was conducted on May 2, 2017 at Pace University, Seidenberg School of Computer Science and Information Systems, NYC Design Factory at 163 William St, 2nd floor, New York, New York. This location is a satellite location where offices for the Seidenberg School of Computer Science maintains offices and classrooms.

The purpose of the survey was to improve the accuracy of infrared thermometers by determining what the offset value for an experimental infrared thermometer from 36” would be to render an oral temperature from the skin-surface temperature (SST) at that distance. The survey contrasted results from 3 different oral thermometers commercially available in this determination. Pace University Institute Review Board reviewed the procedures for this survey and published an approval letter for project 1060760-1 on their IRBnet on May 10, 2017 (copy seen in the Appendix).

4.4 Testing

4.4.1 Subjects

This information was developed by comparing 3 commercial thermometers with the experimental infrared thermometer. An Institute Review Board temperature survey was conducted on May 2, 2017 at Pace University, Seidenberg School of Computer Science and Information Systems, NYC Design Factory at 163 William St, 2nd floor, where the participants in this survey attend classes. The volunteers consisted of 21 males and 14 females, the average age was 27.8; however, if we exclude anyone over 30 (5 subjects) the average drops to 22¼. They are multinational and multicultural, but no records were kept on this aspect. Their average height was approximately 67½ inches and the average weight was approximately 160 pounds. Only 5 individuals were rated obese according to the Body Mass Index information [52]. The actual data for the volunteers will be found in the Appendix under Temperature Survey—Volunteer Data. None of the volunteers were presumed to have a fever or a low temperature of concern.

Figure 16 Temperature survey underway

4.5 Description of the Devices used in the Temperature Survey

One of the three commercially available thermometer used in this survey was Tempa-Dot, a paper strip thermometer. It is a single-use (disposable), clinical (sterile), thermometer for oral or axillary use sold by CVS and made by Medical Indicators, Inc. of Hamilton, NJ. It comes packaged in a box of 100. Individual strips were inserted under the tongue for 60 seconds by the subjects. This thermometer has a series of dots in a labeled matrix with each dot consisting of a chemical that is sensitive to temperature with individual dot changing to reveal a blue dye. The label was arranged in a matrix so that rows of dots were mark off in Fahrenheit degrees, 97, 98, 99 and so on with the columns represent tenths of degrees 0.0, 0.2, 0.4, 0.6, and 0.8. The accuracy of the strip was limited to 0.2 degrees Fahrenheit. The temperature is the last blue dot to change. In the photo below is a photo of the container showing the packaging; in the view on the left the temperature is 98.6ºF.

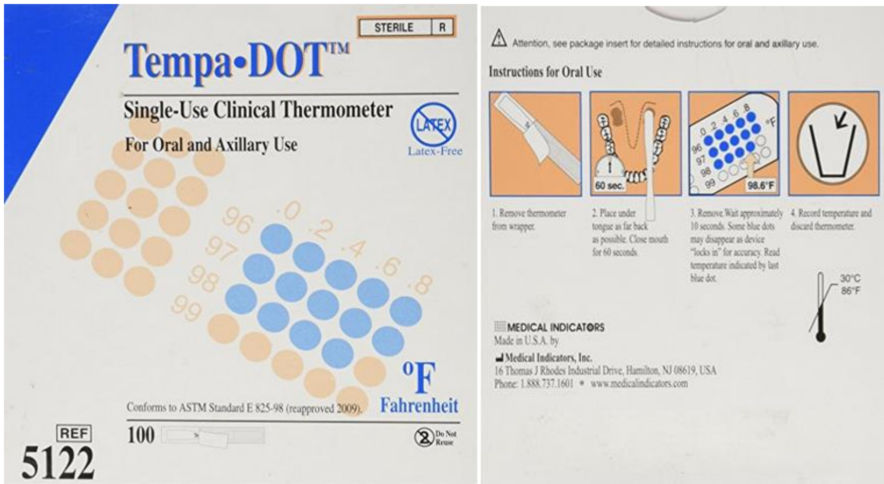


Figure 17 TempaDot sterile disposable strip thermometer, package for oral use.

Another thermometer used in the survey was the CVS rigid tip digital thermometer, considered an electronic thermometer. It was the second commercial device used in this survey. Digital Thermometer KD1340 is made in China and imported by BESTMED, LLC. of Golden, Colorado. They claim to have invented the first electronic digital consumer clinical thermometer in 1978. The current model is an oral thermometer used by inserting the sensor end under the tongue much like a mercury-in-glass thermometer. This was a more expensive model than the strips but with the cost comes accuracy, down to 0.1 degrees. This device requires about a minute to take the temperature of the subject. Both this model and the TempaDot thermometer are subject to placement and timing errors. Placement errors have to do with getting the strip flat across the forehead or the sensor end under the tongue in the mouth cavity correctly. The timing errors are caused by removing the device before the body heat has been fully absorbed by the thermometer.

Figure 18 CVS digital electronic thermometer

The third commercial thermometer used in the survey was a non-contact thermometer that used an infrared temperature sensor that is accurate to ±0.2ºC. It is a near-field proximity sensor because the instructions require you to place the thermometer within ½ to 1¼ inches of the subject’s forehead. It does take the temperature reading quickly and during the survey this device was used at the same time as the digital electronic oral thermometer was waiting for the temperature to update the digital display. The temperature displayed by the device was not the skin-surface temperature seen by the device but a value that incorporated an offset so that the oral temperature was displayed.

Figure 19 Proximity or non-contact infrared thermometer (NCIT)

All three devices are basically oral thermometers. They all displayed an oral temperature. Each use a different method to attain the oral temperature explained below.

ThemaDot is a type of thermochromic thermometer that relies on chemicals sensitive to temperature. The display isolates dots containing increasing densities of the chemical used to reveal the blue dye mix. The results display an oral temperature. The classification can be traced using Figure 53 in the Appendix with the following exceptions: the family name would be Chemical, and the genus would be contacting.

The CVS rigid tip is considered a digital electronic thermometer. It’s a thermometer because there is a transducer to change the heat energy absorbed by the metallic tip into electrical energy for evaluation by the microcontroller. It’s electronic due to the microcontroller handling all the processing chores: ADC conversion, filtering, battery supply, display I/O, and data storage. It's digital in that the display shows digital numbers and after the heat energy is converted to electrical and handed off to the microcontroller, further processing is in digital mode. The results display an oral temperature. The classification can be traced using Figure 53 in the Appendix with the following exceptions: the family name would be Electrical, and the genus would be contacting.

The non-contact digital thermometer (see Figure 19) is exactly like the digital electronic thermometer except that the transducer is an infrared sensor. Since this is the latest design the classification is a non-contact infrared thermometer (NCIT). The results display an oral temperature. The classification can be traced using Figure 53 and Figure 54 in the Appendix.

The experimental device that was being compared with the 3 devices is the infrared sensor evaluation board built by the investigator that is seen below. It functions like the non-contact digital thermometer with a Philips NXP mbed ARM Cortex-M3 microcontroller, model PLC1768. The MCU runs at 100MHz, features USB drop and drag programming, and uses an online compiler [36]. The infrared sensor is a MLX90614, a smart sensor with an onboard processor, a 5° FOV, a 17-bit sigma-delta ADC, EEPROM (read/write) and RAM (read only) memory, selectable FIR and IIR filters, and communicated via SMbus (I2C) bus [35]. In the photo of the prototype below, the 4-digit, 7-segment display was not used in the Temperature survey choosing instead to use a USB connected terminal program, TeraTerm, for data display and recording purposes.

For the processing of the digital temperature data from the infrared sensor and handling I/O the MCU a software C++ program was extensively modified by the author for this dissertation and is available in the Appendix under *Survey program—main.cpp* and *Survey program—MLX9061.cpp*. The program takes and evaluates hundreds of temperature readings in 3 seconds reporting the skin-surface temperature among other parameters.

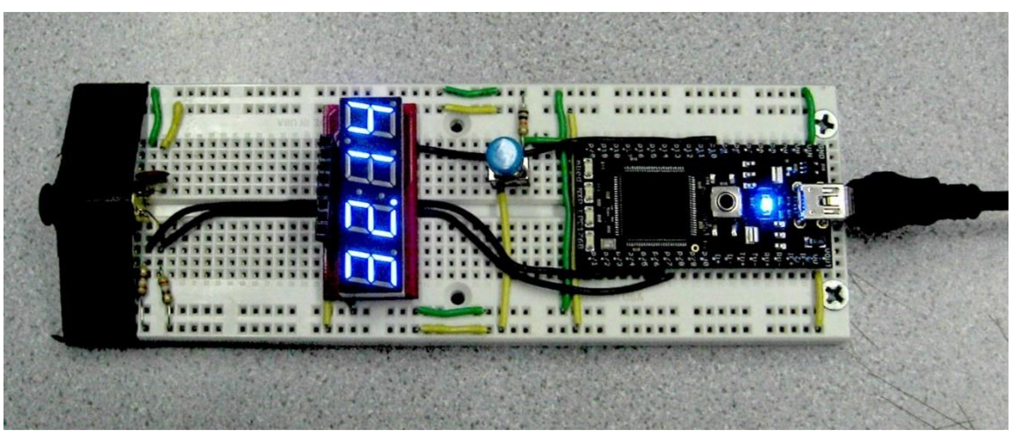


Figure 20 Experimental infrared sensor prototype board

4.6 Calculation of the Offset for the Experimental Thermometer

The data reported by the experimental thermometer is unlike the other three thermometers. It does not report the oral temperature but the skin surface temperature (SST) observed by the sensor at 36". One of the purposes of this temperature survey was to determine the offset value. An offset value is used by all thermometers to add to their transducer reading to convert the actual reading into an oral/core temperature (See Figure 1). Usually thermometers reference by default the oral temperature on their display.

Another difference between the commercial units and the experimental thermometer during the survey is all the commercial devices took one reading to obtain their oral temperature value. The experimental device took two readings, a baseline near-field proximity scan similar to the non-contact thermometer and a second scan 36" away from the subject. The purpose of the two scans, was to determine the amount of roll-off from the higher near-field reading to the cooler reading 36" away. When the experimental thermometer is used by health care professionals, only the 36" reading would be necessary. For the purposes of the temperature survey a temporary value of 3.0 ºC was used for the offset then replaced once the correct offset was determined.

The values detected by the sensor for the two readings were different from the formulas developed in section 3.1, the proof-of-concept experiment using a calibrated black body temperature generator with a 3" diameter source. As described earlier in section 4.2, the temperature being captured by the smart sensor is for the whole face. Since there has never been an infrared temperature sensor developed before that detected human temperature from this large a target or from this distance, a survey was required so that the experimental thermometer could display values that users could related to. The focus of the survey was to find the offset for the skin-surface temperature at 36” that could be added together to display the oral temperature. The data readings, the rows and columns referred to in the explanation below are seen in the Appendix under Temperature Survey—Device Readings & Offset Calculation, Table 35.

What follows is the algorithm for determining the offset to add to the smart sensor’s 36” reading to obtain the oral temperature.

First, the average of the oral temperatures from the three commercial devices detected for each subject were collected in column H of Table 35. Subtract from this high value the skin surface temperature (SST) reading of the Close-up reading of the experimental sensor, column E, and put the difference in column I. This value contains an allowance for the skin-surface temperature reading to be converted to an offset value. By averaging this column over all 35 subjects a key value of 1.31 ºC appears in cell I42. Because it was averaged over all the subjects, that average could be used for each. Next calculate the average roll-off in column G for each subject and average that column. This average appears in cell G42. That value of 2.37 °C is the 2nd key value for the offset. Because this value was averaged over all the subjects, it could be use with each as part of the offset. The addition of these two key values results in a value of 3.7 (1.31 + 2.37= 3.68 which was rounded off to 3.7) seen in cell J4. This is the offset value. This value could then be added to the 36” sensor readings for each subject in column J to generate the Revised Oral results from the skin-surface reading that is recognizable as the oral temperature. Because the offset consists of nothing but averages and the addition of the offset value is a linear function, the Revised oral temperature varies the same as the 36” readings by the experimental sensor listed in column F. Each subject’s derived oral temperature is unique.

This algorithm is verified when the columns for the 3 commercial devices were averaged for all the subjects, cells I42, J42, and K42. Amazingly, all three commercial devices averaged out to 36.7 °C. The average of the Revised oral temperature for the experimental sensor using the derived offset is seen in column J, cell J42 is 36.67 °C. This rounds off to 36.7 °C and is only 0.03 °C different from the commercial devices.

4.6.1 Exceptions

In the calculation, the first volunteer’s roll-off figure was excluded from the average roll-off as a possible recording error.

Subject 15’s whole face temperature was first captured while wearing glasses. With the glasses off, the subject read 0.58 °C higher which is the recorded data (cell F22). In other words, glasses can lower the whole face temperature by over a ½ a degree.

Subject 29 wore a ball cap causing his temperature to read 0.16 degrees higher than with the cap removed. After the cap was removed, the correct temperature was recorded as 33.79 °C in cell F35. It is presumed that the visor of the cap focused the heat projecting it outward.

The ambient room temperature for the temperature survey hovered around 28 °C. There was no concern that the ambient air temperature approached the lower limit of the readings mentioned in section 3.4 rendering the reading valueless.

4.6.2 Summary

The Revised oral temperature seen in Table 35, Column J of the Appendix with the derived offset shows a wide range of readings. On a row by row examination of the four temperatures reading for each subject show a reasonable degree of variation but when you take the group and look at the average value for each device, you see: 36.7 °C, 36.7 °C, 36.7 °C and 36.67 °C across row 42.

The offset was calculated by using the average of the difference between the average reading for the three commercial devices minus the Close-up reading (1st key value). To this is added to the average roll-off (2nd key value). The offset was standardized by using the average for all the readings. The offset for the 36" reading to obtain the oral temperature is 3.7 ºC.

Another variable that affects temperature is circadian rhythm which can cause a person's temperature to rise by +0.5-0.7 degrees Celsius [6]. The Revised oral temperature leaves many subjects with a wide margin and those readings over 37 ºC still have room for additional fluctuation. Part of the temperature survey was conducted during the period the circadian rhythm can cause a temperature increase. Values taken after 3pm are examples. None of the devices used in the survey applied a circadian correction.

The survey has a 100% no false positives rating for evaluating a temperature as a fever when this condition does not exist. I was not able to evaluate false negatives because none of the subjects were known to have a fever.

Temperature is double-sided: you can have too high a temperature and too low a temperature. The fever is most common but the opposite condition, known as Wilson's

Temperature Syndrome can be indicative of thyroid problems [67] or predictive of Addison's disease, diabetes, drug/alcohol abuse, hypothyroidism, hypothermia, infection, liver failure, sepsis, medicine side effects, shock, asthma, cancer, stress, and insomnia [48].

During this survey, subject #2, was below normal, as the temporary offset we were using during the testing was 3.0 ºC. Upon changing to the offset derived from the survey, that issue of below normal corrected itself. I can therefore report that there were no false positives when checking for low body temperature reported as normal. There were no false negative when checking for a normal body temperature reported as a below normal temperature.

4.6.3 Reviewing the Survey Results

When all four devices are assessed statistically, the 3 commercial units had 105 data point and the experimental sensor reading at 36" had 34. The commercial units had a standard deviation of 0.35 °C and a sampling error of 0.068 °C for the mean. The experimental sensor had a standard deviation of 0.52 °C and a sampling error of 0.099 °C. It can be inferred statistically that the experimental sensor's readings of the data were a bit wider by 0.2 °C for the standard deviation and the sampling error was about 0.03 °C larger than the commercial units. There appears to be room for some improvement in the experimental sensor reading. Put simply, while the temperature readings were all within the normal temperature range, they were wide of the mark, the mark being the average. This standard deviation for the experimental sensor could be attributed to a distance error.

4.6.4 A Practical Method to Solve the Distance Problem

As a practical matter, establishing the distance and minimizing the error has a direct effect on the accuracy of the infrared sensor at 36”. Table 3 indicates a 0.22 °C per inch error and even if we use the 24” reading, the error drops to 0.15 °C per inch. To reiterate the finding of the last section, the distance error can overwhelm any emissivity correction as the sensitivity of temperature to emissivity is ~ 0.1 °C by Table 1.

Using a visual application of similar triangles was proposed to minimize the distance error when a portable 3-D print prototype was created in the fall of 2017 to aid in the development of the experimental sensor.

Figure 21 Portable 3-D print prototype with visual aid guides shown.

In Figure 21 the visual aid guides are seen on the top of the prototype which are used to line up the sensor (portal not seen) with the subject’s eyes. The sensor located on the front end of the prototype on the right and is not seen in the photo.

4.6.5 Alignment of the Visual Guides

The key to solving the distance problem is the interpupillary distance between the eyes of a subject are used as the base of a set of overlapping triangles. This distance in adults can vary from 2" to 3" with a mean of 2.5 inches with a standard deviation of 0.3 inches [23]. Taking the mean as the base distance will serve our purposes. See Figure 22 for guidance in the following explanation.

The largest triangle is from the sighting eye of the observer to the eyes of the subject, a distance of 52". The distance from the observer to the sensor opening (on the subject's end of the sensor) is set at 16". That is the smaller similar triangle where the 1st set of visual markers are 12" away from the user's eyes. The second set of visual markers are set just shy of 16" from the observer. The two triangles share the apex angle of these triangles which is 2.75°. The distance between the 1st set of visual markers at 12" (from the apex) is 0.575". That distance is divided in half by the center line of both triangles for the perpendicular bisector at that point. The distance between the markers at 16" is 0.77" also along another perpendicular bisector of the center line. When the "set" of overlapping markers line up with the patent's eyes, the sensor is at 36" from the subject.

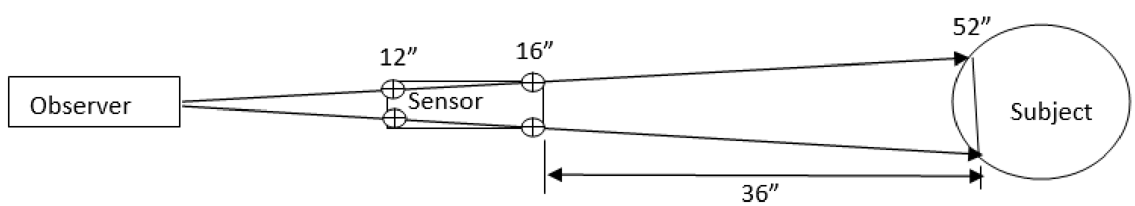


Figure 22 Simultaneous triangles alignment

4.6.6 Instructions for Using the Visual Guides

Alignment of the sensor at the proper distance from the subject is a two-step process.

1. Align the red visual guides up with the guides at the other end of the sensor by adjusting the distance between the observer and the sensor by moving the hand holding the sensor toward or away from the user. The red guides should just cover the blue guides. The subject should be in the background. Hold the arm angle steady for the next adjustment.

2. The observer and the sensor now move in unison using the "set" of overlapping markers as a guide to line up with the subject's eyes. The observer can rotate or move forward/backwards to align the sensor with the subject's eye.

This solution is based on an assumption that the interocular distance between the subject eyes is 2.5". What happens is when the guides are focused on the pupils the eyes are either outside the guides or inside. So before taking a temperature, the user would have to estimate whether or not the subject's eyes are wide-set or narrow and line up the guides accordingly.

Chapter 5

Improving the Temperature Survey

5.1 Overview

In this chapter, a computer simulation for automatic emissivity control was developed and tested using data from the temperature survey. Several trails were undertaken using different assumptions. A behavior was discovered for changes in temperature results for surveys when emissivity was applied.

5.2 Simulating Emissivity Control

Using the data from the Pace temperature survey and making certain assumptions, corrected sensor temperature readings that include emissivity can be generated for analysis that are indicative how infrared temperature sensors can be improved.

The output of the 3 commercial devices and the experimental prototype seen in Table 5 are presented in the following order from left to right: TempaDot (chemical)—Column H; CVS digital/oral—Column I; CVS proximity (infrared)—Column J; and the experimental infrared sensor—Column K. The output are seen down to Row 41 while Row 42 computes the columns average.

Table 5 Readings of the 4 thermometers

	H	I	J	K
5	*All readings are in Centigrade*			
6	Temdot C	CVS oral	Proxmity	Adj. 36"
7	37.11	36.8	36.5	34.67
8	37.11	36.8	36.8	35.61
9	37.11	36	36.8	36.99
10	36.56	36.4	36.5	36.15
11	37.11	36.3	36.7	37.03
12	37.00	36.8	36.7	37.07
13	36.56	36.7	36.6	36.67
14	36.00	36.7	36.9	36.23
15	36.00	36.7	36.6	36.83
16	36.44	36.1	36.7	37.13
17	37.67	37.4	37	37.47
18	36.56	36.2	36.5	36.87
19	37.11	36.6	36.7	37.51
20	36.67	37	36.8	35.79
21	36.56	37.1	36.7	36.75
22	36.33	36.8	36.8	36.53
23	36.56	36.4	36.9	36.15
24	36.67	37	36.8	37.07
25	37.11	36.7	36.8	37.07
26	36.89	36.2	36.8	36.17
27	36.00	37	36.7	36.73
28	35.78	36.5	36.7	36.07
29	35.89	36.4	36.9	36.47
30	37.11	37	37	37.19
31	37.33	37	36.7	35.95
32	37.11	36.8	36.6	36.51
33	37.11	36.9	36.6	36.99
34	36.56	36.8	36.7	36.25
35	36.00	36.4	36.9	37.49
36	37.11	37.1	37	36.89
37	36.56	36.5	36.5	36.29
38	36.89	36.2	36.6	37.57
39	37.11	36.8	36.7	36.83
40	35.67	36.4	36.5	37.07
41	37.33	37	37	37.39
42	**36.70**	**36.7**	**36.7**	**36.67**

While all the averages look remarkably similar, we will examine each thermometer's data to reveal inconsistencies between them. We will start with the three commercial devices taken as one group of 105 samples in Table 7.[5]

Table 6 Statistics of the commercial devices treated as a group

	H	I	J	K	L
44	Statistics on all commercial thermometer				
45	36.70	average of all 105 sample data point (the mean)			
46	0.356803	Standard deviation of a sample (n-1)			
47	0.068247	Excel's confidence interval for 95% for accuracy of average value 36.7			
48	36.77	Confidence hi			
49	36.64	Confidence low			

For this diverse group of thermometers, the standard deviation is approximately ±0.36 °C wide around the median of 36.7 °C. This amounts to a range of 0.72 °C where 68 % of the readings for these devices in this sample will fall [55]. Since these three devices are independent with different accuracies, this is more of a trivial observation.

By examining all four thermometers separately on a column by column basis individual standard deviations for each device are revealed (the same column order as seen above):

Table 7 Statistics for each thermometer stand-alone

	H	I	J	K	L
52	0.504117	0.33128	0.15328	0.52228	Standard deviation of a sample (n-1) for reading from 36"
53	0.167011	0.10975	0.05078	0.17555	Excel's confidence interval for 95% for accuracy of average value
54	36.87	36.78	36.79	36.84	Confidence hi
55	36.54	36.56	36.68	36.49	Confidence low

[55] Table 7 and Table 8 comes from the same spreadsheet as Table 6. The selected table view for the reader to follow the focus of the comments.

Row 52 reveals the standard deviation for each device. The device with the smallest standard deviation whose readings fit closest about the medium is the CVS proximity thermometer. Its standard deviation is ±0.153 °C and offers the best prospects statistically in this sample group of determining the actual temperature of a subject. The CVS oral is next with a standard deviation of ±0.331 °C, followed by Tempadot at ±0.504 °C, and finally the experimental infrared sensor at ±0.522 °C. The latter two devices offer a range of approximate 1 °C wide for determining a temperature reading. This is outside the range required by the FDA for approval. The experimental sensor has the widest standard deviation of all the thermometers. The standard deviations range for these devices from ~±0.15 °C to over ±0.5 °C. These are the basic observations distinguishing the thermometers from one another.

Also shown is the confidence interval and range for the standard deviation for each device in Row 42. These values show how close the individual device zeroed in on that value. These values differ for each device even though the medium is the same for the three commercial thermometers. The best fit is the CVS proximity thermometer from this survey. The ±0.05 °C for the confidence interval is highly accurate at ½ of a tenth of a degree Centigrade. The experimental sensor appears to be the worst performer of the four devices.

The CVS proximity infrared sensor is an example of the many commonly available infrared near-field, non-contact thermometers that have no adjustment for emissivity. The delta changes of the temperature due to emissivity (ΔT—the right-hand column in Table 8 below) would be the corrections added to the sensor skin surface temperature reading of the CVS thermometer where the sensor corrected for emissivity. By not having an adjustable emissivity reading the thermometer is most likely using an average emissivity correction. In Table 8 below, derived from Table 1, is the emissivity value for humans standardized at 37.0 °C:

Table 8 Emissivity (ascending values) ΔT

	emissivity	e factor	ΔT= T-Te¼
T	e	e ¼	ΔT
37	0.96	0.989846	0.375683
37	0.97	0.992414	0.280678
37	0.98	0.994962	0.186404
37	0.99	0.997491	0.092849
37	1	1	0

What about the experimental sensor? There is no compensation for emissivity in column K of Table 5. Readings of the four devices are just the actual data temperatures plus an offset. The standard deviation for these readings is ±0.52228 °C. Of the four devices, the experimental sensor shows the widest spread of data about its medium value of 36.67 °C. Can this reading be improved by the inclusion of emissivity data?

To answer that question using the data collected thus far will require making assumptions about the data and applying a fictious emissivity value to the reading of the experimental sensor (Column K of Table 5) to determine what effect emissivity would have on the temperature we have derived for the experimental sensor.

In this exercise, we would need a value for the skin-tone of the subject that would be applied before the sensor took the infrared sensor reading. However, it is obvious from the table above that a lighter skin-tone would require a greater compensation (ΔT) than that with a darker skin-tone. We will transfer the data for the proximity sensor and the experimental sensor (Column I and K) to another location in the spreadsheet for these trials.

5.3 Trial 1

We make the following assumption: Based on the casual observation that subjects volunteered with a variety of skin-tones to have their temperature read, all the experimental sensor readings will be subject to an emissivity correction using a look-up table like Table 8 seen above. The difference between the CVS proximity sensor and the experimental sensor will also be shown for reference with the average error in column Z of Table 9.

There are several errors introduced with this approach: 1) the compensation applied is assumed to be correct when it could be the wrong amount, 2) we could be inadvertently compensating for a low sensor reading, and 3) the difference seen in column Z uses the temperature data from the CVS proximity sensor to adjust the temperature data from the experimental sensor making the later dependent on the former whereas they were previously independent.

5.3.1 Building a Simulator for an Automatic Emissivity Control Engine

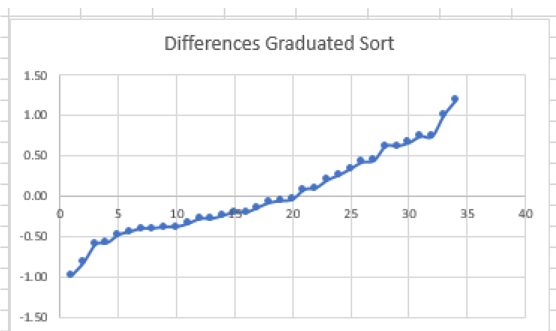
To simulate the effect of an anticipated automatic emissivity control program to be used in software to select the correct emissivity based on RGB pixel evaluation, we will use the Excel VLOOKUP function with a Histogram chart. How this engine works is explained in the following paragraphs and it combines information developed in Table 8, Table 9, and Table 10. The purpose is to generate automatically, based on various assumptions (the trials), an emissivity adjustment to the experimental sensor's outputs from the comparison survey (Table 5, column K) for analysis of the best fit by seeking the smallest standard deviation.

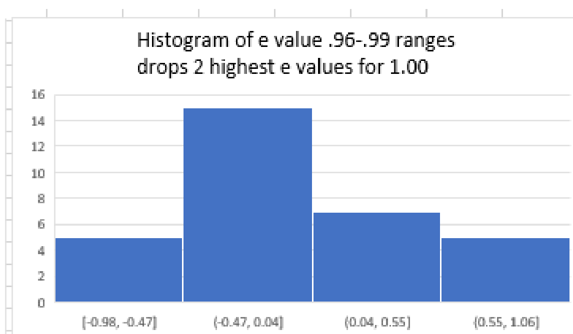
To select the correct ΔT, a histogram chart type was selected. The histogram groups use the difference data arranged in a sorted column revealing their limits of each group as seen in column AA of Table 9 below. The offset (see Table 35) was changed until column Z of Table 9 showed a sum zero balance meaning there were equal parts of positive values that equated to the negative values in this column. This adjustment of the offset while small had no bearing on the standard deviation. The limit information from the partitioning by the histogram chart is part of the Excel VLOOKUP function. This graph, seen in the bottom right of Table 9, indicates the number of data points in each group along the y-axis as the amplitude.

One observation about the correlation value between the proximity sensor and the experimental sensor is noteworthy. In Table 9, the correlation value of 0.16232 is seen at the bottom of data just below the average of 36.74 (Column X, Row 43). This low value indicates that the relationship between the two column is weak[17]. A zero value would indicate a perfect independence so while the 0.16232 shows some dependence since both were thermometers taking the temperature for the same individuals at nearly the same time, the value indicates the degree the columns are independent of each other.

Table 9 Fitting Emissivity, Trial 1

	W	X	Y	Z	AA	AB
6	Proximit	ThermoWand		differenc	sort differences	
7						
8	36.80	35.62		1.18	-0.98	
9	36.80	37.00		-0.20	-0.82	
10	36.50	36.16		0.34	-0.60	
11	36.70	37.04		-0.34	-0.58	
12	36.70	37.08		-0.38	-0.48	
13	36.60	36.68		-0.08	-0.44	
14	36.90	36.24		0.66	-0.40	
15	36.60	36.84		-0.24	-0.40	
16	36.70	37.14		-0.44	-0.38	
17	37.00	37.48		-0.48	-0.38	
18	36.50	36.88		-0.38	-0.34	
19	36.70	37.52		-0.82	-0.28	
20	36.80	35.80		1.00	-0.28	
21	36.70	36.76		-0.06	-0.24	
22	36.80	36.54		0.26	-0.20	
23	36.90	36.16		0.74	-0.20	
24	36.80	37.08		-0.28	-0.14	
25	36.80	37.08		-0.28	-0.08	
26	36.80	36.18		0.62	-0.06	
27	36.70	36.74		-0.04	-0.04	
28	36.70	36.08		0.62	0.08	
29	36.90	36.48		0.42	0.10	
30	37.00	37.20		-0.20	0.20	
31	36.70	35.96		0.74	0.26	
32	36.60	36.52		0.08	0.34	
33	36.60	37.00		-0.40	0.42	
34	36.70	36.26		0.44	0.44	
35	36.90	37.50		-0.60	0.62	
36	37.00	36.90		0.10	0.62	
37	36.50	36.30		0.20	0.66	
38	36.60	37.58		-0.98	0.74	
39	36.70	36.84		-0.14	0.74	
40	36.50	37.08		-0.58	1.00	
41	37.00	37.40		-0.40	1.18	
42		**36.74**	Average	0.00	=Sum of difference	
43		0.16232	Correlation			





From this data, the following Excel VLOOKUP Function was constructed and inserted in the ΔT column to simulate an automatic emissivity control feature:

```
=VLOOKUP(Z9,AN$17:AP$21,3)
```

This function is interpreted in the following manner:

The function looks at the row value in column Z of Table 9 which is the difference column for each individual between the CVS proximity thermometer and the experimental sensor temperature data. This value is evaluated row by row in the emissivity table whose range is AN17:AP21 (3 columns by 5 rows matrix) in the first column of that range. The function looks at the 1st row's value in column AN and if that value is greater than the Z column value but less than the next row's value, it stops on that row. The function repeats row by row until it selects the row where the Z column value "fits" meaning it is larger than the minimum value for that row in column AN but smaller than the value for the next row. It will then output the value that the table has in column AP for that row (column three within the range thus the number three in the function). The values in column AP are the emissivity adjustment calculated previously from the temperature value in column AN. The entire table is slightly larger than the range for human emissivity ratio (0.96, 0.97, 0.98, 0.99, and 1.00) so that the emissivity adjustment, ΔT, is placed in the left most column seen in Table 10 for further processing.

Explanatory Note: Table 9 and Table 10 were originally on one Excel spreadsheet but for the presentation purposes in this dissertation two different tables present a readable visual aid for the reader to understand how they work. An expanded view of the spread sheet is available in the Appendix, *Spreadsheet Simulation of Automatic Emissivity Control*. There are seen sections of the spreadsheet now split between two Tables. This particular spreadsheet allows working with two VLOOKUP functions and two histograms and by changing the function in cell AR8 (see formula bar) then by using the Backup and Redo icons enables the user to compare two different functions at the same time.

Table 10 Fitting Emissivity, Trial 1 Results

Using theoretical emissivity values in Histogram				
T	e	lower lim	e^(1/4)	ΔT= T-Te¼
35.5	0.96	-0.99	0.9898	0.3621
36	0.97	-0.47	0.9924	0.2736
36.5	0.98	0.04	0.9949	0.18615
37	0.99	0.55	0.9975	0.0925
37	1	1.06	0	0

ΔT	Revised 36" with e		diff w/prox
1	36.62		0.17751
0.2736	37.28		-0.4761
0.0153	36.18		0.32221
-0.57	36.47		0.22751
-0.57	36.51		0.18751
-0.57	36.11		0.48751
0.3	36.54		0.35751
-0.57	36.27		0.32751
-0.57	36.57		0.12751
-1.02	36.46		0.53751
-0.57	36.31		0.18751
-1.02	36.50		0.19751
0.3	36.10		0.69751
-0.57	36.19		0.50751
0.0153	36.56		0.24221
0.3	36.46		0.43751
-0.57	36.51		0.28751
-0.57	36.51		0.28751
0.3	36.48		0.31751
-0.57	36.17		0.52751
0.3	36.38		0.31751
0.0153	36.50		0.40221
-0.57	36.63		0.36751
0.3	36.26		0.43751
0.0153	36.54		0.06221
-0.57	36.43		0.16751
0.0153	36.28		0.42221
-1.02	36.48		0.41751
0.0153	36.92		0.08221
0.0153	36.32		0.18221
-1.02	36.56		0.03751
-0.57	36.27		0.42751
-1.02	36.06		0.43751
-0.57	36.83		0.16751
	36.45	Average	**0.291**
	0.24353	StanDev	0.20429
	0.04658	Excel's confidence interval f	
	36.50	Confidence hi	
	36.40	Confidence low	

This analysis uses the formula developed (seen in the 2nd row, right-hand column of the Excel VLOOKUP table of Table 10, spreadsheet on the left) based on the temperature that was most likely to be seen by sensor readings for that Histogram group. The groups from the Histogram are separated by row and by the lower limits of the Histogram chart seen in

Table 9. The amplitude of the groups seen in the Histogram is indicative of the number of data that fills each group.

After processing by the simulated automatic emissivity control (spreadsheet on the left of Table 10) the average for the column of figures (spreadsheet on the right, 2nd column from left in Table 10) was 36.45 °C which is below that of the averages for the commercial thermometers. The standard deviation is ±0.24353 °C which cuts by over half the standard deviation for the raw surface temperature readings of the experimental sensor. This deviation is also lower than the CVS Digital Oral thermometer. The confidence interval is 0.04658 °C with the high and low range limits (0.10 °C) being split in half by the medium value. This confidence value is lower than the CVS proximity thermometer.

These results are an example of the desired results when including emissivity for improvement of infrared temperature sensor readings. Unfortunately, it is not a conclusive finding because the changes were made across the board without regard to any actual individual subject emissivity, the emissivity correction could be simply compensation for a low reading and the data from two different devices, the CVS proximity thermometer and the experimental sensor are combined through the difference used to sort the results.

5.4 Trial 2

A second trail of this data using an “e of convenience” correction could be derived by incrementally changing the reference temperature T in the left-hand column of the Excel VLOOKUP table. The output of the Excel function is in the right-hand column. This value is inserted in the ΔT column for the readings then added to the experimental sensor temperature readings (raw skin surface temperature plus the offset) and entered in the "Revised 36 with e" column:

```
=VLOOKUP(Z8,AN$8:AP$12,3)
```

Table 11 Fitting Emissivity, Trial 2

ΔT	Revised 36" with e		diff w/prox
1	36.62		0.17751
-0.57	36.43		0.36751
0.0153	36.18		0.32221
-0.57	36.47		0.22751
-0.57	36.51		0.18751
-0.57	36.11		0.48751
0.3	36.54		0.35751
-0.57	36.27		0.32751
-0.57	36.57		0.12751
-1.02	36.46		0.53751
-0.57	36.31		0.18751
-1.02	36.50		0.19751
0.3	36.10		0.69751
-0.57	36.19		0.50751
0.0153	36.56		0.24221
0.3	36.46		0.43751
-0.57	36.51		0.28751
-0.57	36.51		0.28751
0.3	36.48		0.31751
-0.57	36.17		0.52751
0.3	36.38		0.31751
0.0153	36.50		0.40221
-0.57	36.63		0.36751
0.3	36.26		0.43751
0.0153	36.54		0.06221
-0.57	36.43		0.16751
0.0153	36.28		0.42221
-1.02	36.48		0.41751
0.0153	36.92		0.08221
0.0153	36.32		0.18221
-1.02	36.56		0.03751
-0.57	36.27		0.42751
-1.02	36.06		0.43751
-0.57	36.83		0.16751
	36.425	Average	**0.3158**
	0.19497	StanDev	0.15312

Compensation Table based on e of convenience				
T	e	lower lim	e^(1/4)	ΔT= T-Te¼
-100	0.96	-0.99	0.9898	-1.02
-75	0.97	-0.47	0.9924	-0.57
3	0.98	0.04	0.9949	0.0153
120	0.99	0.55	0.9975	0.3
1	1	1.06	0	1

This custom adjustment of the emissivity value by changing of the temperature in column T is simply fitting the data to match the CVS proximity sensor data. Because of the grouping for the histogram, the nature of the curve for the experimental sensor that is being fitted to the CVS proximity thermometer becomes obvious where the lowest sensor temperatures with the lowest values are driven into negatives value (an impossibility in the human temperature range). The higher values were adjusted until every reading fits within a rather small standard deviation of < 0.02 °C (0.19497). It could be reasoned that this is a view of the sensor temperature readings that were acceptable but skewed.

5.5 Trial 3

As a further effort to determine if the experimental sensor readings be improved by the inclusion of emissivity data using just the skin-surface temperature (SST) reading and eliminate the tendency to match the data from the CVS proximity thermometer, the following formula was developed for ΔT:

$$\Delta T = T-[(T/T_{highest})]\ (.25)\ {}^{*}T$$

This formula uses the skin surface temperature of the current reading (T) for the experimental sensor. The factor: ($T/T_{highest}$) is used to develop a decimal percent value to use individually, row by row. The fallacy here is that the temperature value to be used for the value of $T_{highest}$ for the 1.0 emissivity level is not known. For this analysis, the reference high temperature was 37.58 °C from the sample group. This brings the bottom of the readings up (raising the average) the most as seen in the ΔT column in Table 12:

Table 12 Fitting Emissivity, Trial 3

	AR	AS	AT
6	ΔT	Revised	36" with e c
7			
8	0.47323	36.10	
9	0.14299	37.15	
10	0.34594	36.51	
11	0.13317	37.18	
12	0.12334	37.21	
13	0.22101	36.90	
14	0.32687	36.57	
15	0.1821	37.02	
16	0.10858	37.25	
17	0.02434	37.51	
18	0.17235	37.05	
19	0.01436	37.54	
20	0.43108	36.23	
21	0.20158	36.96	
22	0.25487	36.80	
23	0.34594	36.51	
24	0.12334	37.21	
25	0.12334	37.21	
26	0.34118	36.52	
27	0.20644	36.95	
28	0.36496	36.45	
29	0.26933	36.75	
30	0.09378	37.30	
31	0.39338	36.36	
32	0.25969	36.78	
33	0.14299	37.15	
34	0.3221	36.58	
35	0.01935	37.52	
36	0.16746	37.07	
37	0.31253	36.62	
38	-0.0006	37.58	
39	0.1821	37.02	
40	0.12334	37.21	
41	0.04425	37.45	
42		**36.947**	Average
43			
44		0.39571	StanDev
45		0.07569	Conf. Inv
46		37.02	Conf hi
47		36.87	Conf low

In this effort, prior knowledge of the highest temperature falsely increasing the readings incrementally and compressing the standard deviation. The medium value increased. Use of a camera system to automatically detect skin-tone and set the emissivity constant is expected to correct this problem. The improvement in the standard deviation follows based on the errors inherent with the determination of the emissivity constant.

5.6 Trial 4

These results indicate that a set point qualifier could be used for the medium by an IF statement that passes thru the temperature if the reading is greater than the medium. The fallacy here and in the next analysis is that prior knowledge of the expected medium is known. Because of that knowledge, 36.9 °C will be used as the set point qualifier and 37.58 °C as $T_{highest}$. The formula for ΔT becomes:

IF ($T>T_{average}$, 0, {T-[($T/T_{highest}$)] (.25) *T}

Results of this formula are seen on the next page:

Table 13 Fitting Emissivity, Trial 4

	AR	AS	AT
6	ΔT	Revised 36" with ε	
7			
8	0.47323	36.10	
9	0	37.00	
10	0.34594	36.51	
11	0	37.04	
12	0	37.08	
13	0.22101	36.90	
14	0.32687	36.57	
15	0.1821	37.02	
16	0	37.14	
17	0	37.48	
18	0.17235	37.05	
19	0	37.52	
20	0.43108	36.23	
21	0.20158	36.96	
22	0.25487	36.80	
23	0.34594	36.51	
24	0	37.08	
25	0	37.08	
26	0.34118	36.52	
27	0.20644	36.95	
28	0.36496	36.45	
29	0.26933	36.75	
30	0	37.20	
31	0.39338	36.36	
32	0.25969	36.78	
33	0	37.00	
34	0.3221	36.58	
35	0	37.50	
36	0	36.90	
37	0.31253	36.62	
38	0	37.58	
39	0.1821	37.02	
40	0	37.08	
41	0	37.40	
42		**36.906**	Average
43			
44		0.37212	StanDev
45		0.07118	Conf. Inv
46		36.98	Conf hi
47		36.84	Conf low

The medium value has moved from 36.947 °C to 36.906 °C due to the lower half of the temperature reading being compressed. The standard deviation has also improved somewhat down 0.02 °C to 0.37212 °C. While impressive, these results are misleading to the assumption that the average has an emissivity of 1.0 (hence no emissivity correction being made.

5.7 Trial 5

Completely isolating the experimental sensor results from the CVS proximity sensor required changing the Excel VLOOKUP function (used as our simulation of automatic emissivity control) from a difference function to having the function read the experimental sensor temperature data directly as seen in column AV of Table 14. After selecting this column for the source data for a histogram chart we see the groupings with the limits and population below.

Using the limits seen in the histogram of Table 14 we can build the Excel VLOOKUP table to simulate the automatic emissivity control feature in Table 15. The command line to execute the simulation is:

```
=VLOOKUP(AV8,AO$8:AQ$12,3)
```

Table 14 Fitting emissivity, Trial 5

	AS	AT	AU	AV	AW
6	ΔT	with emissivity		SST Raw + offset	
7					
8	0.36	35.99		35.62	
9	0.19	37.19		37.00	
10	0.28	36.44		36.16	
11	0.19	37.23		37.04	
12	0.19	37.27		37.08	
13	0.19	36.87		36.68	
14	0.28	36.52		36.24	
15	0.19	37.03		36.84	
16	0.19	37.33		37.14	
17	0.00	37.48		37.48	
18	0.19	37.07		36.88	
19	0.00	37.52		37.52	
20	0.36	36.17		35.80	
21	0.19	36.95		36.76	
22	0.28	36.82		36.54	
23	0.28	36.44		36.16	
24	0.19	37.27		37.08	
25	0.19	37.27		37.08	
26	0.28	36.46		36.18	
27	0.19	36.93		36.74	
28	0.36	36.45		36.08	
29	0.28	36.76		36.48	
30	0.09	37.30		37.20	
31	0.36	36.33		35.96	
32	0.28	36.80		36.52	
33	0.19	37.19		37.00	
34	0.28	36.54		36.26	
35	0.00	37.50		37.50	
36	0.19	37.09		36.90	
37	0.28	36.58		36.30	
38	0.00	37.58		37.58	
39	0.19	37.03		36.84	
40	0.19	37.27		37.08	
41	0.09	37.50		37.40	
42		**36.945**	Average	**36.739**	
43					
44		0.42788	StanDev	0.52228	
45		0.08184	Confidence int	0.0999	
46		37.03	interval high	36.84	
47		36.86	interval low	36.64	

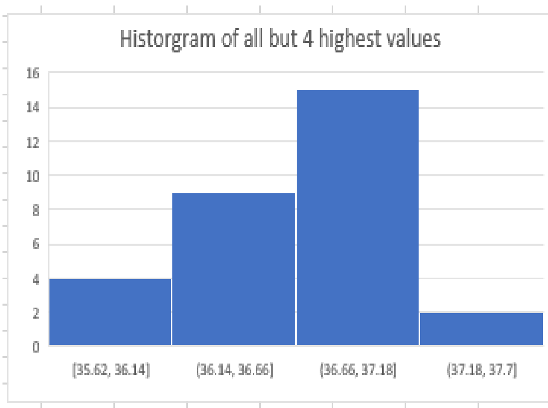


Table 15 Fitting Emissivity, Look Up Tables

	AM	AN	AO	AP	AQ
6	Simulation of automatic emissivity control				
7	T	e	lower lim	e^(1/4)	ΔT= T-Te¼
8	35.85	0.96	35.62	0.9898	0.3640
9	36.45	0.97	36.14	0.9924	0.2765
10	36.90	0.98	36.66	0.9950	0.1859
11	37.10	0.99	37.18	0.9975	0.0931
12	37.52	1.00	37.48	1.0000	0.0000

VLOOKUP =VLOOKUP(AV8,AO$8:AQ$12,3)

	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV
6	Simulation of automatic emissivity control						ΔT	with emissivity		SST Raw +
7	T	e	lower lim	e^(1/4)	ΔT= T-Te¼					
8	35.85	0.96	35.62	0.9898	0.3640		J$12,3)	35.99		35.62
9	36.45	0.97	36.14	0.9924	0.2765		0.19	37.19		37.00
10	36.90	0.98	36.66	0.9950	0.1859		0.28	36.44		36.16
11	37.10	0.99	37.18	0.9975	0.0931		0.19	37.23		37.04
12	37.52	1.00	37.48	1.0000	0.0000		0.19	37.27		37.08
13							0.19	36.87		36.68

At the bottom of the tabular data can been seen the analysis of the data, columns AT and AV of Table 14. The original temperature data which is unchanged has an average value of 36.739 °C and a standard deviation of 0.52228 °C. The confidence interval is nearly ±0.1 °C and displayed are the upper and lower limits of how closely this group of temperature readings adhere together: the medium is bound by 36.84 °C for the upper limit and 36.64 °C by the lower limit.

After the application of the emissivity correct, values seen in column AS, the results of adding the emissivity correction causes the standard deviation to change by approximately +0.1 °C as well as the standard deviation. This is hardly an improvement, but it comes with the presumption of making the correct emissivity adjustment when that information is not known for this sample group. It could be considered simply an adjustment for applying a slight correction to low readings.

5.8 Analysis of Trials

Of the five-different analysis attempted, the first using the theoretic emissivity correction to the sample appears to be the best attempt to simulate actual results. *This analysis successful shows that adding an emissivity correction improves infrared sensor reading*. While that analysis is fitting the experimental sensor results to the CVS proximity sensor; the final analysis that eliminates the CVS proximity sensor also show a slight improvement based on the standard deviation improvement. The use of the Excel VLOOKUP function to simulate automatic emissivity control provided a rudimentary, step-function adjustment to the skin surface temperature. *Because of the universal emissivity adjustment of all the temperature readings, any conclusion that emissivity influences the accuracy of infrared temperature would be indicative but not conclusive*.

Using a sample group to compare results and determine a standard deviation has it purposes. The better determination for emissivity is by formula; which is what is going to occur using hardware. There are two examples of this included in this chapter: Trials 3 & 4. Both formulas provided within the context of the sample data suffered from having to estimate the emissivity constant by using a reference temperature value to develop the emissivity constant. The emissivity correction should be determined from a skin-tone/emissivity table. In the analysis of both these two formulas saw the medium rise by about 0.2 °C.

Chapter 6

Emissivity Testing

6.1 Overview

A substitute for human skin was sought to allow testing of various human skin colorations using the experimental sensor. Using paper with color markers, a test set-up was developed and improved that allowed analysis of emissivity. It is our first look at color's effect upon infrared radiation.

6.2 Test Equipment and Preparation

This testing was conducted by the investigator using the following equipment:

1. Pigment markers of various tones representing the range of human skin tones from black to white were selected.

2. The markers were applied in swatches to separate papers using the broad tip in wide swipes until an area of approximately 4" square was covered fairly evenly.

3. The markers were applied to individual white sheets of paper recommended by the manufacturer of the markers as ideal for blending and color vibrancy.

4. The manufacturer of the markers and the paper are listed below sold by Blick Art Supplies, an art supply retailer. The sample color's name and product number also are recorded in the table below.

Table 16 Sample Color Information

Manufacturer	Color Name	Product #
Winsor & Newton	White Blender	245381019-163
Winsor & Newton	Burnt Umber	245388050-076
Winsor & Newton	Burnt Umber Light	245388670-110
Winsor & Newton	Henna	245388910-105
Winsor & Newton	Light Brown	245388010-112
Winsor & Newton	Parchment	245388230-121
Winsor & Newton	Winsor Orange Light (Red shade)	245384850-013
Winsor & Newton	Yellow Orange Light	245384250-008
Winsor & Newton	Lemon Yellow Light	245384110-001
Winsor & Newton	Black	245382020-030
Winsor & Newton	Pigment Marker paper	106491023
Blick Studio	Black	221482020
Coptic Sketch	Black	221102020-100

6.3 Emissivity Test Procedures

1. A gooseneck lamp for incandescent lighting was used. It is similar to a lamp sold by Park Madison Lighting, part #PMD-5614-31, 16.5 inches tall, available on Amazon.

2. The light source is a GE Soft White 40W replacement bulb that uses only 29 Watts whose brightness is 430 Lumens.

3. The lamp was turned up so its metal lampshade could support a paper with the sample color in the center of the swatch color.

4. Temperature was controlled within the human temperature range by layers of ordinary printer papers upon which the sample sheet was placed. The thickness of

the sheets used was ½ inch of 20 lb. weight paper of 92 brightness. The length of time for a new color sample when place upon the heat source to achieve the target temperature was 5 minutes. Excess heat was release by using paper binder clips holding all the papers about 3/8" above the circular metal lamp shade.

5. Because the weight of the paper tended to make the clips slip down, a wooden pencil was placed in the clips so the binder clip could capture the pencil and obstruct any slippage. Additionally, since the paper was 11 inches long, a footstool was used to support the paper extending beyond the heat source. This assisted the paper to lay flat across the lamp.

6. The ambient temperature was read at the beginning of the testing session.

7. The surface temperature of the sample was measured by the experimental infrared temperature thermometer during the test then that sample sheet was removed and the top sheet of the printer paper was read immediately after the sample was read. The total temperature output of the sample and the input to the sample sheet were read. While the next sample sheet was warming up, these values were transferred to the computer spreadsheet recording the data.

8. Distance is crucial factor and even a slight variation could lead to observation errors large enough to be misinterpreted as emissivity difference. For this reason, the distance for the 5 degrees field of view of the experimental sensor was set to 6 inches resulting in a spot target of 1inch.

9. The means to control the distance was to affix a cardboard tube from a roll of paper towel at the end of the prototype so the sensor was centered within. The diameter

of the enclosing tube was 1.75 inches allowing for slight misalignments but still having 3/8 of an inch for a clear view.

10. Cutting the cardboard tube down to six inches is the first task. Measure from one end six and ½ inches and mark the roll 360 degrees. You are leaving room for the tabs you will be creating with the extra ½ inch. Do not compress the tube to cut the excess length off. Use either an Exacto knife or sharp scissors to make this cut. Excess can be sanded off. Test the flatness by standing the tube up on a flat surface.

11. The method to attach the cardboard tube to the prototype is as follows: make one notch of 7/16 inch and ½ inch deep to create a tab. Bend the tab outward. The second tab is positioned by first inserting the sensor end of prototype board into the tab over the sensor. Position the tube so that the sensor is at the center of the tube when observed from the distant end. MARK the outside of the tube where you will make the cuts for the second tab. The depth of the cut will control the alignment of the tube with the sensor which is laid along the centerline of the prototype board and held in place with tape. The tabs you cut should go over and slightly compress the tape holding the sensor. When the 2nd tab has been cut, place the tube upon the prototype and trim off the excess of the tabs. Tape the tube into place after observing the sensor at the center of the tube. Double check often.

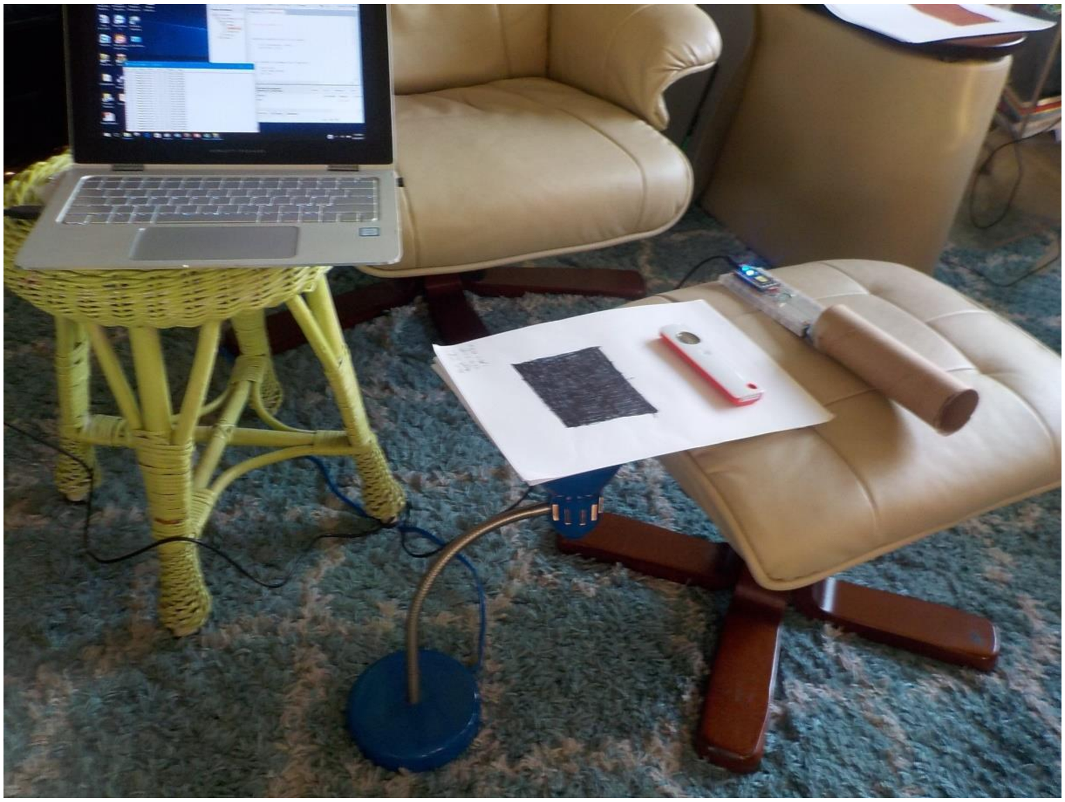


Figure 23 Setting up for equipment for first trial

6.4 Observations:

With the tube in place, you also insure the minimal effect from ambient air flow upon the experiment. Because the swatch was approximately 4" square, six readings could be taken across the sample, 3 in one row and 3 in the other thus collecting information about the heat distribution across the samples without too much overlap. This method of obtaining readings will be referred to as the six-spot sampling method.

The spectral content of the pigment colors and the paper were not considered relevant due to commonality of the paper and the manufacturing process thus allowing a comparison of the one variable that was being tested: the color of the marker covering the paper whose emissivity should reveal itself in the different of the temperature readings.

A session of testing was begun on June 25, 2017, then halted when results confirmed erratic temperature readings that far excessed the ability of this test to detected subtle changes due to emissivity. The standard deviation across the color sample was at least 1 °C and higher. Statistically, a meaningful average was not obtainable that would allow for a small margin of error. The following table shows surface temperature reading at 6" of color samples from six different spot locations

Table 17 Data of Emissivity for Trial 1

Color	read 1	read 2	read 3	read 4	read 5	read 6	Std Dev
Ambient temperature	26.87	26.89	27.37	26.69	26.63	27.97	
Black	37.61	38.71	39.43	37.47	40.01	39.61	1.07
White	37.83	41.47	40.33	38.31	40.29	39.93	1.37
Burnt Umber	35.93	39.17	37.93	38.29	40.43	39.53	1.56
Parchment	36.41	39.61	40.05	36.99	39.11	38.91	1.47

6.5 Comments

The standard deviation was considerably greater than the theoretical sensitivity of temperature to emissivity. For this reason, the testing was halted before the full range of colors were tested. It was noticed that the temperature tended to read higher on one side as opposed to the other. This was a mechanical error where the pencil being used as a spacer in one binder clip had collapsed possible causing this problem.

The standard deviation is made up from six separate reads from six separate locations all of which varied considerably. This lead to consideration of a means to lower the standard deviation. In the photo below, a close-up of the forehead of the investigator is shown. A casual examination of the skin reveals it is multi-colored with some locations more of a white tone while other are more of a red tone.

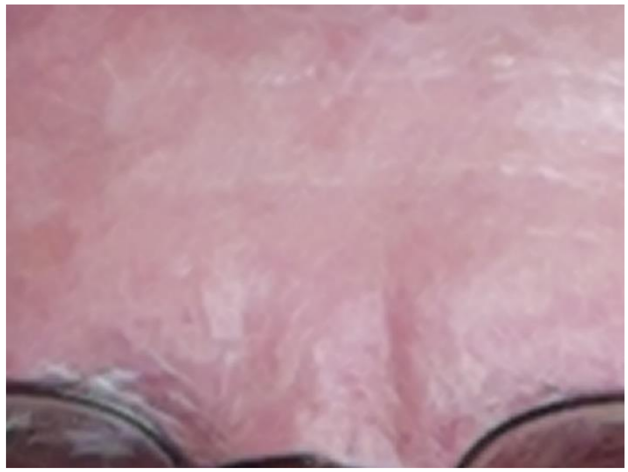


Figure 24 Example of camera zoom for RGB analysis

This variation in colors and temperatures of the pigment markers reminds me of pixelated photos, such as, below:

Figure 25 Pixelated photo of the Mona Lisa

The only way to make sense of the variety is to "back up" merging all the variations into a different focus. In this instance the merging is through the limitations of the eye ability to process the image. The same thing happens in infrared, all parts of the object are radiating different temperature values which when read from a distance have merged into one value. One of observed values is higher than others due to ambient temperature diffusion assuming the ambient temperature is lower than the object.

This is the solution that I have used to capture the whole face temperature from 36" based on my conclusions of the study by Jan Rustemeyer in Germany in 2007 [46].

6.6 Trial 2

Testing resumed on June 25, 2017 with a smaller wattage bulb: a 7½ Watt night light. The number of sheets of paper was reduced considerably down to 15. Better attention was paid to the lamp arrangement and checking alignment from the two axial directions. Changes made to the test setup are seen below:

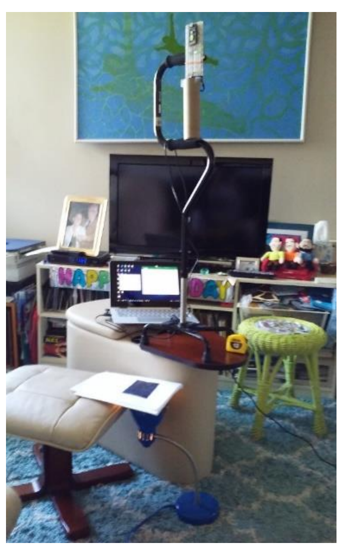


Figure 26 Complete setup for emissivity testing from 36"

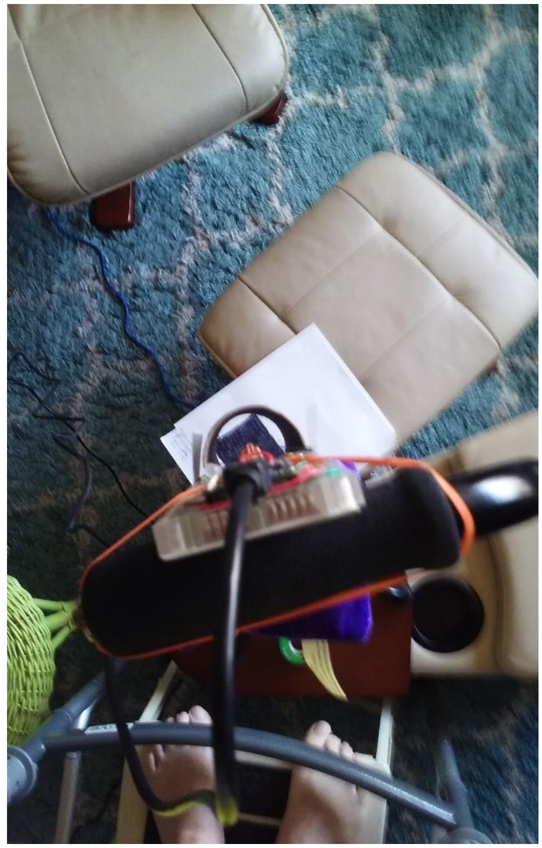


Figure 27 Sensor mounting and targeting view

Table 18 Data for Emissivity at 36"

Color	read 1	read 2	read 3	read 4	read 5	read 6	Std Dev	Average
Ambient tempera	26.87							
Henna	29.49	30.03	30.17	29.33	29.69	29.85	0.32	29.76
White	29.37	29.85	29.45	29.97	29.79	29.53	0.24	29.66
Windsor Orange li	29.37	29.41	29.39	29.29	29.39	29.35	0.04	29.37
Burnt Umbe lite	29.37	29.15	29.21	29.39	29.25	28.93	0.17	29.22
Lemon Yellow Lite	29.61	29.19	29.19	29.31	29.01	28.99	0.23	29.22
Yellow Orange Lit	29.17	29.21	29.25	28.95	29.15	29.53	0.19	29.21
Lite Brown	29.09	28.95	28.97	29.09	29.11	29.85	0.34	29.18
Parchment	28.87	28.99	28.99	29.53	29.31	29.27	0.25	29.16
Burnt Umber	28.93	29.33	29.19	29.15	28.85	28.89	0.19	29.06
Black	29.11	28.85	29.05	28.75	29.49	29.03	0.26	29.05

6.7 Analysis Trial 2

These results with the targeting being held to a tighter standard, showed a standard deviation average that was significantly better. The colors except for the white, black, and Burnt Umber (a deep red) lined up correctly with lighter colors showing a lesser amount of heat radiated due to the increased emissivity associated with the color.

Upon the analysis of the result from the 2nd testing regime, additional testing was delayed pending delivery of addition markers and improvements to the testbed set-up.

Additional issue needed to be addressed:

1. A pigment marker for white needed to be found because the white Winsor & Newton paper showed hotter temperatures than the permanent black marker by Sharpie.

2. A better black marker was needed as these results don't show an emissivity reflective of a black pigment, only a blocking of heat transmission out of line with the theoretical.

3. The markers added include:

    a. Floral white sold under the label Coptic Sketch

    b. Black sold under the label Blick Studio

    c. Black 100 by Coptic Sketch

4. Some of the color samples were made with first moving the marker horizontally then were covered by vertical strips thus creating a two-layer pigment. A single

layer for each color is the best way to compare the effects of emissivity. Those color samples were redone. One sample with the two-coat method of applying the pigment marker was kept providing information about consistency in observations.

5. Since the pigment markers were placed upon a layer of paper made by Winsor & Newton this becomes the 16^{th} layer upon which a layer of pigment was placed with the marker. It would be possible to determine the temperature loss through a single unmarked layer of this parchment called the 16^{th} sheet if one knew the temperature of sheet #15 (the uppermost sheet in the layers used to separate the lamp from the sample sheet). Using these values, a direct temperature source method to calculate the emissivity could be used.

6. The prototype begins its reads by the investigator pushing a button on the board that has a strong detent. This causes the board to deflect changing the focus of the sensor. To minimize this effect on the recording of the temperature, the mbed program was rewritten to allow for one turn-on then automatically take six separated reads of the same spot in the sample color. This could allow for a comparative value evaluation of emissivity. It would also improve the standard deviation by simply throwing out the first read and only using 5 reads for evaluation of temperature.

7. The method of taking the sample reading was changed slightly to have the sensor affixed directly to the cane above the sample instead of slightly off the normal axis. The sensor measured distance was 36”.

8. Once the targeting of the sensor was completed and essentially locked in, a 34" length of floss taped to the paper tube served as a centering guide for placing color sample paper into position directly under the sensor focus. While the floss is easily observable it was small enough to not affect the temperature reading and indicated any ambient air movement. One observation was held up after a door was opened in the apartment.

9. The cushion used as a shock absorber was changed out for a folded up stretch band that was stiffer that could return the sensor to its target faster.

6.8 Result of Data Collection from Trial 3

Table 19 Comprehensive Testing of Color Samples from 36"

	A	B	C	D	E	F	G	H	I	J	K
1	Records of SST at 36" taken on June 30, 2017										
2	Stricter controls: 6 read program means one turn on/dangling floss indicating center of target									Dropping first read	
3	Colors	read 1	read 2	read 3	read 4	read 5	read 6	Std Dev	Average	Std Dev	Average
4	Ambient temperature	28.21	28.07	28.99	29.57	28.27	29.19				
5											
6	sheet 15	33.17	33.07	33.05	33.05	33.09	33.09	0.04	33.09	0.02	33.07
7	sheet 16	32.41	32.31	32.27	32.29	32.31	32.29	0.05	32.31	0.02	32.29
8	White floral E000 Copti	31.01	30.95	30.95	30.95	30.93	30.93	0.03	30.95	0.01	30.94
9	sheet 15	32.95	32.93	32.93	32.87	32.87	32.91	0.03	32.91	0.03	32.90
10	Lemon Yellow Lite	32.47	32.39	32.35	32.35	32.37	32.33	0.05	32.38	0.02	32.36
11	sheet 15	33.53	33.23	33.21	33.17	33.19	33.21	0.14	33.26	0.02	33.20
12	Yellow Orange Lite	32.35	32.33	32.29	32.25	32.33	32.25	0.04	32.30	0.04	32.29
13	sheet 15	32.85	32.81	32.77	32.71	32.73	32.69	0.06	32.76	0.05	32.74
14	Windsor Orange lite	32.39	32.35	32.25	32.21	32.21	32.17	0.09	32.26	0.07	32.24
15	sheet 15	32.77	32.73	32.63	32.65	32.57	32.53	0.09	32.65	0.08	32.62
16	Burnt Umber single coa	32.47	32.43	32.41	32.41	32.43	32.43	0.02	32.43	0.01	32.42
17	sheet 15	32.75	32.59	32.61	32.55	32.55	32.55	0.08	32.60	0.03	32.57
18	Parchment	32.03	31.97	31.95	31.99	31.95	31.91	0.04	31.97	0.03	31.95
19	sheet 15	32.95	32.97	32.93	32.93	32.87	32.87	0.04	32.92	0.04	32.91
20	Burnt Umber 2 coats	32.37	32.21	32.21	32.21	32.25	32.29	0.06	32.26	0.04	32.23
21	sheet 15	32.99	32.79	32.69	32.71	32.71	32.71	0.11	32.77	0.04	32.72
22	Lite Brown	32.29	32.11	32.05	32.07	32.07	32.07	0.09	32.11	0.02	32.07
23	sheet 15	33.15	32.97	32.91	32.93	32.89	32.87	0.10	32.95	0.04	32.91
24	Black100 Coptic Sketch	32.77	32.75	32.67	32.61	32.69	32.69	0.06	32.70	0.05	32.68
25	sheet 15	32.93	32.83	32.79	32.83	32.79	32.81	0.05	32.83	0.02	32.81
26	Black Blick Studio	32.41	32.45	32.43	32.41	32.37	32.41	0.03	32.41	0.03	32.41
27	sheet 15	33.05	32.95	32.89	32.83	32.93	32.91	0.07	32.93	0.05	32.90
28	Black Sharpie permane	32.77	32.75	32.77	32.77	32.73	32.73	0.02	32.75	0.02	32.75
29	sheet 15	33.15	33.07	33.05	33.05	33.05	33.05	0.04	33.07	0.01	33.05
30	Burnt Umber light	32.95	32.19	32.17	32.17	32.19	32.19	0.31	32.31	0.01	32.18
31	sheet 15	32.99	32.95	32.93	32.91	32.85	32.85	0.06	32.91	0.05	32.90
32	Henna	32.95	32.81	32.85	32.83	32.87	32.85	0.05	32.86	0.02	32.84
33	sheet 15	33.11	32.79	32.79	32.73	32.75	32.79	0.14	32.83	0.03	32.77
34	sheet 16 check	32.89	32.85	32.79	32.79	32.85	32.85	0.04	32.84	0.03	32.83
35	sheet 15	32.95	32.95	32.95	32.91	32.91	32.87	0.03	32.92	0.03	32.92

6.9 Analysis of Trial 3:

The standard deviation for the first time is below 0.10 °C in most reads of the groups. This is a ten-fold improvement over the second round of testing. Eliminating first read of every row improves nearly every single one of the standard deviations. The averages changed slightly also.

One piece of information that can be derived right away is: what is the temperature loss through sheet 16 (without any marker). If we use the 5-read averages the temperature directly below sheet 16 is the temperature read for sheet 15 in cell K6 is 33.07 °C. The temperature read for sheet 16 when placed on the stack and warmed up is seen in cell K7 is 32.29 °C. The difference and the temperature loss through sheet 16 with no coloring on it is 0.78 °C.

Immediately after taking a temperature reading for a sheet 16 marked up with a sample color, the sample color sheet was removed and the temperature read for sheet 15 which was heating up the sample color. The data for sheet 15 is recorded in the row immediately below the temperature for the sample color sheet. The temperature for the sample color sheet with white marker in cell K8 is 30.94 °C and sheet 15 temperature reading in cell K9 is 32.90 °C. This means the marker and sheet 16 accounts for a loss of 1.96 °C. The Excel formula is K8-K9 resulting in a negative number to represent the loss. Since we had previously calculated the loss through sheet 16 as 0.78 °C then the emissivity accounts for a loss of 1.18 °C through the sheet of paper with the white sample color.

6.10 Analysis of the Input Temperature to the Sample Color Sheet

Sheet 15 temperature was taken 90 times. This accounts for a large portion of the analysis of emissivity. Let's examine those 90 temperature values recorded for sheet 15, seen in the graph below, Figure 28. For the purposes of this dissertation, the temperature values represent a vector and are displayed in a sequential manner. Since there were six reading for each sample color, those reading will be grouped together (binned) and displayed in a sequential order based on the order they were collected. The temperature is on the vertical axis and the horizontal axis display the sort order number. Through the rest of this chapter displays of this or similar data is presented in the same manner.

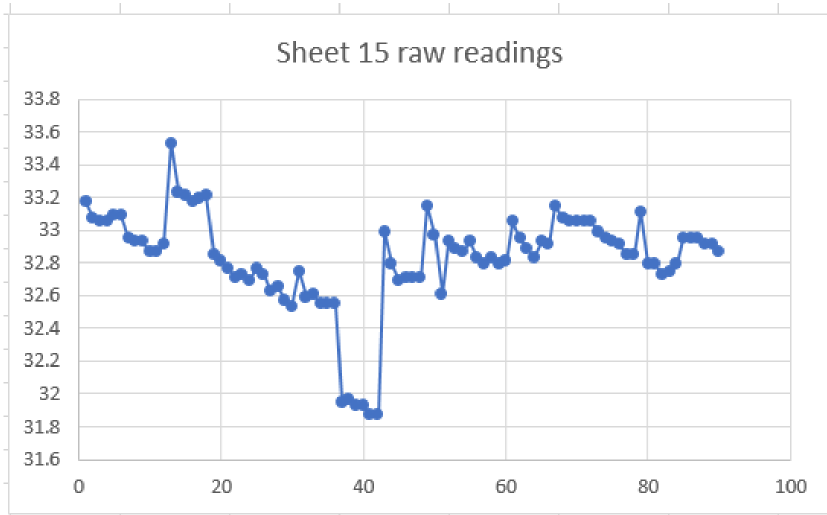


Figure 28 Raw temperature data for sheet 15, sequential vector sort

These raw values grouped in sixes show some errors like the first value spiking that can be solved by just reading the last five values. The group 37 to 42, or the 7th group in the table above, row 19, are the sheet 15 temperatures for the parchment color sheet. Obvious there was a recording error of one digit, the units digit, as a one is seen when it should have been a two. Additional recording errors for data point 51, 32.61 °C should have been a 32.91 °C. Making these changes reveal the following about sheet 15 reads:

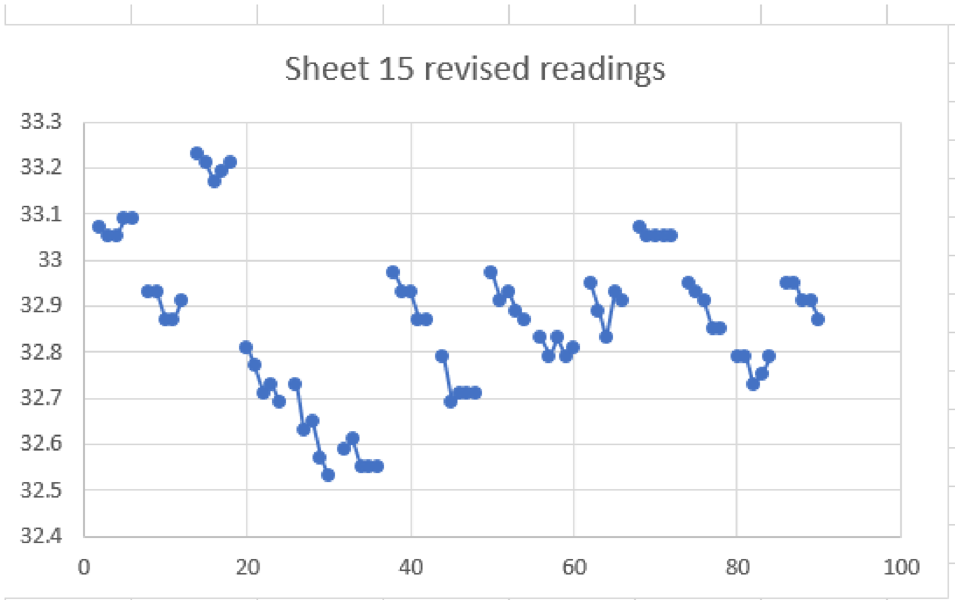


Figure 29 Corrected values for Sheet 15, the input temperature.

This graph reveals 15 sets of temperatures in an exaggerated saw tooth pattern that range from a high of 33.23 °C to a low of 32.53 °C. Each set has an extremely low standard deviation below 0.04 °C (except for set 5 which is 0.08 °C) but as a group the standard deviation is ±0.17 °C around the group average of 32.87 °C. One source of this behavior might be attributed to the night light. This heat source is not a calibrated source and easily could oscillate up and down. There is at least a five-minute gap for heat-up time before the next set of reading is taken. This could explain the gap between sets and the fact that very few readings showed a monotonic increase. This is enough to disqualify any conclusion about emissivity except for one point: the sheet 15 reading was taken immediately after the sample color sheet temperature, so the oscillating temperature should be valid for both the sample color sheet and sheet 15. Let's examine the sample color sheets and the source temperature in the same chart:

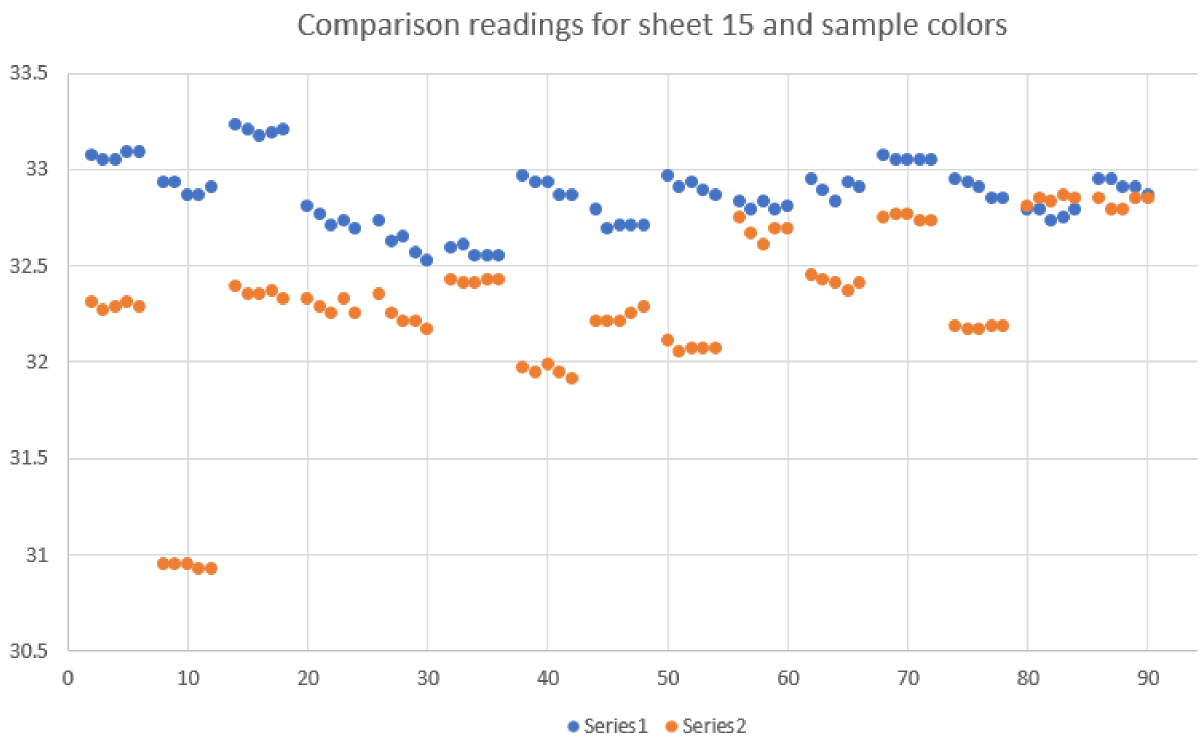
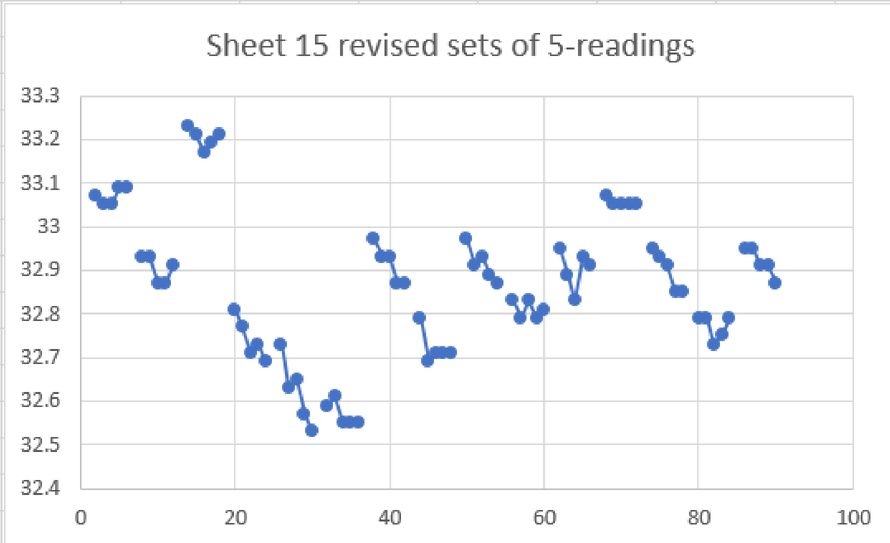


Figure 30 Data collected for each set of sample colors

Series 1 in blue is the temperature readings of sheet 15 or the baseline temperature that is heating up the sample color sheet. Let's call that reading the input heat source. Series 2 in orange is for the sample color sheet which we could call the output temperature. The difference in temperature between the 15 sets of five values is the difference between what is heating up and what is being emitted. The graph is hard to interpret but it is easy to see that there are sets of readings in blue with sets of reads in orange; but, they are quite mixed up. Since each individual set of reads are valid, in the sense that the difference between the input and output are related; it might be useful to determine some way to normalized the blue readings revealing more deciferable and meaningful information. The standard deviation for the output temperatures uncorrected for emissivity is 0.459 °C. Without white the standard deviation is 0.263 °C. Let's look at just the input temperatures:

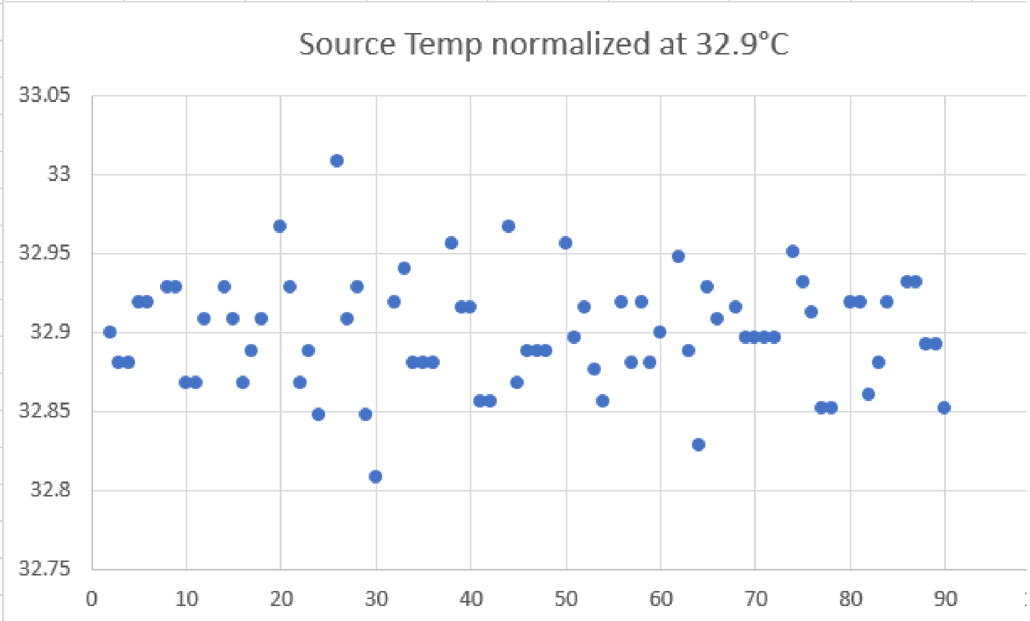


Reveals a saw tooth patter that ranges from a high of 33.23 to a low of 32.53 degrees C.

Std Dev	Average
0.17	32.87

Figure 31 Input temperatures after more filtering

This graph clears up some of the confusion and clarifies our next move. With the standard deviation of 0.17 °C and the average of 32.87 °C for the entire group, normalizing the sets around the average of 32.9 °C will help once individual offset are found for each set of colors. The calculation requires determining the difference between the set average and the desire normal value. The results of the making this change is seen in the next graph:



Reveals a cluster pattern that ranges from a high of 33.23 to a low of 32.8 degrees C.		
Sheet 15 is the source temperature		
Std Dev	Average	←of the above source temperature reading
0.03	32.90	←of the above source temperature reading

Figure 32 Input temperatures after normalizing input & outputs to 32.9 °C

This normalization created a standard deviation of 0.03 °C around an average of 32.90 °C for the input temperature source. The same offset was applied to the values for the sample color sheets so they moved with the input sources of each set. This adjustment of the output temperatures maintained the original difference between the input and the output. The X-axis is simply a sequence that only has meaning with the sets. Since we've dropped the 1st read for an improvement in the standard deviation number, we are now seeing sets where the majority of set's standard deviation is less than 0.04, a ten-fold improvement over earlier charts. What we lose by this normalization is the real, actual temperature values for a point on the chart. There are two valuable pieces of information on the new chart and they are:

1. The difference between the source temperature and the output temperature hasn't changed.
2. With the multiplicity of sets, a comparison between the information in item 1 is now possible between sets (different colors).

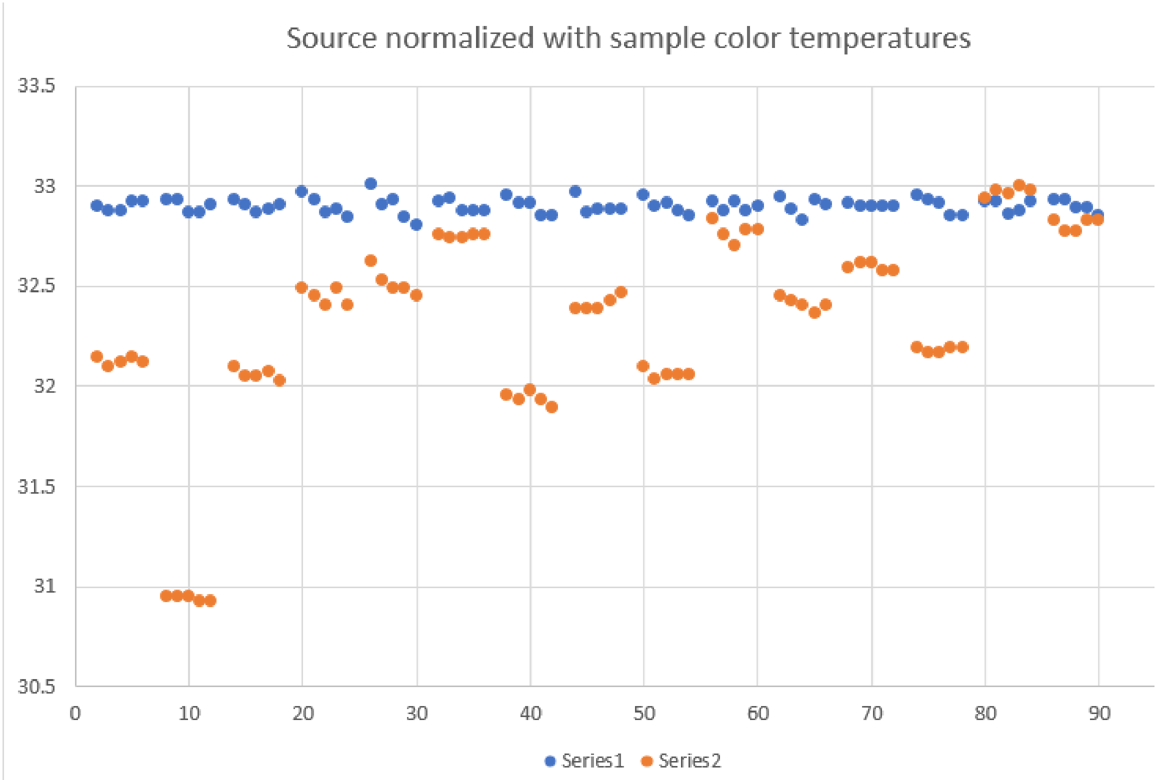


Figure 33 Preliminary look at normalized emissivity data

At this point in our analysis, the chart is beginning to make sense. All that remains to be done is sort the colors from lightest to darkest. The first set and the last are checks on the input/output temperature for the unmarked sheet 16 which are dropped from the display.

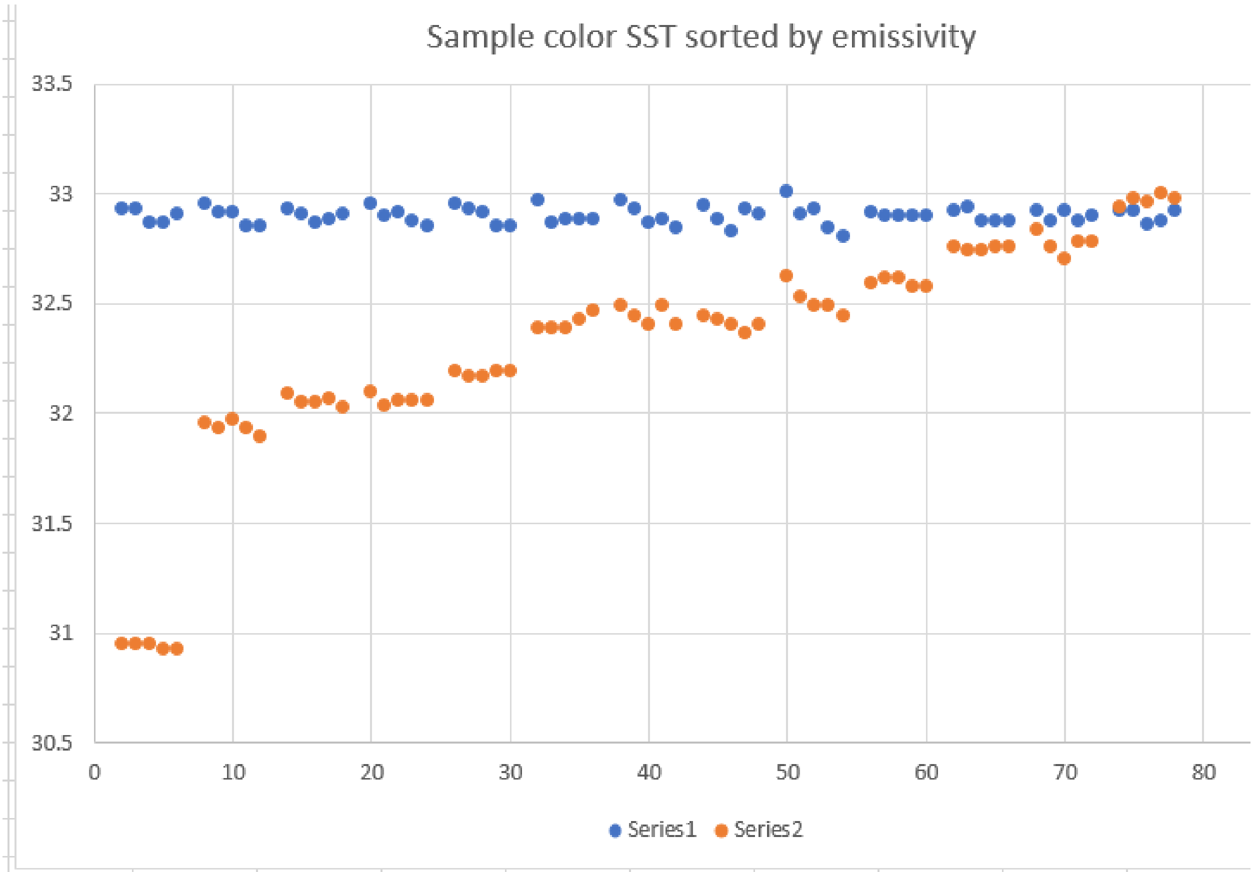


Figure 34 Emissivity sorted by descending ΔT (ascending emissivity)

In the graph above, the colors are sorted lightest to darkest (left to right) based on the emissivity. The first color on the left is white and it has a lower emissivity than the darker colors on the right. This means that white internally reflects the heat back into the body. There are about 2 degrees between the source heat into the white sample color and the output temperature sensed by the infrared sensor. On the right side of the chart are Black and others colors that read equally high. Theoretically, black radiates out whatever comes in providing no impedance to the heat flow. All the colors are showing what the external temperature would read for an infrared sensor if the input heat source was set at 32.9 °C. As the colors shift from lighter to darker, there is less and less heat reflected internally and more heat emitted. This is exactly as it should be according to theory.

In the final graph below, the colors are sorted lightest to darkest (left to right) based on the emissivity. The first color on the left is white and it has a lower emissivity than the darker colors on the right. This means that white internally reflects the heat back into the body. There are about 2 degrees between the source heat into the white sample color and the output temperature sensed by the infrared sensor. At the other extreme on the right of the chart are the colors Black and others colors that read equally high. Theoretically, black radiates out whatever comes in providing no impedance to the heat flow. All the colors are showing what the external temperature would read for an infrared sensor if the input heat source was set at 32.9. As the colors shift from lighter to darker, there is less and less heat reflected internally until the final colors where everything that enters the body is emitted meaning the input heat is the same as the output heat.

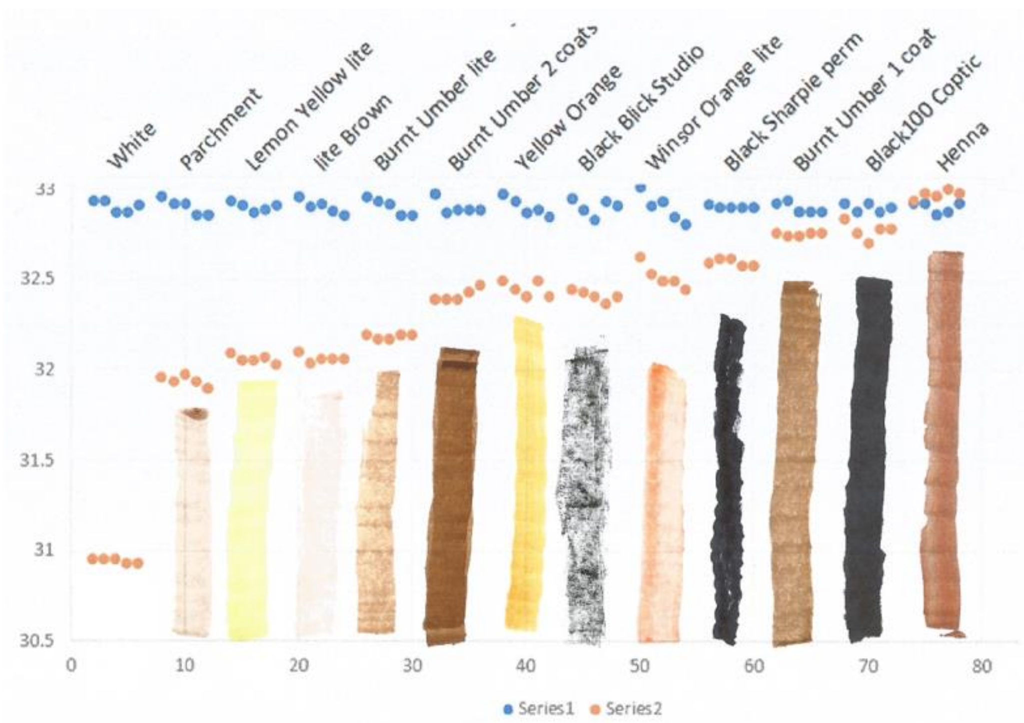


Figure 35 Sample colors shown using normalized input temperature

6.10.1 Highlights of Sample Color Testing

1. The blue data points (series 1) are the normalized input temperatures corrected from the observed temperatures by the experimental infrared sensor. The medium value for this series is 32.90 °C with a standard deviation of ±0.03 °C.

2. The orange data points (series 2) are the output temperature observed by the same experimental infrared sensor. The medium value for this series is 32.26 °C with a standard deviation of ±0.459 °C.

3. The color white is nearly two degrees below the base line source temperature of 32.9 °C. This is equivalent to an emissivity of 0.788, well below common usage. The pigment marker was from a different manufacturer and may account for some of that difference.

4. Several colors have essentially the same emissivity: Lemon Yellow lite and Lite Brown; Burnt Umber 2 coats, Yellow Orange, and Black Blick Studio; and Burnt Umber 1 coat and Black100 Coptic. This is good information as we now know that colors of different hues can have the same emissivity.

5. Based on the results for the color Burnt Umber which included two samples, one with one coat applied in horizontal strips and one with two coats where an overlaying vertical stripe pattern were applied showed contradictory information. Depending upon the number of coats (thickness), the emissivity changes for the same color in an inverse ratio: the more coats the lower the emissivity. Technically, the sample with one coat was darker when viewed by the infrared sensor while in visual light by eye, the two-coats were darker in appearance. Since the colors for

the layers were the same, one would think that the emissivity should be the same. Evidently, a different factor was at work causing the two-coat sample to pass less energy out of the sample (low surface temperature). This factor was not tested in this experiment and remains unknown.

6. The heat transmission through the Winsor & Newton paper used for the sample colors changes from 2 degrees of loss (white) to no loss (Henna). This is an effect of the emissivity.

7. Not withstanding the above data, in a 2nd separate experiment recorded in the Appendix, the heat loss passing through the printer paper stack was measured and evaluated at -0.076 °C per sheet. As part of that experiment, the loss through one unmarked Winsor and Newton paper was measured at -0.5 °C degrees.

8. Set 13 data merges and overlaps with the normalized temperature values. Since the temperature data for set 13 is within the standard deviation for both the normalized input temperatures for the color Henna and the raw output temperature, this result is to be expected and not considered erroneous.

6.10.2 Summary

These results demonstrate that the experimental infrared sensor can detect emissivity. after improvements, the testing regime showed improved to the standard deviation for the various sample colors from over 1 degree to mere hundreds of a degree. As a result, taking the skin-tone of persons into account use a look up table based on experimentation, such as Table 20, can improve the infrared temperature sensor reading. This is a second validation of the hypothesis for this dissertation.

6.11 How Much Improvement is Seen?

What is the degree of improvement for infrared sensors using emissivity information we have developed?

This question can be answered by examining the improvement to the data from the results of the July 30, 2017 experiment. We had previously looked at the source data for anlaysis. This time we will look at the output data from that experiment.

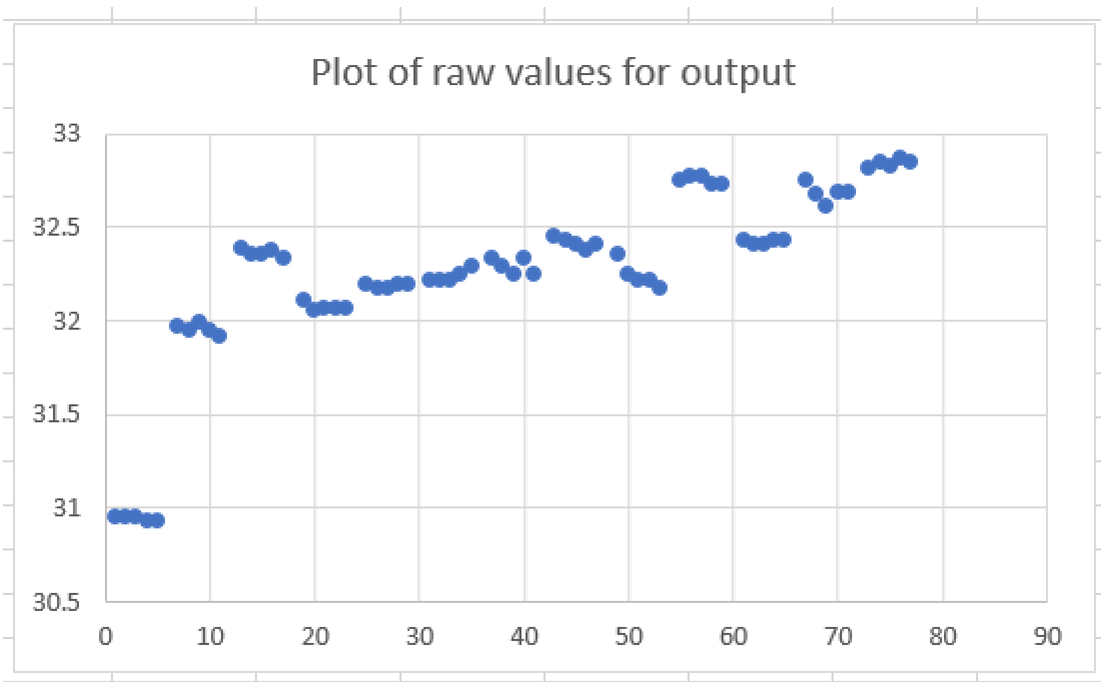


Figure 36 Output values before being corrected for emissivity

The output ranges from 30.9 °C to 32.9 °C making the reading seen by the sensor vary over 2 °C uncorrected. While this graph does display the group in the same sorted sequence from the last chart, the standard deviation is ±0.459 °C around the average of 32.26 °C no matter what sequence the values appear. Because I have raised some question about the white data, if we discount the data set from the white reading, the standard deviation is ±0.263 degrees Celcius around 32.37 °C. The medium is a whole tenth of a degree higher due to our dropping the lowest values. This makes the standard deviation bunch a bit tighter as the white data is easily a degree below the rest of the data sets.

The high point temperature for this experiment is Set #13, Henna, and could be assigned the default values of zero difference and an emissivity of 1 based on the colocation of the source and output data points because their input and output temperatures are overlapping but within the group standard deviation for the input and output temperatures.

Application of emissivity can be done using a spreadsheet. Table 20, on the next page is the spreadsheet showing the temperature difference between the input and the outputs in column Temp Diff. These values are added to the raw-date output temperatures. Below is the graph of the emissivity corrected results without the white set of data include:

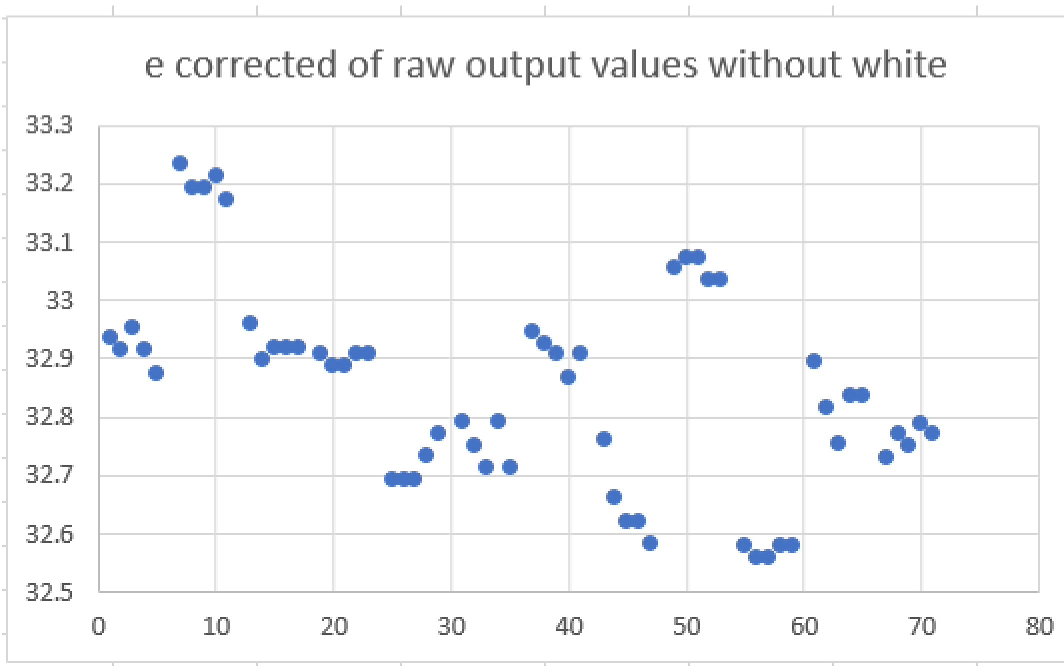


Figure 37 Output temperature shown after being corrected for emissivity

In this chart, the range of data points goes from 32.5 °C to 33.2 °C or about 0.7 °C. The standard deviation is **±0.166 °C** around an average of 32.85 °C. The standard deviation for the output temperatures shows an improvement of 0.092 °C or nearly 0.1 °C over the same sets of data points (without white). The average increases by 0.48 of a degree. With the sample color white is included, the standard deviation improvement is ±0.292 °C.

While this experiment does not use human volunteers, the same effect can be expected in human trials: a tighten of the standard deviation and an increase in the average temperature. If the white data set were to be included, the standard deviation stays the same: ±0.166 °C, at the 0.1 °C improvement, with the average staying the same.

A valuable aid to making the emissivity correction is the use of a look-up table. Since we have access to the input and output temperatures of the color samples we can use the definition of emissivity in its creation.

Table 20 Look Up Table for Emissivity Based on Color Samples

Colors sorted left to right			
Set #	Color	Temp Diff	Emissivity
Set 1	White floral Coptic Sketch	1.96	0.94043
Set 2	Parchment	0.96	0.97083
Set 3	Lemon Yellow Lite	0.844	0.97458
Set 4	Lite Brown	0.84	0.97448
Set 5	Burnt Umber lite	0.716	0.97824
Set 6	Burnt Umber 2 coats	0.488	0.98509
Set 7	Yellow Orange	0.452	0.9862
Set 8	Black Blick Studio	0.488	0.98517
Set 9	Winsor Orange lite	0.384	0.98823
Set 10	Black Sharpie permanent	0.304	0.9908
Set 11	Burnt Umber single coat	0.148	0.99546
Set 12	Black100 Coptic Sketch	0.128	0.9961
Set 13	Henna	0	1

Chapter 7

Temperature Survey using Emissivity

7.1 Overview

This chapter presents survey data from an emissivity enabled thermometer using human subjects in an IRB approved survey. Volunteers were engaged in selecting the value of the emissivity for their skin using the Fitzpatrick Scale [58]. The method of entering the value selected was with a software-controlled potentiometer. The high end of the voltage range represents 1.00 and the voltage at the other end represents the lower end of the emissivity range. Moving the potentiometer clockwise would lower the emissivity. The gradient scale is marked with color icons like those seen for the Fitzpatrick Scale in Figure 38 Fitzpatrick scale. Since the scale is a potentiometer, a continuous range is established with darker or lighter shades of the various icons giving the Fitzpatrick scale transitional values.

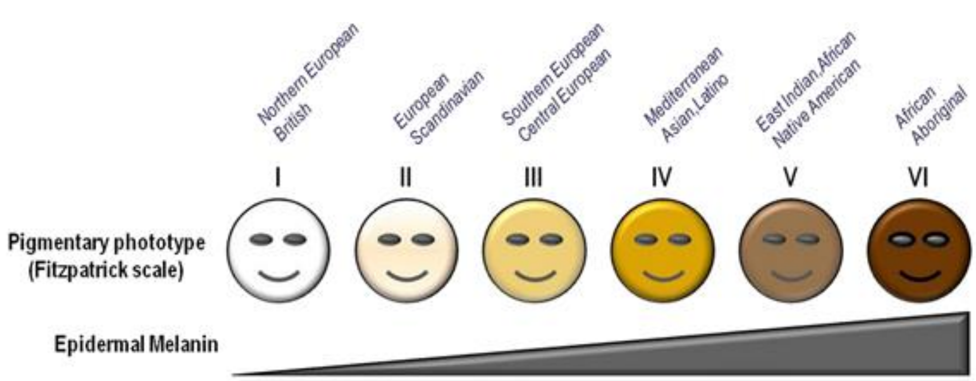


Figure 38 Fitzpatrick scale

7.2 Hardware Preparation

For this emissivity survey, a 3-D print prototype was designed that allowed for sensor placement at the front, reset button placement at the rear, a Celsius/Fahrenheit selection switch, a 4-digit 7-segment display, sight guides for range finding (covered in section 4.6.4), and an emissivity adjustment potentiometer. This section will address the potentiometer.

Installation of the potentiometer required 3 connections: V+, Ground, and Sweep (output voltage). The voltage range for a basic potentiometer sweep would show V+ to Ground. Since the voltage is being converted to the emissivity percentage having the bottom of the range go to zero was not desired as no humans have that low a reading. A dropping resistor was installed on the ground side of a 10K potentiometer so that when the sweep was at its lowest point, approximately 70% of V+ would be read. The voltage would be resolved into a digital value by the ADC unit. The determination of the resistance of the dropping resistor was calculated by dividing the unknown dropping resistor (Rx) resistance by the sum of the potentiometer resistance value (R_{V+}) plus the unknown dropping resistor set equal to 0.70.

$R_x/(R_{V+} + R_x) = 0.70 \rightarrow R_x = .7(R_{V+} + R_x) \rightarrow$

$R_x = .7R_{V+} + .7R_x \rightarrow (R_x - .7R_x) = .7R_{V+} \rightarrow .3R_x = .7R_{V+} \rightarrow$

$$\mathbf{R_x = (.7/.3)R_{V+}}$$

Equation 10 Solving for dropping resistor value for emissivity potentiometer

This formula resolves using 10K for R_{V+} into $(7/3)*10K \rightarrow 23{,}333\ \Omega$

A convenient value found in resistor packs is 23K ohms. The voltage at the zero position now becomes 2.3 voltages. When this value or any voltage value associated with any position on the potentiometer is divided by the full voltage of 3.3 volts, a percentage appears on the ADC output. At the zero position the percentage appears as a decimal number: 0.70 representing the emissivity for use later in the program. An emissivity value of 0.70 is assumed to be the lower limit for human emissivity.

7.3 Software Controlled Hardware

A guide for positioning the emissivity pot using the Fitzpatrick Scale was designed:

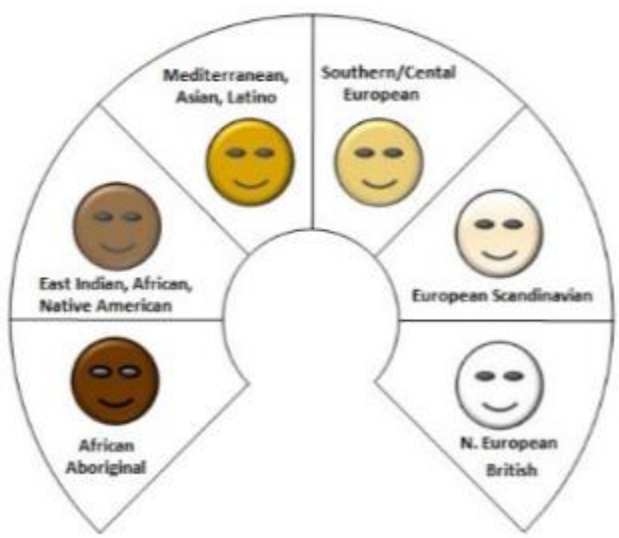


Figure 39 Label for emissivity dial

This scale works fine if the human emissivity lowest range is 0.70. But suppose it's a higher value for the individuals at the bottom of the scale? What if human emissivity is more like the sample sheets from Chapter Six, Table 20, where the range low value is 0.94? The dial would be out of position not relaying to the volunteers that the skin-tone selected is anywhere near their skin color. Needed is a means to morph the emissivity pot range from 1.0—0.7 into 1.0—0.9.

There were two requirements for the potentiometer: to read 1.0 when the knob is fully counterclockwise and 0.9 when in the fully clockwise position. Since the hardware is soldered in place we would need the value of 0.2 as an adjustment factor to be added to the potentiometer's reading when fully clockwise or some portion of this factor when the dial was not reading 1.0. When the emissivity was 1.0, no portion of the 0.2 would be needed to be added to the emissivity. To turn the factor off, a coefficient of (1-emissivity) is used so that when the emissivity is 1.0 the factor would become zero cancelling out the factor.

The following algorithm is executed in the section for reading the emissivity pot in the program code seen in the Appendix, Survey Program May 2017—main.cpp.

> *Line 39: //V13 Log Ready, added varible "factor" at line 94 so you can add adjustment to emissivity so that other than .734 VDC is assigned to emiss, see line 194*
>
> *Line 99: float factor=0.166; //use to make lowest point in emiss range = 0.900, enter .001 if no change is desired, others use formula "desired lowest emissivity value -0.734 = factor.*
>
> *Line 194: emiss = emiss + (1-emiss)*(factor/.266);*

The factor value is calculated by subtracting the real value for the lowest emissivity: .734 from the desire lowest value. If there is no desired change in the lowest emissivity value, then the value of .73**5** should be entered so the program doesn't get hung up on division by zero.

The value for emissivity is printed out for data logging purposes. To record the data readouts, a computer terminal program like TeraTerm software was required to be connected via USB to receive and capture the data.

In field trials the algorithm worked flawlessly generating emissivity reading of 1.0 when the potentiometer was clicked off. Other values straight up—0.994, 0.98, 0.96, horizontal—0.95, 0.94, 0.93, 0.92, 0.91, 0.90 were also marked on the label. At the extreme end of the potentiometer, fully clockwise, the reading for the lowest generated emissivity value generated was .868 with a voltage value of 0.627 V on pin 20 (the I/O pin used for the potentiometer's sweep).

7.4 Emissivity Temperature Survey

The emissivity temperature survey was conducted over two days, November 29 and 30th, 2017 at The Design Factory located at 163 Williams Street in New York, NY. Thirty student volunteers participated in the collection of data: 20 males and 10 females. The survey took longer than the previous survey because more time was being spent with each student explaining what was being tested and the procedure. This survey used the same Institute Review Board authorization upon notification of reasons which is good for a year.

7.4.1 The Emissivity Survey Protocol

Student volunteers were first given a copy of the description of the protocol that explained what the survey was about and how and what would occur which they signed. They then filled out a data information sheet that include a survey ID # for their anonymity and room to include their age, sex, weight, height, and presumed Fitzpatrick scale value for their skin-tone. After these matters were squared away, the student volunteers first had their temperature's taken using the same CVS near-field thermometer that was used in the first survey, Figure 19. This was the best performing device of the three commercial units and it was an infrared sensor. After a discussion of what emissivity was, the volunteers would pick a value for the emissivity to be used referencing the Fitzpatrick Scale, see Figure 38. The volunteer then sat through one or more readings (to allow for emissivity adjustments) using the experimental sensor from 3 feet away. The students sat in a chair at the end of a table with the experimental sensor placed 36 inches away. At the conclusion of the testing, the back of one of their hands was photographed on a piece of paper with only their survey identification to tie the photo to the data. An exception to this final procedure occurred in that 3 volunteers missed getting their skin-tone photos taken: #6, #9, and #13. However, for these volunteers their Fitzpatrick Scale category information was captured during the data collection phase. The volunteer information is shown in the Appendix under “Emissivity Survey—Volunteer Information”.

Lighting becomes an issue with photos for consistency of color representation. For the record, lighting for this survey was under typical office fluorescent lights, one of the CIE Luminant series F [65]. Throughout both days the lighting was consistent. No flash was used when capturing the photos of the back of the hand.

7.4.2 The Quandary?

As the survey began, with the setting of the emissivity potentiometer, additional “heat” is supplied to the volunteer’s readings. The question is “What emissivity setting will give us the temperature outcome we are looking for? The quandary develops because we don’t know what the correct temperature is supposed to be using the experimental sensor with the emissivity included. It was for this reason that the use of the CVS near-field thermometer to record the volunteer’s temperatures proved useful.

7.4.3 Distance Error Complications

For volunteers with the darkest skin-tones, their emissivity setting was set at 1.0 so there was no emissivity compensation used to calculate their distance compensated adjusted temperatures. There were several student volunteers that fit into this category. Their SST temperatures, as well as all volunteers, would include some unknown distance error based on the k factor, see Figure 7. Since the experimental sensor is a different thermometer, their adjusted reading would be expected to be different from the CVS near-field thermometer reading. The temperatures from these volunteers could set the upper limit for emissivity temperatures except for the fact that their SST temperatures included some random distance error **and** the volunteers all didn't have the same temperature.

All the student volunteers have a random distance error because the positioning of the sensor in front of the volunteer's face is considered an operator error. It was not a consistent error. While a visual positioning design was created and included on the prototype, see Figure 21 and Figure 22, the reliability and repeatability were susceptible to operator error. A back-up system using a bench mark[6] was also used.

Given these difficulties compounding our quandary, could the emissivity be determined if the correct temperature output was unknown? The following two measurements were used to insure accuracy: the visual positioning guides for distance and the temperature value read by the CVS near-field thermometer. Many volunteers had repeated temperature readings taken; often with different emissivity settings. The skin surface temperature (SST) is considered the subject's temperature sensed at the observer's location. This value is all that the sensor senses and the only temperature value reported by the sensor. To that value the emissivity correction and a distance offset is added. That sum becomes the Adjusted temperature for the subject representing the subject's body temperature.

7.4.4 Summary of Emissivity Survey Results

Once the data was transcribed from the TeraTerm terminal program log sheets into Excel software where analysis was conducted using Excel statistical functions. The average

---

[6] A bench mark is a measure distance marked off from a known starting point; in this case, from the end of the table where the volunteer was seated such that their face was above the table's edge.

value, standard deviation (for a sample), and range of the experimental sensor SST readings were analyzed. Below is a sample log sheet data recording for one reading of subject #1:

```
#1 36.5 C
 emissivity potentiometer reading on pin 20 is 0.903 Adjusted value for emissivity is  0.963
The ambient sensor temperature is 26.13 C and 79.03 F
 Sensor Accuracy is 0.2
 Your temperature is within the NORMAL temperature range
 SST temp is 32.68 C and 90.82 F
 Temperature is 37.71 C and 99.88 F
 end of report Emissivity Survey 11/29/2019 Pace University
```

Figure 40 Sample data capture from Tera Term software

The first line contains the student ID # and the CVS near-field infrared thermometer reading. This data was entered using a comment feature to the log sheet. All the following lines are automatically generated by the print data commands contained in the program software. For this sample the primary data used in the analysis were: the student ID, #1; the CVS proximity thermometer reading, 36.5 C; the adjustable emissivity value (used to modify the SST), 0.963; the SST temperature, 32.68 C; and the Temperature, 37.71 °C. The Temperature is the SST value adjusted by offset and emissivity for the subject's body temperature that is displayed on the device. Information used but not shown is the offset value of 3.70 °C for that recording.

Not all the information collected or displayed was used for analysis. There were 127 temperature readings captured during the survey with some volunteers having just one reading by the experimental sensor and others having considerably more making the average of the SST readings inaccurate without taking weighted readings into consideration *or* partitioning this group into sets. One approach was to sort the temperatures by binning used the CVS temperature readings. This assisted in sorting the results by temperature.

The average skin surface temperature (SST) of the experimental sensor for all 127 SST data points collected from the volunteers was 32.67 °C and the standard deviation was ± 0.8804 °C. The range for All SST readings was 5.00 °C (maximum to minimum value). Since each reading has an emissivity reading associated with it, the statistics of All Adjusted calculations was computed using both the offset (3.7 °C) and the emissivity value.

Table 21 All SST and Adjust Temperatures

	All SST temperatures	All Adjusted temperatures
Average	32.67 °C	37.04
Standard Deviation (population)	±0.8804 °C	±1.0062 °C
Range	5.00 °C	6.06 °C

The average for the CVS near-field infrared thermometer was 36.7 °C and the standard deviation was ±0.166 °C. The range for the CVS thermometer readings was 0.70 °C. Strangely, there were no CVS thermometer readings over 37.0 °C. This led to the assumption that no one had a fever that took the temperature survey.

The standard deviation of the SST for the experimental sensor from the first survey, ±0.5223 °C, was smaller than the standard deviation for all the readings from the experimental sensor from the emissivity survey, ± 0.8804 °C but that was for a survey that didn’t include emissivity.

The immediate conclusions from this overview of the data was that the experimental sensor had a problem with the standard deviation and that perhaps the survey was useless. The first observation was correct but the second turned out to be wrong. The data when partitioned has quite a bit of useful information because the focus is on the emissivity value and not on the spread of the standard deviation. For instance, the correlation between the SST temperatures and the Adjust temperatures is 0.8712 which is acceptable and the average is quite near the normal temperature for humans in centigrade. But, the range is 6 degrees for the Adjusted temperature that include the offset and the emissivity value and is unacceptable.

7.4.5 Binning the Data

Keeping in mind the CVS device does not use emissivity, a number of volunteers have the same CVS reading and are presented here:

Table 22 Common CVS Temperature Groups

Count	Temperature	Volunteer ID
2	36.3	21,22
3	36.4	4,7,27
6	36.5	1,2,3,5,10,12
6	36.6	11,15,16,19,20,23
9	36.7	6,8,9,13,14,17,18,24,25
2	36.8	29,30
1	36.9	26
1	37.0	28
30	Total	

The grouping seen in Table 22 makes the analysis useful in the same manner as binning is used in Big Data because it partitions the data into useful chunks. All together there were 127 data rows where each volunteer's individual readings were collected. We will return to this subject of binning after selecting a sample partition that can be used to evaluate emissivity starting in the next section.

Some volunteers only need one reading and their survey participation concluded rather quickly. Others required multiple readings to the point that after five readings further data collection seemed pointless; however, even this pointless excess data collection has information that was beneficial for the analysis. This data is shown in the Appendix under Emissivity Survey—Data Collected.

For the analysis of the emissivity adjusted temperatures, the Excel software needs an *engine* to generate an adjusted Temperature. The engine would use the same formulas as the program software but allow the investigator to use different emissivity and/or SST values to produce a trial adjusted temperature. This would be entered on the same row as the data collected but in the "Adjusted" column. The adjusted column can be considered the survey results. The engine is the formula:

"SST + (SST+offset)*(1-Emiss) + offset"

Equation 11 Excel engine for calculating Adjusted temperature

In this formula, the "Emiss" refers to the cell location for the emissivity value used, "SST" refers to the cell location where the value of observed heat at the sensor is written, and the offset used for distance mentioned earlier. The term "(SST+offset)*(1-Emiss)" is the computation of the heat at the source times the percentage that the emissivity reflects back into the body. This gives three term: the SST value, the (missing) emissivity heat, and the offset to render the Adjust temperature for the subject.

7.4.6 Selecting a sample partition

Looking at the results of the Emissivity Survey—Data Collected (seen in the Appendix), can be seen results that appear inconclusive. A decision was made for the first trial to only consider the 1^{st} reading from each volunteer as that was most likely the best observation to capture the data. This decision is based on the knowledge that several students (14) only required one or two readings to capture their data. Because of the numerous readings taken, multiple sets of temperature data can be created.

For this dissertation, only two sets will be considered for the base set of temperatures: 1) the first temperature taken during a session with a volunteer and, 2) the highest temperature taken during a session with the volunteer determined by a simple sort of the data for that volunteer. Because five volunteers' data was captured with one temperature reading, both sets share these common temperatures; the two sets are not entirely independent.

7.4.7 Emissivity Survey Preliminary Results

	S	T	U	V	W	X
1	**nine ori**	All temperatures in Centigrade				
2	**First** SST reading after setting emiss				(7 Fever temps)	
3	with subject includes original SST				(3 low temp)	
4	readings, emiss setting, and calculated					
5	original settings				Is Adjusted	
6	subject #	SST	emiss usec	Adjusted	>CVS temp	CVS Tem
7	21	32.20	0.973	36.56	TRUE	36.3
8	22	31.02	0.972	35.38	FALSE	36.3
9	4	33.54	0.975	37.86	TRUE	36.4
10	7	33.12	0.975	37.43	TRUE	36.4
11	27	32.22	1.000	35.62	FALSE	36.4
12	1	32.68	0.963	37.41	TRUE	36.5
13	2	32.58	0.927	38.61	TRUE	36.5
14	3	33.48	0.989	37.29	TRUE	36.5
15	5	32.98	0.987	36.85	TRUE	36.5
16	10	32.76	0.985	36.70	TRUE	36.5
17	12	32.86	1.000	36.26	FALSE	36.5
18	11	33.96	0.967	38.59	TRUE	36.6
19	15	32.56	0.977	36.79	TRUE	36.6
20	16	32.56	0.977	36.79	TRUE	36.6
21	19	32.38	0.977	36.60	TRUE	36.6
22	20	32.64	0.968	37.19	TRUE	36.6
23	23	31.66	0.960	36.46	FALSE	36.6
24	6	32.92	0.987	36.79	TRUE	36.7
25	8	32.60	0.960	37.44	TRUE	36.7
26	9	33.64	0.983	37.67	TRUE	36.7
27	13	33.26	0.999	36.70	FALSE	36.7
28	14	32.78	0.976	37.05	TRUE	36.7
29	17	33.24	0.957	38.22	TRUE	36.7
30	18	33.94	0.967	38.57	TRUE	36.7
31	24	32.56	0.975	36.86	TRUE	36.7
32	25	33.00	0.993	36.65	FALSE	36.7
33	29	33.12	1.000	36.52	FALSE	36.8
34	30	29.16	1.000	32.56	FALSE	36.8
35	26	32.96	0.960	37.81	TRUE	36.9
36	28	32.96	0.999	36.40	FALSE	37
37						
38	Average:	32.71	0.978	36.92	Average	**36.61**
39	Std Dev	0.9054	0.0167	1.143	Std Dev	0.1639
40				0.4091	=95% confidence	
41		33.96	Range ma	38.61		37.00
42		29.16	Range mi	32.56		36.30
43		4.80	Range	6.05		0.70
44				30	=# samples	

Figure 41 Emissivity survey Initial readings

Figure 41 shows 30 readings in row format for each volunteer with its adjustments. The first column (S) is the volunteer ID number. This and subsequent graphs will keep the same row order. All readings and calculations are in Celsius. The 2nd column (T) is the skin surface temperature (SST) reading by the experimental sensor (the observer) to 2 decimal places. The 3rd column (U) is the emissivity reading used by the microcontroller to calculate the Adjusted value using the engine mention earlier. This value in this partition has a unique origin: it was set by the student in discussions with the investigator before the reading. The 4th column (V) is the "Adjusted" temperature that is displayed on the instrument and represents the body temperature calculated by the software. This includes the offset and the emissivity contribution. The 5th column (W) compares the results from the Adjusted column with the CVS near-field thermometer reading seen in the 6th column (X) and answers the question: Does the Adjusted temperature exceed the temperature value detected by the CVS thermometer? The data is sorted by the CVS near-field temperature value listed in ascending order in the last column (X) to match the bin number for this data field. Key assessment statistics for the columns are found directly below the columns of interest in rows 38 to 44.

To examine the question seen in the 5th column (W) in the survey results, 27 Adjusted readings are higher than the CVS readings which is an indication that the experimental sensor with emissivity reads hotter. So hot that 4 volunteers are in the fever territory which is a FALSE condition based on this survey's use of the CVS temperature value as a standard. Those readings that equal or exceed 37.8 °C (100 °F) are marked with a reddish color background. There are two possible sources for these readings, 1) a distance error by placing the experimental sensor too close to the subject, or 2) an incorrect emissivity setting that is too low creating addition heat to be added into the calculation for the actual temperature. Three volunteer readings are below normal reading below 36.0 °C (below 97

°F). These values are marked with a bluish color background. The source of this FALSE condition could be operator error by holding the sensor further than 36” from the subject.

Here are the basic statistical results for this set of data:

Table 23 Results for Initial Partition

	SST temperatures	Adjusted temperatures
Average	32.71 °C	36.92 °C
Standard Deviation (sample)	±0.9054 °C	±1.143 °C
Range	4.80 °C	6.05 °C

The average SST temperature for this partition was slightly higher than the All SST temperatures of Table 21. The standard deviation for this sample was ±0.025 wider with the range slightly better by 0.2 °C. The Adjust temperatures column show the effect emissivity caused compare to the All Adjusted temperatures: the average was slightly lower, the standard deviation wider by ±0.1368 °C, and the range stayed essentially the same. There were operator errors with nearly equal over and under readings. This partition’s Adjust temperatures compared the SST reading is like the curve of a bow being drawn. It could be said he emissivity puts a bend in the SST readings.

For the record, the CVS near-field thermometer average reading was 36.61 °C with a standard deviation of ±0.1639 °C and a range of 0.70 °C with a maximum of 37.0 °C and a minimum of 36.3 °C. Additionally, the emissivity average was 0.978 with a standard deviation of ±0.0167 °C.

Also noticed in this partition was the high range for the SST. Upon examination of individual SST reading in Column T, the first temperature reading for volunteer #30 revealed it was the SST minimum value for this data field. If this volunteer's readings were discarded, the range would improve to 2.94 °C and the SST standard deviation would drop to ±0.6188 °C from ±0.9054 °C. This shows the effect a bad reading can have on a 30-member group. A bad reading can occur by being closer than 36" (reading is hot) or farther away (reading is cooler) than it should be were the sensor exactly at 36". This is a distance error and can be attributed to operator error as subjects usually sit rather still when a reading is taken.

Because of the consultation with the volunteer and the investigator, this survey is called the Initial partition that has a "planned" emissivity.

The rule of thumb for infrared temperature taking is to take the hottest temperature recorded as the basis for the subject's SST value. This partition is presented here:

	F	G	H	I	J
5	**Highest** temp reading of subjects				
6	subject #	SST obser	emiss obs	Adjusted	
7	21	32.20	0.973	36.56	
8	22	31.68	1.000	35.08	
9	4	33.86	0.991	37.60	
10	7	33.44	0.971	37.91	
11	27	32.22	1.000	35.62	
12	1	32.68	0.963	37.41	
13	2	32.80	0.974	37.14	
14	3	33.48	0.989	37.29	
15	5	32.98	0.987	36.85	
16	10	32.76	0.985	36.70	
17	12	32.94	0.999	36.38	
18	11	33.96	0.985	37.92	
19	15	32.64	0.982	36.69	
20	16	32.56	0.977	36.79	
21	19	32.38	0.977	36.60	
22	20	32.64	0.968	37.19	
23	23	32.04	0.970	36.50	
24	6	32.92	0.987	36.79	
25	8	33.90	0.984	37.90	
26	9	33.64	0.983	37.67	
27	13	33.26	0.999	36.70	
28	14	33.58	0.990	37.35	
29	17	34.08	0.933	39.99	
30	18	34.02	0.998	37.49	
31	24	32.82	0.980	36.94	
32	25	33.06	0.989	36.86	
33	29	33.12	1.000	36.52	
34	30	32.90	0.976	37.17	
35	26	33.50	0.992	37.20	
36	28	32.96	0.999	36.40	
37					
38		33.03	0.983	37.04	Average
39		0.6201	0.014	0.8409	STD. DEV.
40				0.3009	95% confid
41		34.08	Range ma	39.9912	
42		31.68	Range mir	35.08	
43		2.40	Range	4.91	
44				30	# samples

Figure 42 Highest SST values captured during emissivity temperature survey

These values differ from the Initial partition seen in Fig 41 except for the five readings held in common as mentioned previously. The emissivity setting for each temperature reading is also different creating different statistics for the Adjusted temperatures. The columns follow the pattern discussed after Figure 41. Here the SST values have an average temperature of 33.03 °C, a standard deviation of ±0.6201 °C, and a range of 2.40 °C.

Table 24 Highest Temperature Partition

	SST temperatures	Adjusted temperatures
Average	33.03 °C	37.04 °C
Standard Deviation (sample)	±0.6201 °C	±0.8409 °C
Range	2.40 °C	4.91 °C

For this Highest partition a comparison is present with the Initial partition. The SST average temperature is higher than the Initial partition by 0.32 °C, the SST standard deviation is significantly smaller by 0.285 °C, the range become smaller by half, and only four Adjusted temperatures are seen to rise into the fever zone.

This set of SST values is better for the purposes of this dissertation and as such becomes the basis of comparison for emissivity improvement. The Initial partition with its planned emissivity is not useful as the emissivity causes additional problems in the Adjusted temperature results with a wider standard deviation and range. Figure 42, column G, becomes “the” partition of base SST values to which various permutation of emissivity will be used to create the Adjusted temperatures needed to decide which if emissivity improves infrared temperature readings. The standard deviation for this partition (±0.6201 °C) contains the variables for the SST temperatures and the distance error. By using this partition for emissivity trials, the emissivity standard deviation when applied will be revealed in the Adjusted temperature standard deviation less the SST standard deviation (±0.6201 °C). The reason this is true is because the Adjusted temperature standard deviation contains the same variables seen in the SST value plus whatever standard deviation the emissivity contributes. The offset is a linear adjustment moving the SST’s standard deviation plus the emissivity’s effective standard deviation X number of degrees.

The Adjusted temperature values seen in Figure 42, column I, are one such permutation akin to spinning the dial in a game of chance because at the time of the observation there was no guide to the setting of the emissivity dial. During the survey, after the initial setting was taken, random settings were tested. The Highest partition’s Adjusted temperature results could be considered a random emissivity setting. Even so, its random emissivity settings reveal a better (smaller) standard deviation than the Initial partition for the Adjusted temperature and a better (smaller) range.

This selected partition of SST temperature values has the emissivity setting that may or may not be based on the subject’s preferences as recorded in Figure 41. The results of the adjustment to these SST values using the observed emissivity values and the offset resulted in four subjects having temperatures that range above the fever criteria of a temperature greater than or equal to 37.8 °C. Since none of the students are presumed to have a fever, even a mild fever, these are False positives for fever. If the emissivity is correct, then a distance error has pushed the SST temperature up too high. A similar argument can be advanced for the low temperature readings. At this point in the investigation, there were no answers.

The average for the Highest partition set's Adjusted temperature is 37.04 °C, its standard deviation is ±0.8409 °C, and a range of 4.91 °C. The average value is quite close to normal having four readings showing a fever but there are offsetting low readings. The standard deviation is an improvement of approximately 0.3 °C, over the Initial partition of Adjusted values of Figure 41. Plus, the range dropped from 6.05 degrees to 4.91 °C. This is a second confirmation that the partition of Highest SST temperature readings a slightly better fit for temperature readings than the Initial's SST readings.

7.4.8 Emissivity Comparison Test

To restate the selection, the emissivity test for improvement we will use the Highest partition. For this test we will replace the observed emissivity values with the value of one. The value of one removes any additional heat the emissivity variables of the subjects generating the Adjusted temperatures. This means only the offset is used to calculate the Adjusted temperature. For the emissivity testing during the survey the offset was +3.7 °C. Due to ambient temperature differences at the testing location between the first survey and the emissivity survey[7] during analysis, a better fit was obtained by using an offset of 3.4 °C. All the Figures and Tables related to the emissivity testing use 3.4 °C as the offset in Chapters 7 and 8.

---

[7] seasonal change from office cooling to office heating,

	Z	AA	AB	AC	AD	AE
5	Subsitute 1.00 for EMISS				Is Adjusted	
6	subject #	SST	emiss used	Adjusted	>CVS temp	CVS Bin
7	21	32.20	1.00	35.60	FALSE	36.3
8	22	31.68	1.00	35.08	FALSE	36.3
9	4	33.86	1.00	37.26	TRUE	36.4
10	7	33.44	1.00	36.84	TRUE	36.4
11	27	32.22	1.00	35.62	FALSE	36.4
12	1	32.68	1.00	36.08	FALSE	36.5
13	2	32.80	1.00	36.20	FALSE	36.5
14	3	33.48	1.00	36.88	TRUE	36.5
15	5	32.98	1.00	36.38	FALSE	36.5
16	10	32.76	1.00	36.16	FALSE	36.5
17	12	32.94	1.00	36.34	FALSE	36.5
18	11	33.96	1.00	37.36	TRUE	36.6
19	15	32.64	1.00	36.04	FALSE	36.6
20	16	32.56	1.00	35.96	FALSE	36.6
21	19	32.38	1.00	35.78	FALSE	36.6
22	20	32.64	1.00	36.04	FALSE	36.6
23	23	32.04	1.00	35.44	FALSE	36.6
24	6	32.92	1.00	36.32	FALSE	36.7
25	8	33.90	1.00	37.30	TRUE	36.7
26	9	33.64	1.00	37.04	TRUE	36.7
27	13	33.26	1.00	36.66	FALSE	36.7
28	14	33.58	1.00	36.98	TRUE	36.7
29	17	34.08	1.00	37.48	TRUE	36.7
30	18	34.02	1.00	37.42	TRUE	36.7
31	24	32.82	1.00	36.22	FALSE	36.7
32	25	33.06	1.00	36.46	FALSE	36.7
33	29	33.12	1.00	36.52	FALSE	36.8
34	30	32.90	1.00	36.30	FALSE	36.8
35	26	33.50	1.00	36.90	FALSE	36.9
36	28	32.96	1.00	36.36	FALSE	37
37						
38		33.03		36.43	Average	36.61
39		0.6201		0.6201	STD. DEV.	0.1639
40				0.2219	=95% confidence	
41		34.08	Range max	37.48		
42		31.68	Range min	35.08		
43		2.40	Range	2.40		

Figure 43 Emissivity test

Without an emissivity adjustment, no volunteers are showing a fever temperature in the Adjusted column. The output for the infrared sensor reading without emissivity is merely the SST value plus the offset. The standard deviation and the range are unaffected by this linear addition, so they remain at ±0.6201 °C and 2.40 °C. There are 9 readings that now exceed the CVS near-field thermometer readings compared with 23 when the random emissivity was considered for the selected sample partition seen in Figure 42. Six registered below normal now compared with two for the Highest partition with the random emissivity of Figure 42. These lower readings in the Adjusted column are to be expected as just the offset is being considered.

Table 25 Emissivity Comparison Test

	SST temperatures	Adjusted temperatures
Average	33.03 °C	36.43 °C
Standard Deviation	±0.6201 °C	±0.6201 °C
Range	2.40 °C	2.40 °C

The goal of this dissertation is to show that by including emissivity, the Adjusted temperatures are improved. The Adjusted temperatures from this table become the basis for any comparison as the thermometer "without e" for this dissertation.

Again, the average for the SST readings was 33.03 °C with a standard deviation of ±0.6201 °C. The range is 2.40 °C wide. The average for the Adjusted output was 36.73 °C with an identical standard deviation and range as the SST column.

One statistic to consider is the correlation between this Emissivity test Adjusted temperatures and the CVS thermometer temperatures. Since in this test the emissivity is not a factor because an emissivity value of 1.00 amounts to zero emissivity correction; the two devices can be compared. That correlation value is 0.3825. This value shows little agreement between the two thermometers. The difference in the ranges indicate the same with the Adjusted temperature being 3 times larger than the CVS range. This tells us that each thermometer readings are independent of the others. The Adjusted temperature values of this test can be used to represent a thermometer that doesn't use emissivity or uses an average value for emissivity for comparisons with the experimental sensors Adjusted temperature values.

7.4.9 Human Emissivity Rankings

The emissivity information collected at the start of the survey was the first time for the investigator and each of the students to answer the question: What's your emissivity value? All we had was the color photos from the Fitzpatrick scale on the permission sheet. Yet some students would look at the photos and the heritage information and pick a value rather quickly while others, were befuddled and unsure and the investigator had to suggest a value for them.

The following graph is presented showing how some of the student's skin-tone values line up from lighter to darker colors with emissivity.

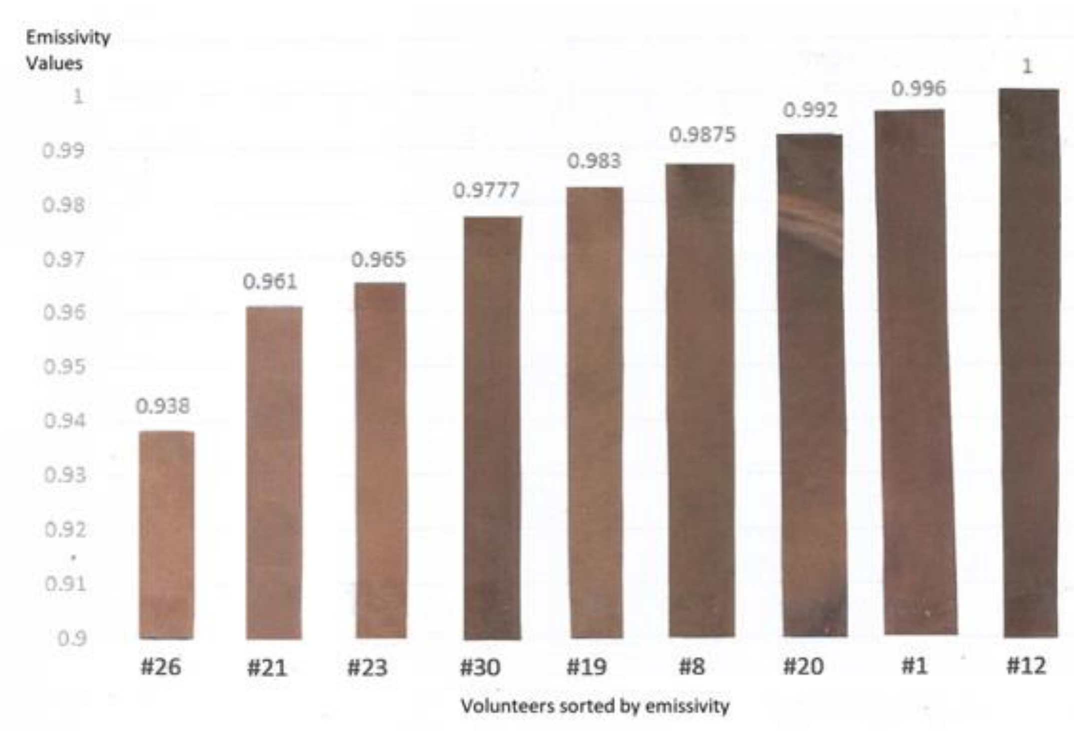


Figure 44 Ranking of emissivity for humans with skin-tone photos

The above graph shows sample skin-tone coloration ranked by emissivity value and linked to volunteers by ID numbers. Volunteer #30 which looks out-of-place, is out-of-place because the volunteer had a difference between the skin-tone on her face which was captured by the reading and the skin-tone captured in the photo of her hand.

Another issue is present in this graph. Volunteer #12 emissivity is ranked as 1.00 but the next three volunteers to the left are nearly as deeply dark but have slight shading variations from #12. They could easily be grouped together as 0.99.

Because of other students having similar emissivity rating issues, the investigator undertook a sort/grouping/binning of the volunteer's emissivity based on the back-of-the-hand photos. By visual comparing individually these photos full screen on a computer with other volunteer back-of-the-hand photos to decide which photos have look-alike skin tones, were similar, or were not alike and too dissimilar. They were then arranged into folders with emissivity values 1.00 down to 0.94. This was a visual sorting than can at a future time be done by machines based on RGB values.

7.4.10 Student Emissivity Rankings after Binning

The results for blending the outcomes for the binning of the back-of-the-hand photos into emissivity groups with the Fitzpatrick scale photos are presented here.

In the highest emissivity group are the African/Aboriginal skin-tone volunteers at level 6: Since none of the volunteers were perfectly black (emissivity of 1.0) this group includes those who were darkest and assigned a value of 1.00. Volunteers in this group were: 7, 12, and 22.

7.JPG

12.JPG

22.JPG

The next group were volunteers for East Indian/African/Native American, Level 5, with an emissivity value assigned as 0.99. This groups included volunteers: 1, 8, and 20.

1.JPG

8.JPG

20.JPG

The next level is the Mediterranean/Asian/Latino. Level 4. This group was assigned an emissivity value of 0.98. This group contained volunteers: 3, 11, and 27.


3.JPG


11.JPG


27.JPG

Following level is the Southern European/Central European, Level 3. Their assigned emissivity value is 0.97. This group contained volunteers: 10, 19, and 30.


10.JPG


19.JPG


30.JPG

The next level were the European/Scandinavian, Level 2. Their emissivity is assigned 0.96. This group contained volunteers: 17, 23, 28, and 29.


17.JPG


23.JPG


28.JPG


29.JPG

The final group contained Norther European/British, Level 1. Their emissivity is assigned 0.95. This group contained volunteers: 4, 5, 14, 15, 16, 18, 24, and 25.


4.JPG


5.JPG


14.JPG


15.JPG


16.JPG


18.JPG


24.JPG


25.JPG

Extending the Fitzpatrick scale somewhat to include albinos, Level 0, whose emissivity was assign a value of 0.94. Included in this group are volunteers 2, 21, and 26.


2.JPG


21.JPG


26.JPG

The volunteers without photos were slotted into the Fitzpatrick scale that was selected by them before beginning of their survey.

This binning of skin-tones is not considered perfect but represents an attempt to connect skin-tone with emissivity using the Fitzpatrick scale.

7.4.11 Applying the Emissivity to Infrared Sensors Reading.

Suppose we were to develop an emissivity guide line like the Fitzpatrick scale for each one of the groups in that scale. We would be taking the lessons we learned about emissivity and apply them to the distance compensated temperatures we determine for the volunteers from their SST temperatures. We would then compare those output readings with the CVS near-field thermometer readings. We will use a simple step value of -0.01 to differentiate the groups using the results from Table 20 in Chapter 6. Here is how the Fitzpatrick scale emissivity guide could be written.

Table 26 Fitzpatrick Scale with Emisssivity Settings

	Fitzpatrick Scale	
Group	Description (heritage)	Setting
6	African/Aboriginal	1.00
5	East Indian/African Native US	0.99
4	Mediterranean/ Asian/Latino	0.98
3	Southern & Central European	0.97
2	European/Scandinavian	0.96
1	Northern European/British	0.95
0	Albino	0.94

7.4.12 Emissivity Driven Temperatures

With the emissivity now binned, let's see what results when these new emissivity values are substituted for the original emissivity values seen in Figure 42, column H, into Figure 45 below:

	AF	AG	AH	AI	AJ	AK
3		Binning by skin-tone				
4		Assign New Emissivity				
5		based on photo review				
6		subject #	SST	New emiss	Adjusted	
7		21	32.20	0.94	37.74	
8		22	31.68	1.00	35.08	
9		4	33.86	0.97	38.38	
10		7	33.44	1.00	36.84	
11		27	32.22	0.98	36.33	
12		1	32.68	0.99	36.44	
13		2	32.80	0.94	38.37	
14		3	33.48	0.98	37.62	
15		5	32.98	0.95	38.20	
16		10	32.76	0.97	37.24	
17		12	32.94	1.00	36.34	
18		11	33.96	0.98	38.11	
19		15	32.64	0.95	37.84	
20		16	32.56	0.95	37.76	
21		19	32.38	0.97	36.85	
22		20	32.64	0.99	36.40	
23		23	32.04	0.96	36.86	
24		6	32.92	0.99	36.68	
25		8	33.90	0.99	37.67	
26		9	33.64	0.99	37.41	
27		13	33.26	1.00	36.66	
28		14	33.58	0.95	38.83	
29		17	34.08	0.97	38.60	
30		18	34.02	0.95	39.29	
31		24	32.82	0.95	38.03	
32		25	33.06	0.95	38.28	
33		29	33.12	0.96	37.98	
34		30	32.90	0.97	37.39	
35		26	33.50	0.94	39.11	
36		28	32.96	0.96	37.81	
37						
38			33.03	0.97	37.54	Average
39			0.6201	0.0201	0.9518	STD. DEV.
40					0.3406	=95% confic
41			34.08	Range max	39.29	
42			31.68	Range min	35.08	
43			2.40	Range	4.21	
44					30	=# samples

Figure 45 Emissivity driven binning

While we are more confident about the emissivity readings, making this substitution drives 13 of the Adjusted temperatures into the fever region with one temperature below normal. The assignment of emissivity by color binning appears to be unsuccessful.

Summarizing these results:

Table 27 Emissivity Driven Binning

	SST temperatures	Adjusted temperatures
Average	33.03 °C	37.54 °C
Standard Deviation (sample)	±0.6201 °C	±0.9518 °C
Range	2.40 °C	4.21 °C

The SST reading were not changed so the previous average, 33.03 °C, is still good as is the standard deviation, ±0.6201 °C and range. The Adjusted values now have a high average of 37.54 °C and the standard deviation has ballooned out to ±0.9518 °C. The range for the Adjusted became 4.21 °C which is wider by 1.81 °C from the SST temperatures whose range is 2.40 °C. The correlation between these results and the CVS near-field thermometer is 0.0848 an extremely low value. If we consider the binning correct or even somewhat correct, then what can address these high temperatures?

7.4.13 Revising the Emissivity Setting for the Fitzpatrick Scale

If the offset was too high, just reducing that value would drop all the temperatures lower. However, the problem is not the offset as much as the range. Something is expanding the range. We can see from the change in the range from the SST temperatures to the Adjusted temperatures grows even larger to 4.04 °C that perhaps another adjustment can be made. We could shrink the emissivity range!

As a trial of this solution, the emissivity will be cut in half by use of the Excel formula:

1-(1-Emiss)/2

Equation 12 Excel formula used to calculate ½ scale for Fitzpatrick Table

The Excel columns seen in **Error! Reference source not found.** are copied and pasted in the same spreadsheet to its right. In this formula above, the Emiss variable references the cell in the same row of the column "New emiss" that was copied for that volunteer. This formula will allow the emissivity seen in Figure 44, if it is one to stay as one, but if the emissivity was, for instance, 0.98, the formula cuts the value for emissivity to 0.99. The results are seen on the next page in**Error! Reference source not found.**.

	AU	AV	AW	AX	AY
3	**color binning**				
4	Assign New Emissivity				
5	emiss 1.000-0.970				
6	subject #	SST	New emiss	Adjusted	
7	21	32.20	0.97	36.67	
8	22	31.68	0.97	36.13	
9	4	33.86	0.99	37.82	
10	7	33.44	1.00	36.84	
11	27	32.22	0.99	35.98	
12	1	32.68	1.00	36.26	
13	2	32.80	0.97	37.29	
14	3	33.48	0.99	37.25	
15	5	32.98	0.98	37.29	
16	10	32.76	0.99	36.70	
17	12	32.94	1.00	36.34	
18	11	33.96	0.99	37.73	
19	15	32.64	0.98	36.94	
20	16	32.56	0.98	36.86	
21	19	32.38	0.99	36.32	
22	20	32.64	1.00	36.22	
23	23	32.04	0.98	36.15	
24	6	32.92	1.00	36.50	
25	8	33.90	1.00	37.49	
26	9	33.64	1.00	37.23	
27	13	33.26	1.00	36.66	
28	14	33.58	0.98	37.90	
29	17	34.08	0.99	38.04	
30	18	34.02	0.98	38.36	
31	24	32.82	0.98	37.13	
32	25	33.06	0.98	37.37	
33	29	33.12	0.98	37.25	
34	30	32.90	0.99	36.84	
35	26	33.50	0.97	38.01	
36	28	32.96	0.98	37.09	
37					
38		33.03	0.98	37.02	Average
39		0.6201	0.0098	0.6408	STD. DEV.
40		0.2219		0.2293	=95% confid
41		34.08	=SST max	38.36	
42		31.68	=SST min	35.98	
43		2.40	SST range	2.38	
44				30	=# samples

Figure 46 Revising the manual emissivity range

There are now only 5 temperatures venturing into the fever realm and one below normal reading[8]. This immediately appears to be a good improvement. The statistics for this revised emissivity range are as follows:

Table 28 Results from Half Scale of Fitzpatrick Table

	SST temperatures	Adjusted temperatures
Average	33.03 °C	37.02 °C
Standard Deviation (sample)	±0.6201 °C	±0.6408 °C
Range	2.40 °C	2.38 °C

Changing the emissivity scale has caused the Adjusted temperature average to drop to the normal average, losing 0.5 °C; but this is way below the previous Fitzpatrick scale's average of 37.54 °C which was unacceptable. The standard deviation is now within 0.02 °C of the SST readings. The range is again cut in have and below the SST value at 2.33 °C. These results have certainly met some intrinsic standards, such as, not making the Adjusted results standard deviation wider than necessary. A difference of ±0.0201 °C in the standard deviation is quite acceptable. The range being 0.02 °C different and smaller after processing by the emissivity is certainly acceptable. The emissivity has only slightly

[8] It should be pointed out that the below normal reading switched from one volunteer to another.

changed the output temperatures into nearly the same shape as the SST temperatures. This modification of the emissivity values has been very successful and perhaps represent the minimum effect on infrared temperature sensor that emissivity should have. We will call these results the "manual" results because setting the emissivity values has been done manually.

The changes in emissivity seen in **Error! Reference source not found.**6, are tabularized below in Table 29. This is the revised Fitzpatrick Scale for Human Emissivity.

Table 29 Human Emissivity Guide

	Human Emissivity Guide	
Group	Description (heritage)	Setting
6	African/Aboriginal	1.000
5	East Indian/African Native US	0.995
4	Mediterranean/ Asian/Latino	0.990
3	Southern & Central European	0.985
2	European/Scandinavian	0.980
1	Northern European/British	0.975
0	Albino	0.970

7.4.14 Assessment of the Survey

The survey can be considered a success in that it has shown that the variety of skin-tones play a part in the determination of temperature when using an infrared sensor thermometer. The difference between using emissivity or not is the difference between using individual emissivity or using the value of 1.00 for the emissivity for the same group of people. In the results shown below for the amended results of the last version seen in Figure 46, values in temperature Celsius, the difference shows up in the statistics:

Table 30 Emissivity Results[9]

	without e	with e
average	36.43	37.02
Std Dev	0.6201	0.6408
range	2.40	2.38

The results were balanced around the normal temperature of 37.0 °C for humans when emissivity was used and had a nearly identical standard deviation of ±0.6312 °C as the SST readings. The range is nearly the same as the SST readings without emissivity and it split the reading with 50% higher than 37.0 °C and the other 50% lower. The emissivity added 0.61 °C to the average that was not present when emissivity was not used. This was different from the CVS near-field temperature used in conjunction with this survey which showed no one over 37.0 °C. The correlation coefficient between the experimental sensor Adjusted temperatures for color binning and the CVS near-field temperatures, seen in

[9] Both averages reflect changes to the offset of -0.3 °C not shown in the summary Table values. These are the new average values derived after that change.

Figure 41, column X, is .0848. This is even lower than the correlation with the Emissivity Test when emissivity was set to one. This show there is a change due to the color binning.

The correlation coefficient between the experimental sensor Adjusted temperatures for color binning and the Adjusted thermometers of the Emissivity Test values, seen in Figure 43, column AC, is 0.8370. The alignment of the color binning is much higher with the Emissivity Test results.

Only actual temperature values observed were used and none were excluded. It should be noted that five readings were in the fever zone, greater than 37.8 °C. These results were developed using less than optimum instrumentation meaning that with machine distance-ranging and machine evaluation of skin-tone, fewer errors will occur due to operator error.

Using the sensitivity of temperature to emissivity of ±0.01 °C per 1/100 of emissivity would indicate that any error due to emissivity could amount to less than ±0.01 °C. The error is a small error. Again, because of size of the distance error, the emissivity error is often overlooked or discarded by thermometers but it's effect on the shape of the results is large. Emissivity moves the average, pulling low temperatures up and shortening the range of temperatures. This effect is the main reason that infrared temperature sensor can be improved by using emissivity.

The emissivity developed using the Fitzpatrick Scale is much like matching colors of a paint chip at a paint store for a touch up can of paint. Manually, people can compare their skin color of their forearms or back of hand with a sample color wheel making the method used to achieve these results quite easy to do. The matching setting can be digitally entered, and a temperature taken without much hassle.

Chapter 8

Automatic Emissivity Control

8.1 Overview

This chapter presents a method to automate the emissivity correction to take the guesswork out of emissivity settings. A python language program is presented to standardize the assignment of emissivity. The program is tested using actual data captured in the emissivity survey. The results are compared to the results without any emissivity setting and with the results from the emissivity correction of the binned assignments developed in the last chapter.

8.2 Methodology

Since there has not been a device developed with an automatic emissivity control module for human temperatures, a means to simulate the steps undertaken in automatic emissivity control were developed and are present here. Due to the limited nature of the survey an accommodation for universality is attempted here through an extension of the luminance range. With any adoption of this methodology, it is expected that cloud data collection techniques will close this gap. This aspect is not addressed in this dissertation.

8.2.1 Idealized Automatic Emissivity Control Work Flow

Ideally, a functional model with automatic emissivity control would have a camera system included with the infrared temperature sensor. It would have a camera for image capture facing forward toward the subject, an image processing component, and an image display unit at the back of the device or some user observation location were remote control of the thermometer used. The camera system is two-fold: 1) to capture an image of the subject for display so that the user would be confident that they captured the target correctly, and 2) to capture a small photo of the subject where bare skin is visible.

The captured image could be anywhere from 200 to 300 pixels square or rectangle in size. Selection of this location is inconsequential for the purposes of this dissertation only so long as the image captured is associated with the subject's observed skin surface temperature in some manner. If the photo is taken in color, then the skin-tone of the subject has been captured in the photo. It was found useful in the analysis to have the photo captured named the same as the subject's ID number.

Since the emissivity parameter of infrared temperature is related to the skin-tone of the subject, the captured picture contains in each pixel of the photo the information that can be used to develop what is known as the luminance parameter, L [18] [59]. Without going too deeply into color theory, the RGB pixel information is extracted from the photo using a conversion formula [19] [59] video:

$$\mathbf{L = R*0.299 + G*\ 0.587 + B*0.114}$$

Equation 13 Equation to calculate Luminance from RGB values

The luminance is a value between 0 and 1 where the zero value represent the lack of light or black and the closer to 1 the more light is available with a color of white. In between are all the shades of the rainbow and of human skin coloring. The easy way to convert the RGB pixels values into the L parameter to convert the color photo into a black and white photo using a PNG format, import the image into an array, and average the array's value for L [59]. For this reason, the photo should be only the selected skin-tone without any scars, tattoos, clothing, wrist bands, rings, or jewelry.

The final step is to take the L parameters and convert them into an emissivity value. Once you have the emissivity values from a machine analysis of the photos, you can then begin to compare these results of the temperature survey with emissivity applied with other results for the same group of people where emissivity was not applied and with the system of color binning.

8.2.2 A Simulated Machine Analysis

Using the images of the volunteer's back-of-the-hand taken during the emissivity survey works very well as the photos are already named after the subject's ID number making the association with the infrared temperature that was read. In an actual device, this naming convention would be unnecessary as everything is stored and reported together.

All the photos included an image of a hand of the volunteer and the volunteer's number on a white piece of paper. This is too large a photo to read and other colors besides the skin-tone are present. These photos usually have a standard deviation of 30 lums or more. As part of the simulation, the photos are cropped to a pixel size of 200 to 300 square. The spot location is set to the middle of the back-of-the-hand where shadows caused by tendons or blood vessels in this window are minimized. Also, some hands showed pigmentation lighter between the thumb and fingers which should be avoided. It is possible by spot location to vary the luminance value. In an actual device, the spot would be located on the forehead which is flatter. The spot location is one variable of this particular analysis.

8.2.3 Python Code

A decision was made to utilize python software for writing the coding that would be utilized in an actual device [43]. This simulation would take place on a PC using the Spyder IDE running Python(x,y) 2.7.10.0 [47]. This software is design to run on Windows offering authentic python coding that is transferable to Unix or Android machines. The eventual program was saved as a program called *emissivity.py* which is the transferrable piece. It also facilitated learning over a software package that is an industry standard in Windows known as an Integrated Development Environment, IDE. A screen shot of this software with the code is seen in the Appendix, *Screenshot of Spyder IDE*. Figure 47 shows the code used for the simulation:

```
from PIL import Image
#import numpy as np
#import pylab
import mahotas as mh
img=Image.open('c:\Users\Timmothy Johnson\Documents\Pace\Y2018\img-processing\grayscale images\ID-15a.jpg')
img.show()
img=Image.open('c:\Users\Timmothy Johnson\Documents\Pace\Y2018\img-processing\grayscale images\ID-15a.jpg').convert('L')
img.show()
print img
img.save('c:\Users\Timmothy Johnson\Documents\Pace\Y2018\img-processing\grayscale images\gs-15a', 'png')
grayscale = mh.imread('c:\Users\Timmothy Johnson\Documents\Pace\Y2018\img-processing\grayscale images\gs-15a')
print ('ID-15a')
print grayscale.shape
print grayscale[1,1]
print grayscale.mean()
print grayscale.std()
print grayscale

```

Figure 47 Automatic emissivity control coding

The output for this code is seen below:

```
IPython console
Console 1/A

In [1]: runfile('C:/Users/Timmothy Johnson/emissivity.py',
wdir='C:/Users/Timmothy Johnson')
<PIL.Image.Image image mode=L size=256x230 at 0x9F501E8>
ID-15a
(230, 256)
97
107.970805027
5.00256186719
[[ 94  96  97 ..., 101 100 100]
 [ 95  97  97 ...,  99  99 101]
 [ 96  97  97 ..., 100 101 105]
 ...,
 [113 111 110 ..., 111 114 116]
 [114 112 110 ..., 111 114 118]
 [114 112 111 ..., 108 112 117]]
```

Figure 48 Automatic emissivity control output (for testing purposes)

8.2.4 Code Discussion

Line 15 imports a package called Pillow (PIL—Python Imaging Library) used by Python software to handle images [10]. Lines 16-18 imports 3 packages used by Python to handle arrays, display graphs, and computer vision: numpy, pylab, & mahotas. [2] Two of these programs were not used and were commented out with the # sign.

Line 19 is the key command to open a file for handling by Python. The path shown is the Windows path to the photo and with the correct formatting, Python is able to find the desired file. Line 21 opens that same image again and converts it to grayscale parameters for PNG [45] [59]. Lines 20 and 22 where used for troubleshooting purposes and verification that the code was working and opening a color photo followed by a grayscale photo. These lines were commented out for subsequent runs as they were not needed each time the code was run.

Line 23 prints statistics for the photo “img” seen in the output as <PIL.Image.Image…(like the image size in pixels) and is the first line of the outputs seen in Figure 51Figure 48. Line 24 allows you to save the grayscale image under a different name in the same directory. The photo is then opened using the mahotas package (an image handling package) to enable various commands that allow analysis of the image [65].

The analysis of the renamed image as “grayscale” included:

Line 26 is the subject’s ID number

Line 27 is the size of the array (called shape).

Line 28 shows the value of the first pixel which has to match the number when the array is printed out. Verifies images with Line 31 that prints out the entire array.

Line 29 is the average value of all pixels for the “L” parameters of the cropped photo of the subject’s hand. The key goal for this methodology is to obtain this value.

Line 30 was the standard deviation indicating how smooth the skin tone was over the selected spot. It also served as a check if a different image is read, for instance, if a step was missed during the image cropping process. The standard deviation across the cropped photos was usually between 3 to 7 lums but the original images are larger than 30 lums.

Line 31, prints out the array's start and finishing rows and columns, an abbreviated representation. This is also another check point on the value derived for "L". The arrays can also be accessed in the Variable Explorer using the Spyder IDE.

The images were all stored in one folder for later machine analysis using the same path. In an actual device, the image is passed from function to function with no path until the final number is derived and applied for computation. Below is shown the results of the code for all the cropped photos for luminance from the survey ranked from largest (lightest skin tone) to smallest (darkest tone).

Table 31 Luminance by Machine Analysis

ID #	Luminance
26	122.0553
18	121.9791
24	121.9753
25	119.4819
2	114.8605
16	114.4852
28	114.2654
5	113.6449
14	113.5098
21	112.7459
17	110.4848
15	107.9708
4	107.0875
11	100.2529
19	97.25753
10	92.94234
23	90.82698
3	87.88481
30	85.48656
27	80.92213
8	78.08088
29	76.04488
1	73.21967
22	71.54473
20	69.06276
12	59.54823
7	56.41898

In Table 31 can be seen the luminance for individuals that are nearly the same and by checking the photos of the back-of-the-hands, the similarity stands out. However, with this small of a group, an easier method for sorting other than binning was available. Here is the graph of the above values, seen in Figure 49 below.

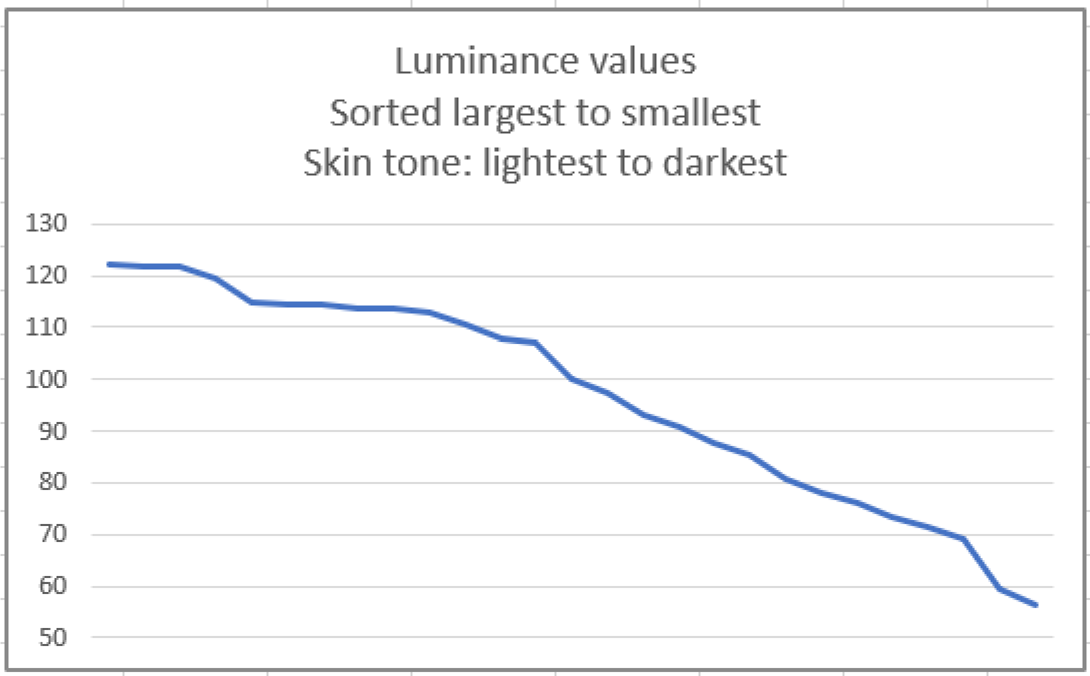


Figure 49 Sorted luminance “L” Values

In this graph can be seen similar luminance values where the graph flattens out; this reveals persons of nearly similar skin tone who took part in the survey. Slopes that are steeper simply reflect the transition from one luminance group to the next without have a representative human being who, by happenstance, wasn’t present that day to take the survey.

8.2.5 Converting Luminance into Emissivity

The next challenge is converting the luminance which is a segmented, linear graph into emissivity values. Emissivity we have already established is linear, ranging from 1.00 to 0.00. The human portion of that range we have reasoned previously ranging from 0.97 to 1.00 for 0.03 emissivity units, see Table 24. The luminance range for the emissivity survey ranges from ~56 to ~122, over 66 luminance units. Given that the volunteers for this survey may not have the darkest skin tone possible or the lightest skin tone possible; our extremes are unknown. If we allow for a margin of approximately 7 luminance units at either end, the range could be extended to 80 luminance units starting at 50. The (key) ratio of 0.03 emissivity units divided by 80 luminance units gives a value of 0.000375 emissivity units per luminance unit (1 Luminance = .0.000375 emissivity unit). This approach, unique to machine analysis, will allow for a custom emissivity reading as opposed to a sort using group binning based on the Human Emissivity Guide, Table 24. The ratio is known as a compression ratio as it drives a wide scale range for luminance into a smaller emissivity range.

The following ratio-driven formula uses the luminance for a back-of-hand photo to convert the luminance value into an emissivity value:

$$\text{Emissivity X} = 1 - (\text{lum X} - \text{lum low})*(\text{emiss range}/\text{luminance range})$$

$$\mathbf{Emissivity\ X = 1- (lum\ X - 50)*(0.000375)}$$

Equation 14 Calculation of emissivity from low side L value

A second formula accomplishes the same task using different values from the two ranges:

$$\text{Emissivity X} = (\text{lum high} - \text{lum X})*(\text{emiss range}/\text{luminance range}) + 0.97$$

$$\mathbf{Emissivity\ X = (130 - lum\ X)*(0.000375) + 0.97}$$

Equation 15 Calculation of emissivity from high side L value

Regardless of the formula used, outcome of converting all the luminance values into emissivity values is seen below in column BM of Figure 50. These numbers are copied into column BQ along with 3 volunteers that didn’t have photos using their default values.

	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU
1					Correction by Automatic Emissivity Control						
2									(6 Fever temps)		
3									(2 low temp)		
4		Lum Range	130-50=80		substitution of machine emissivity calculation						
5		Emiss Range	1-.97=0.03		includes 3 non-photo subjects (6, 9, &13)				SST temps	Adjusted	Adjusted
6		ratio	0.000375		subject #	SST	New emiss	Adjusted	without e	> 37.8 C?	< 36.0 C
7	Machine Analysis Worksheet				21	32.20	0.976	36.44	35.60		
8	ID	Lum	Emissivity		22	31.68	0.992	35.36	35.08		TRUE
9	26	122.055	0.9729793		4	33.86	0.979	38.06	37.26	TRUE	
10	18	121.979	0.9730078		7	33.44	0.998	36.93	36.84		
11	24	121.975	0.9730093		27	32.22	0.988	36.03	35.62		
12	25	119.482	0.9739443		1	32.68	0.991	36.39	36.08		
13	2	114.861	0.9756773		2	32.80	0.976	37.08	36.20		
14	16	114.485	0.9758181		3	33.48	0.986	37.40	36.88		
15	28	114.265	0.9759005		5	32.98	0.976	37.25	36.38		
16	5	113.645	0.9761332		10	32.76	0.984	36.74	36.16		
17	14	113.51	0.9761838		12	32.94	0.996	36.47	36.34		
18	21	112.746	0.9764703		11	33.96	0.981	38.06	37.36	TRUE	
19	17	110.485	0.9773182		15	32.64	0.978	36.82	36.04		
20	15	107.971	0.9782609		16	32.56	0.976	36.83	35.96		
21	4	107.088	0.9785922		19	32.38	0.982	36.41	35.78		
22	11	100.253	0.9811552		20	32.64	0.993	36.30	36.04		
23	19	97.2575	0.9822784		23	32.04	0.985	35.98	35.44		TRUE
24	10	92.9423	0.9838966		6	32.92	0.995	36.50	36.32		
25	23	90.827	0.9846899		8	33.90	0.989	37.69	37.30		
26	3	87.8848	0.9857932		9	33.64	0.995	37.23	37.04		
27	30	85.4866	0.9866925		13	33.26	1.000	36.66	36.66		
28	27	80.9221	0.9884042		14	33.58	0.976	37.86	36.98	TRUE	
29	8	78.0809	0.9894697		17	34.08	0.978	38.29	37.48	TRUE	
30	29	76.0449	0.9902332		18	34.02	0.973	38.43	37.42	TRUE	
31	1	73.2197	0.9912926		24	32.82	0.973	37.20	36.22		
32	22	71.5447	0.9919207		25	33.06	0.974	37.41	36.46		
33	20	69.0628	0.9928515		29	33.12	0.990	36.88	36.52		
34	12	59.5482	0.9964194		30	32.90	0.987	36.78	36.30		
35	7	56.419	0.9975929		26	33.50	0.973	37.90	36.90	TRUE	
36					28	32.96	0.976	37.24	36.36		
37											
38					Average:	33.03	0.98	37.02	36.43		
39					Std Dev:	0.6201	0.0085	0.7319	0.6201		
40	e							0.2619	=95% confidence		
41					Range max	34.08	1.00	38.43	37.48		
42					Range min	31.68	0.97	35.36	35.08		
43					Range	2.40	0.03	3.07	2.40		
44								30	=# samples		

Figure 50 Applying automatic emissivity correction results

The machine code to convert luminance into emissivity is seen below in Figure 51:

```
23 print img
24 img.save('c:\Users\Timmoth
25 grayscale = mh.imread('c:\
26 print ('ID-15a')
27 print grayscale.shape
28 print grayscale[1,1]
29 print grayscale.mean()
30 print grayscale.std()
31 #print grayscale
32 L = grayscale.mean()
33 E = 1-(L-50)*.03/80
34 print E
```

```
In [4]: runfile('C:/Users/Timmothy
Johnson/emissivity.py', wdir='C:/Users/Timmothy
Johnson')
<PIL.Image.Image image mode=L size=256x230 at
0x9FBE170>
ID-15a
(230, 256)
97
107.970805027
5.00256186719
0.978260948115
```

Figure 51 Machine coding to convert luminance into emissivity

In the left half of Figure 51, the printing of the array grayscale is suppressed on line 31 with the # sign. The variable for luminance is L and the variable for emissivity is E. The conversion formula [68] is seen on line 33 is discussed here. The output of this code is in the right half of Figure 51 showing E with a value of 0.9782… at the bottom line of the print out. This is the value seen in Figure 51 for subject ID#15 in cells BM20 and BQ19 (highlighted in yellow). The key ratio of 0.000375 (.03/80) merges the two ranges (L & E) together. Fifty is the offset for the luminance with the value of 1.0 being the emissivity in the formula. The value of the factor (L-50) is the number of luminance units above the luminance starting point. This is multiplied by the ratio of luminance to emissivity, in this case it is 0.000375 giving the value to be subtracted from the high value for emissivity. The difference of those numbers gives the emissivity value which is seen in the output display as 0.978260948115. This value is processed by the Adjust formula in column BR of Figure 50 that includes the emissivity factor and the offset for distance. Columns BT and BU check the Adjusted column's upper and lower limits.

8.2.6 Machine Emissivity Evaluation

Figure 50 is the spreadsheet test bed for this Machine Emissivity analysis. The figures based on the ratio 0.000375 emissivity units per luminance created an Adjusted value (seen in Column BR of Figure 50) for the infrared sensor where six values are greater than 37.8 °C (fever threshold) and two readings are below normal (shown in red or blue highlight). The standard deviation for the Adjusted values is ±0.7179 °C. This is approximately 0.1118 °C larger than the SST standard deviation of ±0.6201 °C. This widening of the standard deviation is due to the emissivity value calculated in our machine analysis of the subject's skin-tone.

Table 32 Statistical summary of Machine Analysis

	SST temperatures	Adjusted temperatures
Average	33.03 °C	37.02 °C
Standard Deviation (sample)	±0.6201 °C	±0.7319 °C
Range	2.40 °C	3.07 °C

The comparison between the values from the manual binning for the Adjusted temperatures used in Chapter 7, the manual fit seen in Figure 46, column AW, and the machine analysis for emissivity using the Excel correlation function is 0.8105. If they were perfectly the same their correlation would be one. This is in the same range as the correlation between the color binning Adjusted temperatures and the temperatures for thermometers that don't use emissivity. This could be due to any number of reasons as the skin-tone is processed first by a photo, then converted to grayscale, followed by Python code conversion to emissivity and observer bias. The correlation function when subtracted from 1.00 could be interpreted as showing a 19% improvement of machine analysis over a manual assignment of emissivity.

Of the several reasons for the wider standard deviation of the machine analysis over the manual assignment is the manual binning has 8 emissivity values of 1.00 in that partition making that standard deviation much thinner (a one emissivity adds no heat to the output). The machine emissivity has built-in margins for the perfectly black individual thus those same 8 individuals in the machine analysis are contributing heat to the output. This results also reveals a bias in the manual binning of the photos for Figure 46 that was not revealed during its analysis.

To continue with the analysis of the machine analysis, the average is 37.02 °C. There has been no change from the color binning or manual model. The Adjusted value also include the offset for the distance correction set in Chapter 7 as 3.4 °C, in addition to the emissivity factor. The range is widened to 3.0 degrees to accommodate the extra heat seen by the machine analysis of emissivity.

These results are compared side by side to the SST temperatures without an emissivity correct. A correct for temperature without emissivity can be seen in Column BS of **Error! Reference source not found.**. The standard deviation and the range is the same as the SST standard deviation in column BP and the average is SST temperature plus the offset of 3.4 °C. What is indicated is that while the obvious resides with the manually assigned emissivity; for reason discussed, the standard deviation of the machine analysis should be favored. The 7 exceptions at the upper and lower extremes can be attributed to operator distance error. *What machine analysis did do is take the guess work out of assigning an emissivity value*. It eliminated a lot of ambiguity inherent in using the Fitzpatrick Scale. These results show the effect of including emissivity to improve infrared temperature sensor temperatures readings. By using the machine emissivity reading, all the subjects' temperature readings were validated including the exceptions showing FALSE highs and FALSE lows.

Since the CVS near-field thermometer was used for this emissivity survey as a check, it should be mentioned that NONE of those reading exceed 37.0 °C. The temperature reading for this thermometer of 36.61 °C and the low standard deviation of ±0.1639 °C is indicative that emissivity is not used based on the behavior of the experimental thermometer.

The conversion formula has two adjustments that bare mentioning. The luminance range when enough temperatures are taken will eventually settle out to a specific universal range. The range's upper and lower limits were estimated for the purposes of analysis in this study. These values can be changed. Another adjustment available is the range for emissivity can be adjusted to something other than 0.03.

What are the limitation on this analysis of automatic emissivity control? This sample with 27 photos presented here is not the entire universe. The sample was affected by the light available at the testing location. Different lighting conditions will result in different luminance values, see Color Temperatures in the Appendix. Spot location (used to determine the luminance value) has an effect upon the luminance values derived. Camera setting can affect the luminance values derived. User targeting if not consistent will have an effect on the luminance values. Minimization of external variables with an impact on luminance can be undertaken and is desirable. A one to one relationship is assumed between luminance and emissivity.

The automatic emissivity "with *e*" results compared with not using emissivity and manual mode are shown below:

Table 33 Comparison of AEC

	without e	with e	manual
average	36.43	37.02	37.02
Std Dev	0.6201	0.7319	0.6408
range	2.40	3.07	2.38

In this final summary, Table 33, the statistical results of the automatic emissivity control simulation compared to infrared temperature readings without emissivity and the manual results. The readings using emissivity have a higher average reading, a wider statistical deviation that reflects the contribution to temperatures by emissivity, and a wider range due to emissivity values not considered. The range's lower limit is raised moving the temperature average closer to the normal average assumed for human temperatures. Another comparison between the temperature readings based on machine analysis of emissivity to the SST temperatures compensated "without *e*" (how current infrared thermometer function) was: 0.9074. This shows a fairly close relationship between the two. That correlation gives us a number for the improvement of the infrared temperature readings when using machine analysis of emissivity of ~9% for this study. Finally, the machine analysis of emissivity has the potential to take the guess work out of assigning emissivity values seen in Chapter 7.

Chapter 9

Conclusions, Limitations, Contributions, and Future Work

9.1 Conclusions

The first conclusion of importance is whether you can measure a temperature from a distance accurately. You see numbers in the display but are they valid temperatures? What do they relate to? These questions were put to rest with the experiment conducted April 16, 2016, in Bellerose, NY related in Chapter 3. Using a calibrated heat source two different temperatures, one representing a normal temperature and another representing a fever temperature, the experimental sensor detected temperature readings from both that were unique and attributable to the source temperature out to 36 inches. Another lesson from this experiment was finding the heat signal among the ambient temperatures present in the room. Also, by taking readings at incremental distances, temperature readings from the heat source are indicative of the heat loss over distance. Formulas derived from plots of the roll-off curve were useful to establish a compensation value to convert observed local readings into estimates for the original source temperature at different distances for this date, place, and circumstances. Calculations using the Beer-Lambert Law established a theoretical basis for this phenomenon and revealed the sensitivity of temperature to distance.

Moving from the theoretical to the practical, a comparative temperature survey of four thermometers was undertaken on May 2, 2017 at Pace University, Seidenberg School of Computer Science and Information Systems, NYC Design Factory at 163 William St, 2nd floor, New York, New York. The results are discussed in Chapter 4. The results from this survey demonstrated the practical aspects of using the experimental sensor and formed the basis for establishing if improvements in infrared temperature sensor reading were possible. These survey results were without emissivity corrections. None of the thermometers used in this comparison used emissivity corrections including the experimental infrared sensor. This survey helped establish the distance correction.

In Chapter 5, a series of Excel function were used to simulate an automatic emissivity correction in hardware for emissivity were developed. Trials using the survey results from May of 2017 with various adjustments for emissivity were compared and analyzed. The conclusion from this chapter were: if emissivity is included in infrared temperature sensor reading, the standard deviation would improve, and the average value would raise.

In Chapter 6, the emissivity parameter was examined and tested using sample pigment colors on sheets of paper where the input and output temperatures could be obtained. The results were impressive. When the output temperatures were corrected for the emissivity using Table 20, the standard deviation for the group of output temperatures for all the sample colors improved by nearly 0.3 degrees and the medium value rose slightly.

Chapter 7 discussed a second survey that was undertaken in late November of 2017 to determine the effect of emissivity upon the accuracy of infrared temperature sensors. The results of that survey showed it was possible to detect, evaluate, and utilize the emissivity of humans by estimation of their emissivity using the Fitzpatrick Scale and manually adjust the output using a potentiometer calibrated for emissivity compensation. With the inclusion of the emissivity parameter using a modified Fitzpatrick Scale, the resulting temperatures behaved the same as in Chapters 5 and 6: improving the infrared temperature readings when using emissivity than when emissivity was not used. Based on statistical analysis a revise Fitzpatrick Scale was proposed and tested.

Chapter 8 sought to automate the assignment of emissivity using the luminance from a photo taken of the volunteer's hands captured during the November 2017 survey. This method equated luminance with emissivity using a grayscale average value for each pixel in the photo. A one to one relationship was assumed and a conversion between the luminance scale and the human emissivity scale. This manner of assignment was written and tested using Python 2.7 programming language. The resulting adjustment of the output temperature from machine automated assignment of emissivity was compared with the results from Chapter 7 detecting a bias that was not discernible just using methods developed in Chapter 7.

The comparison of infrared temperature readings when using emissivity and when not using emissivity demonstrated improvement substantiating this dissertation contention that infrared temperature sensor reading can be improved using emissivity.

9.2 Limitations

The main limitation on this work is the error factors associated with distance and emissivity. The temperature error of distance was calculated in Table 4 and Figure 12. The emissivity survey in November of 2017 was able to isolate on the distance error through the reading of the skin surface temperature. The standard deviation of the SST partition used was ±0.6201 °C was outside the FDA requirement for accuracy. This was a manual survey with students positioned at a measured distance. Using the regime estimation of ±0.15 °C per inch for the distance based on Figure 12, the standard deviation of ±0.6201 the operator error could have been as much as 4" out of position. A better method of locking in distance needs to be developed.

The emissivity error discussed in Chapter 7 for the November 2017 survey could be because of errors in placement of the skin-tone in the wrong bin which translates into assigning the wrong Fitzpatrick category to an individual. This means the temperature reading could be affected by as much as two categories or 0.01 units (in the revised Fitzpatrick Guide, each category became .005 unit wide). This is an estimated error in temperature of ±0.01 °C. Because the emissivity error is smaller than the distance error; machine learning is key to solving this small of an error which could improve infrared sensor temperature readings even more. The limitation for emissivity using machine analysis was discussed in Chapter 8. The biggest sources of error in this methodology is target selection of the skin-tone and the range assumed for luminance.

9.3 Contributions

1. Developed a table that computed the sensitivity of temperature to emissivity using the Stefan-Boltzmann Law in Chapter 2.

2. Developed a table that computed the sensitivity of temperature to distance using the Beer-Lambert Law in Chapter 3.

3. Developed a system level model for infrared temperature sensors using the Beer-Lambert Law and the Stefan-Boltzmann Law in Chapter 3.

4. Proposed in Chapter 3, a general rule limiting distance readings: the distance a temperature source can be detectable is limited by the difference between the heat signal temperature and the ambient temperature where the local heat signal temperature value must be the greater value.

5. Conducted a temperature survey in Chapter 4 that was unusual in that the average of 3 different commercial thermometers were the same in May of 2017. The outcome indicated that the group temperature was 36.7°C. Individually, each thermometer had different standard deviations and ranges including the experimental infrared sensor. This outcome was useful in determining the core body temperature off-set used to correct SST temperature to body temperatures for the experimental sensor.

6. Designed a simulation in Chapter 5 for Automatic Emissivity Control using an Excel VLOOKUP function and a Histogram chart for analysis of limits based on real temperature reading on a spreadsheet for implementation as a LUT in

hardware. The purpose was to simulate the correct selection of emissivity after analysis by pixel RGB averages of a small region of a person's face.

7. Proved that the experimental sensor was capable of detecting emissivity in a temperature emissivity survey of June 12, 2017 by inference from the color sample testing discussed in Chapter 6. In this test, a method was developed to evaluate emissivity temperatures using paper with a color sample. Surface temperatures revealed output temperatures different input temperatures and varied according to emissivity. Arranging the colors by decreasing/increasing emissivity was now possible.

8. Because the field-of-view (FOV) of the sensor is quite narrow but when used to focus on objects further away cause the spot diameter to enlarge. At 3 feet, the FOV spot size of 3 inches allow the user to take the **whole face** temperature. This refers to the accumulation of all parts of a face contributing heat for the best temperature reading. This changes the temperature reading from a spot temperature to a region that is being tested. Discussed in comments of Section 6.5.

9. Developed C++ programs for the testing of the experimental sensor used in Chapter 6. Among the programs codes written are the display of the temperature on a 4 digit, 7-segment display, an ultrasonic distance sensor (included in Appendix), a continuous test mode, a test mode for 200/300 test loops, display of parameters used during testing for recording purposes (included in the Appendix), the temperature capture mode that takes 300 readings and process them by dynamic filtering. In addition, I added an indicator for patients and users: a tri-LED green,

red, and blue LEDs display based on set points to indicate a fever, normal, and below normal temperatures. These programs were developed incrementally from over 20 versions that solved various problems related to taking infrared sensor temperatures.

10. In the emissivity survey conducted in November of 2017, data was collected that directly contributed toward an understanding of the role of emissivity in infrared sensor thermometers. Emissivity setting based on the Fitzpatrick Scale is presented in Table 29 Human Emissivity Guide at the end of Chapter 7.

11. A method for automatic emissivity correction using Python 2.7 programming code was presented in Chapter 8. In this chapter, photos of the subject's skin-tone were evaluated for luminance, converted to grayscale then equated with the human emissivity scale developed in Chapter 7. The data from the survey in November of 2017, were evaluated showing an improvement for infrared temperature readings by inclusion of emissivity. The results were implemented in a spreadsheet and compared with the results of Chapter 7 and compared with infrared temperature sensor reading that did not use emissivity. The automatic emissivity correction methodology showed an improvement over both comparison and avoided a bias discovered in Chapter 8 about the results of Chapter 7.

9.4 Future Work

The next stage in the utilization of this sensor is to transition to a more advanced platform. A prototype thermometer system that consists of the infrared temperature sensor used in this dissertation will have added a video system that consists of a camera and display for the purposes of targeting and sampling the RGB content of the subject.

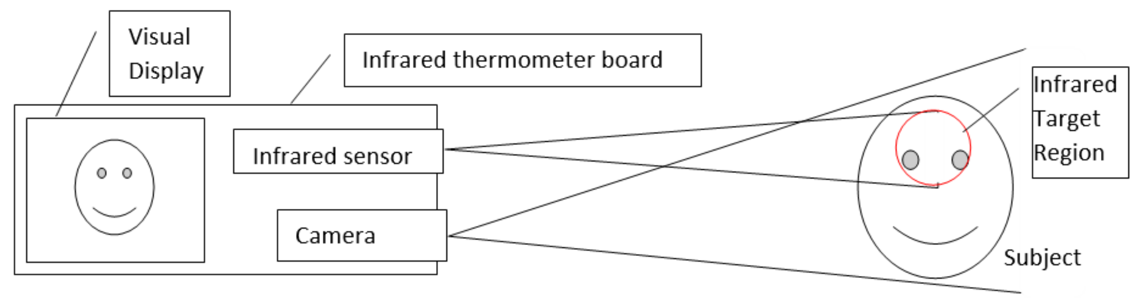


Figure 52 Sketch of proposed camera enabled thermometer system.

The platform could be the Raspberry Pi Model 3 with operating system Debian running on a Broadcom BCM2837 chip. The Raspberry Pi model 3 consists of a CPU made up out of a 1.2 GHz 64/32-bit quad-core ARM Cortex-A54 with 1 GB LPDDR2 RAM accessible at 900Mhz with a Broadcom VideoCore IV running a Multi-Media Abstraction Layer over OpenVAS (a multi-media processor architecture) for easy camera control [1]. With the addition of a subVGA display unit, target acquisition and distance reading become possible.

The automatic emissivity control Python code as written can be called by the Raspberry Pi operating system for evaluation of photos taken using Python commands. The user aims the sensor by observing the display screen, keeping the patient’s eyes in view using the MMAL facial tracking feature. The photo yields the emissivity value to correct the observed skin-surface temperature into an adjusted temperature value for the subject within three seconds. Addition embedded features of the Raspberry Pi operating system allow WiFi or Blue-tooth connectivity to a local router for connection to a local computer or uploading to the Cloud for advance machine learning processing/data storage/data access by consumers for historical analysis.

Additional features such as a real-time clock can be used to provide an offset for temperatures reading due to circadian rhythm during a 24-hour period.

Once the design is functional a clinical study is needed for FDA approval of this device.

Appendix

Classification of an Infrared Temperature Sensor

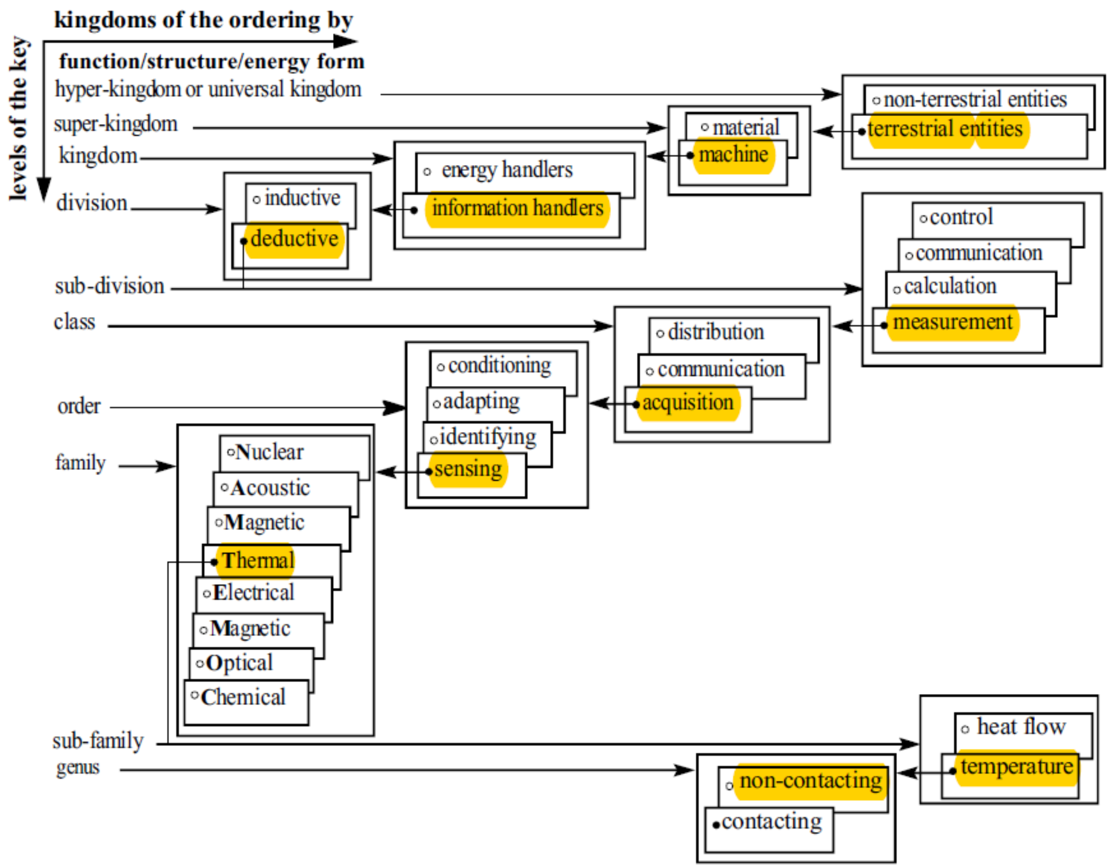


Figure 53 Classification of an infrared temperature sensor

Sources for Figure 53 and Figure 54 are from the Wiley Online Library, *Temperature Measurement* by Michalski, Eckersdorf, Kucharski, and McGhee [37].

Classification of a Non-Contacting Infrared Temperature Sensor

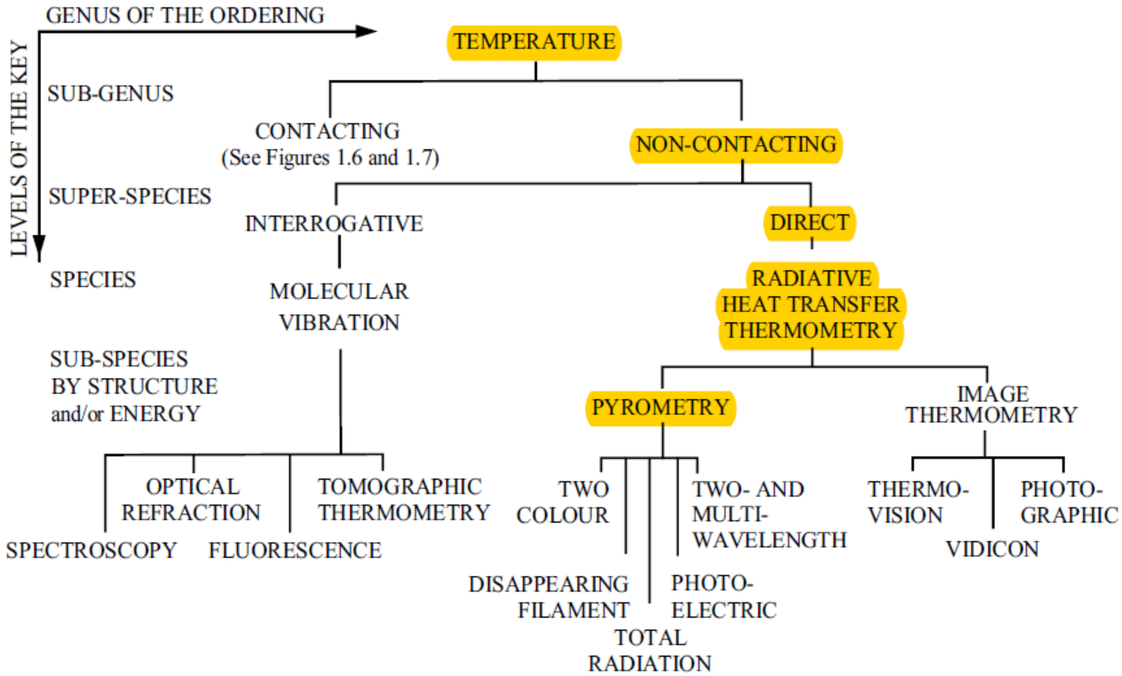


Figure 54 Classification of a NCIT sensor

At one time, pyrometry thermometers mean high temperature thermometers but it now applies to measurement of cooler objects down to room temperature [62]. This chart doesn't recognize this further delineation of infrared thermometers.

IRB Approval Letter

- 1 - Generated on IRBNet

INSTITUTIONAL REVIEW BOARD (IRB)
NOTIFICATION OF REVIEW

To: Tim Johnson, BPS, MA, MSEE
From: Pace University Institutional Review Board
Date: May 10, 2017
IRB Code #: 17-79
Project Title: [1060760-1] Improving infrared sensor temperature readings
Study Review: Expedited Review
Action: Approved
Expiration Date: May 4, 2018

Thank you for your submission of New Project materials for this project. The above-referenced human subjects
research project was **APPROVED** by the Pace University Institutional Review Board (IRB) for
the period of May 3, 2017 through May 4, 2018.

Approval is limited to the activities described in the approved Protocol Narrative. Additional conditions for the general conduct of human-subjects research are detailed on the Office of Sponsored Research website (http://www.pace.edu/office-sponsored-research/research-protections-IRB-IACUC)

Federal regulations require that all research be reviewed at least annually. It is the Principal Investigator's responsibility to obtain review and continued approval 30 days before the expiration date of the protocol. If there is a lapse in approval, you may not continue any research activity (i.e. enroll participants, engage in study procedures, or analyze identifiable data) until the IRB renewal is reviewed and approved.

Please contact the IRB when you need to:

• Renew your project (please submit a continuing approval form at least 30 days prior to expiration);
• Submit a final report when the project is completed;
• Revise any aspect of the approved protocol. All changes (e.g., change in procedure, personnel, recruitment materials, etc.) must be prospectively reviewed and approved by the IRB; or
• Report any unanticipated problems involving risk to subjects or any serious adverse events.

Please send all communication to paceirb@pace.edu; all forms and additional information can be found on the Pace IRB website.

Thank you for your continuing cooperation, and best of luck with your research!

Sincerely,

- 2 - Generated on IRBNet

Gerald P. Ardito, DPS Lucille R. Ferrara, EdD, FNP '94, RN
Co-Chair of Institutional Review Board Co-Chair of Institutional Review Board

Cc: Office of Sponsored Research
OHRP IRB# 0003970 FWA00023526

This letter has been electronically signed in accordance with all applicable regulations, and a copy is retained within Pace University Institutional Review Board's records.

Temp_blended_v15—main.cpp

/*Temp_blended_v15_Log-Ready main program used for emissivity survey
Changed display pinout for 3-D print prototype to use shorter F/F jumpers yellow/green/blue models
line 179 emissivity input to turn pot on/off now on p14 of mbed
cleared trouble with left in variables that set emissivity at .95 and took .05 off the oral
Temp_blended_v10 is a 4 digit, 7 segment display showing C or F, & distance readings
Continuous display holding readings with ability to switch between C & F at any time after initial reading.
Holds and displays until reset button is pushed for a new reading.
Choice of C or F selectable by ground of input pin 30 with a jumper (a manual switch).

Offset can be changed on line 80
v7 Designed for portable usage and if USB link is used the terminal programs shows all info.
v7 Certain pinouts for analog usage (Vref+, p10, Vref-, p12) resulted in changes to the LED digital control pins
v7 Until these changes are propagated thru earlier code version, the 7-segment will not display correctly on those version.
v7 This version will include the formula for distance mentioned in version 4. (since discarded due to unreliable ultrasonic reedings)
v7 Fixed issue with using I2C by moving LED G off pin 27 to pin 29

v8 Arranged all the pins to allow for using two female plugs for assembly, previous versions will not work
v8 Organized initialization of sub-sections and variables to specific locations.
v8 Discovered when POT added it drained V+ source causing erratic reading of sensor and display

v9 adds controlled voltage source to emiss Potentiometer to limit drain on voltage source
v9 above means POT must be adjusted for emiss before RESET to take next subject
v9 adds the read of emissivity as a float and display of data to send to sensor. See lines 167 - 183
v9 restored printing of C & F to terminal display with decimals by changing Oral to a float and location of print function

v10 straightens out finesse of digits for 4 Digit, 7-segment display
v10 calculates Oral based on centigrade value, Fahrenheit derived C*1.8 +32
v10 uses centigrade for tri-color LED evaluation and print out of temperature
v10 uses either for display temperature depending on switch setting
v10 shows on display X.X.xx for temperatures over 100 with first cap X being 0, 2nd cap X being 0,1,2...with a leading 1 being understood.
v10 has adjusted emissivity pot that shows 100% down to 74% using dropping resistor 27K on gnd, pickoff value to pin 20,yellow.

V12 was rewritten to include modification to pinouts for digital display and colors and a few other I/O's

V13 At Pace University DPS meeting 10/28 I realized I could address emissivity post data capture
V13 See lines 167-183, value insert into temperature at line 204
V13 Log Ready, stores hitemp to SST then adds in offset and emissivity as Oral temp
V13 Log Ready, add factor so I can add adjustment to emissivity other than .734 lineXX

V14 restored modex variable to get ambient temperature

V15 erased modex method of getting ambient temperature by using another program to get ambient memory from 0x06.
V15 works with two methods of reading I2C data lines, one using C programming and the other using C++, weird.

Uses Radio shack Full-Color LED part#276-0028
lay LED down pins toward you with flat of lens on the left
Pin Out wiring guide:

```
CONTROL    LED color        MBED Pin#   Jumper    LED pin
-----------------------------------------------------------
FEVER        RED           5          ORN      medium length on left
LOW          BLUE          6          BLUE     Short 2nd from right
NORMAL       GREEN         7          PURPLE   Short on right
GND          SOURCE 3.3V   40         brown    Long pin
```

Common anode (gnd, long pin, 2nd from left) wired in series with 820 ohms resistor connected to 3.25V (for testing and control). You write a one to turn off the LED and a 0 to turn it on.

Sensor connection seen looking a bottom of sensor, tab at bottom (pretend box is round...)

```
    |------------------------|
    | * SDA/Gray  3.3V/Red * |
    |                        |
    | * SCK/WHT   GND/BLK  * |
    |------------------------|
             |__|
```

The emissivity Potentiometer is a 10K pot, shows .996% at 10K (fully CCW) and 0% at 0 ohms (fully CW).
The potentiometer ground has to have a 27K resistor before it goes to ground to show 74% at fully CW.
*/

```
#include "mbed.h"
#include "mlx90614.h"
```

```
#define SAMPLE_RATE   150000
#include "adc.h"

I2C i2c(p28,p27);              //turns on and selects pins for I2C: sda,scl
//Serial pc(USBTX,USBRX);        //turns on serial usb config for terminal display
program
MLX90614 IR_thermometer(&i2c);  //turns on sensor
ADC adc(SAMPLE_RATE, 1);        //turns on ADC to maximum SAMPLE_RATE and
cclk divide set to 1
float temp = 0;     //temperature in degrees C
float hitemp = 0;   //loop to determine highest C temperature read
float offset = 3.7; //allows offset to be changed here
int count = 0;      //way to count # of temp reading...and other loops
int loop1 = 0;      //incremental counter for display loop
float Oral = 0;       //used in tri-color evaluation routine lines 130+
float f = 0.005;    //sets persistance (wait for digital display, set persistence, aka flash rate,
used starting line 250+ in wait command
int t =0;           //used to finesse digits out of temp value
int tc = 0;         //temp centigrade
int tf = 0;         //temp Fahrenheit
float emiss = 0;          //emissivity voltage value
float emiss_raw = 0;      //used during testing of input from potentiometer
int emiss_pot = 0;      //used to limit emissivity pot drain on LPC1768 voltage supply
int temp1a, temp2a, temp3a, temp4a = 0; //used in finessing digits out of temperature
float SST = 0;     //variable to store barebones reading without offset or emissivity
float factor=0.166; //use to make lowest emiss range 0.900 at line 193
float ambient_temp;  //used to get chip temperature and for accuracy readings
int accuracy; //variable to store accuracy readings for sensor ranges

//code below turns on pinouts for digital display digits outputs and inputs
DigitalOut Digit1(p26);
DigitalOut Digit2(p23);
DigitalOut Digit3(p22);
DigitalOut Digit4(p13);
//turns on pinouts for tri-color LED
DigitalOut FEVER(p5);
DigitalOut LOW(p6);
DigitalOut NORMAL(p7);

DigitalOut myled(LED1);     //signal used for testing
DigitalOut emiss_led(LED2); //signal used for testing
DigitalOut emiss_pot_on(p14);       // used to quickly turn on/off Pot before Display and
tri-color LED is turned on line 196
DigitalIn display_selection(p30);   //select for temperature C or F

/* LED wiring for display
```

```
CONTROL   DISP-Pin#  MBED Pin#  Color
----------------------------------------------------
Digit1        12        26   White
Digit2         9        23   Orange
Digit3         8        22   Purple
Digit4         6        13   Black
DP             3        10   Yellow
A             11        25   Gray
B              7        21   Black
C              4        11   Orange
D              2         9   Gray
E              1         8   White
F             10        24   Yellow
G              5        12   Purple

Alternate method of recording the wire color of the pins out
display pin |  7  |    8   |    9   |   10   |  11  |   12  | top row display
  mbed pin | 21  |   22   |   23   |   24   |  25  |   26  | mbed V+ side pins 21-26
wire color  | BLK | Purple | Orange | Yellow | Gray | White |colors duplicated for bottom
row of display
display pin |  6  |    5   |    4   |    3   |  2  |    1  | bottom row of display
  mbed pin | 13  |   12   |   11   |   10   |  9  |    8  | Gnd side pins 8-13
This alternate works best when the switch F/C is position to your right then color patterns
are copies of each other, left to right top display to top ucontroller
*/

//these are the pins associated with writing to the display "led"
DigitalOut led[8]={p25, p21, p11, p9, p8, p24, p12, p10};

//segments are in alphabetical order a-g, followed by D decimal point in the array below
int matrix[11][8]={
            {1,1,1,1,1,1,0,0},      //zero
            {0,1,1,0,0,0,0,0},      //one
            {1,1,0,1,1,0,1,0},      //two
            {1,1,1,1,0,0,1,0},      //three
            {0,1,1,0,0,1,1,0},      //four
            {1,0,1,1,0,1,1,0},      //five
            {1,0,1,1,1,1,1,0},      //six
            {1,1,1,0,0,0,0,0},      //seven
            {1,1,1,1,1,1,1,0},      //eight
            {1,1,1,0,0,1,1,0},      //nine
            {0,0,0,0,0,0,0,1}       //dot...if in first position, a leading null space
indicating 100+ temp
           };

//create matrix to handle decimal point
```

```
int matrixdecimal[11][8]={
            {1,1,1,1,1,1,0,1},      //zero
            {0,1,1,0,0,0,0,1},      //one
            {1,1,0,1,1,0,1,1},      //two
            {1,1,1,1,0,0,1,1},      //three
            {0,1,1,0,0,1,1,1},      //four
            {1,0,1,1,0,1,1,1},      //five
            {1,0,1,1,1,1,1,1},      //six
            {1,1,1,0,0,0,0,1},      //seven
            {1,1,1,1,1,1,1,1},      //eight
            {1,1,1,0,0,1,1,1},      //nine
            {0,0,0,0,0,0,0,1}       //dot...actually a leading null space
           };

int main()
{
//set tri-color LED off
   FEVER = 1;
   LOW = 1;
   NORMAL = 1;

//Next--Collect skin-tone color potentiometer readings
      emiss_led = 1;          //test signal indicator
      emiss_pot_on = 1;        //powers up POT
      adc.actual_sample_rate();
      adc.setup(p20,1);        //Set up ADC on pin 20
         wait(.1);
      adc.select(p20);         //Set ADC to select p20
      adc.start();             //Start ADC conversion
      while(!adc.done(p20));    //Checking to see if conversion complete
      emiss_raw = adc.read(p20);  //assign output to variable
      wait(.1);
      float conv(8.056e-4);
      emiss_raw = static_cast<float>(emiss_raw*conv);  //may be wrong value...nope
need this
      emiss = emiss_raw/3.3;    //convert actual voltage into a percentage (voltage read
divided by max voltage possible)
      //if pot turned off, emissivity = 1.00, if pot is fully CW the emissivity is 0.734
      printf(" emissivity potentiometer reading on pin 20 is %4.3f\n\r",emiss);
      emiss = emiss + (1-emiss)*(factor/.266);   //if emiss = .99, then adds portion of CW
pot back into emiss.
      //if emiss is at lowest range 0.734 adds in .266 otherwise % of factor (1-emiss)/.266
      printf(" Adjusted value for emissivity is % 4.3f\n\r", emiss);  //check on mathc
      //printf(" \n\r");
      emiss_led = 0;          //turn off dist led indicator
      emiss_pot_on = 0;        //turns off emissivity potentiometer
```

```
 //  end of emissivity potentiometer read...there are two different readings printed out...
 // one is the actual voltage reading of the pot, which will be lower than the adjusted
emissivity reading (the 2nd emissivity reading)
//was going to write emissivity to sensor but realized I could do it post data capture in the
microcontroller as long as sensor emissivity is set at 1.00

myled = 1; //turn on indicator lamp for sensor temperature testing begins

while (count<270) {
       if (IR_thermometer.getTemp(&temp)) {
//Below adjust 90614DCI dependancy on VDD per data sheet page 32 and LPC1768
Vout (3.25-3)=>.25*.6=.15)
        temp=temp-.15;
//The formula above linearizes the reading

//below adjusts temperature to highest in sample so far
  if (temp>hitemp){hitemp=temp; }
        count ++;
      }
    }

//highest temperature is now stored in variable hitemp
myled = 0;  //turns off led indicating readings are done.
//Offset below based on May 5, 2017, Pace comparative survey.
           Oral = hitemp + offset; //offset based on Pace Survey 5-2-2017
           SST = hitemp;            //collect skin surface temeperature reading...set emiss to
1.00 and get SST plus offset
           Oral = Oral + Oral*(1-emiss);  //post-processing of emissivity (emiss here is
0.9X or something so the (1-emiss) allows formula to calculate the fraction adjustment
of (1-.9X) of the Oral temp (under the skin) which is seen on the skin (SSF)
//write loop for ambient reading due to temps outside ranges per data sheet below
 int p1=0;
 int p2=0;         //to store adc high and low and PEC is p3 (packet error correction)which
I cut out
 int ch=0;         //to establish memory location in sensor
 do{                             //loop repeat if repeated start codition is not acknowledge
                  do{            //loop repeat if device ram address(reg address where the Tobj
value present) condition is not acknowledge
                            do{                      //loop repeat if device address acdition is not
acknowledge
                                  i2c.stop();         //stop i2c if not ack
                              wait(0.2);
                            i2c.start();                //start I2C
                                 ch=i2c.write(0x00);     //device address of mlxIRtemprature
sensorwith write condition
                               } while(ch==0);         //wait for ack
```

```
                    ch=i2c.write(0x06);        //device ram address where ambient value
is present
             } while(ch==0);                   //wait for ack
              i2c.start();
                        //repeat start
              ch=i2c.write(0x01);              //device address with read condition
     }while(ch==0);                            //wait for ack
     p1=i2c.read(1);                  //Tobj low byte
     p2=i2c.read(1);                    //Tobj high byte
     i2c.stop();                    //stop condition
                                      //degree centigrate conversion
     ambient_temp=((((p2&0x007f)<<8)+p1)*0.02)-0.01;  //convert to Kevins
     ambient_temp=ambient_temp-273;              //convert to Celsius
     printf(" The ambient sensor temperature is %5.2f C and %5.2f F\r\n",ambient_temp,
ambient_temp*1.8+32);

//end of ambient read, below is IF conditions for error estimate
     if((ambient_temp<20.0)||(ambient_temp>30.0)){
       accuracy= 3;
       }
       else if((SST>39.0)||(SST<36.0)){
         accuracy= 2;
        }
         else{
           accuracy= 1;
           }
     printf(" Sensor Accuracy is 0.%d \r\n", accuracy);
 //end evaluation of accuracy
//evaluate tri-color LED status using temperature centigrade
   if(Oral < 35.0) {
     FEVER = 1;
     NORMAL = 1;
     LOW = 0;         //sets tri-color LED to BLUE
     printf(" Your temperature is BELOW the NORMAL temperature range \r\n");
     //printf("\r\n");
   } else if(Oral > 38.00) {
     FEVER = 0;          //Sets tri-color LED to RED
     NORMAL = 1;
     LOW = 1;
     printf(" Your temperature is ABOVE the NORMAL temperature range \r\n");
     //printf("\r\n");
   } else {
     FEVER = 1;
     NORMAL = 0;   //if it ain't hot or cold, it's normal turns LED to GREEN
     LOW = 1;
     printf(" Your temperature is within the NORMAL temperature range \r\n");
```

```
        //printf("\r\n");
    }
 //end tri-color evaluation
 //Print out the temperature on Tera Term, a standard output device
 printf(" SST temp is %5.2f C and %5.2f F\r\n", SST, (SST*1.8+32));
 printf(" Temperature is %5.2f C and %5.2f F\r\n", Oral, (Oral*1.8+32));
 printf(" end of report \r\n");
 printf(" \r\n");

 //resume setting C & F temperatures variable for use in code
            t = Oral * 100; //trans value to LED display code and into 4 digit intergers
            tc = t;  //store hitemp interger in tc centigrade
            tf = Oral*180+3200; //convert hitemp to integer and into fahrenheit
            myled = 0; //signal testing concluded

            //begin read input pin 30 for F or C
            display_selection.read(); //reads p30 input as high or low
            if (display_selection==1){t=tf;}
            else if (display_selection==0){t=tc;}

//begin code segment for 7 segment display
while (1){

//finessing the digits out one at a time knowing 2nd digit has the decimal
//int tempasinteger = temp * 100;  //removes decimal and typecasts float to integer
int temp1a = t/1000;    //typecast float to integer for 1st digit (was)
int temp2 = t - temp1a*1000;  //gets last 3 digits
int temp2a = temp2/100;   //typecast float to integer for 2nd digit
int temp3 = temp2 - temp2a*100;  //get last 2 digits

int temp3a=temp3/10;    //typecast float to integer for 3rd digit
int temp4=temp3-temp3a*10;   //gets last digit
int temp4a = temp4;     //convenient renaming for writing digit to display

//begin one write of the display by turning off all the digits
  //move these to start of program
    Digit1 = 1; //turn off digit1
    Digit2 = 1; //turn off digit2
    Digit3 = 1; //turn off digit3
    Digit4 = 1; //turn off digit4

        //turns off last led's segments values
        for(int i = 0; i<8;i++){
            led[i] = 0;}

         //belows holds row of matrix and assign column value from matrix
```

```
 Digit1 = 0;             //turns on digit1
  //if (t>0){
    for (int i=0; i<8; i++){
        led[i] = matrix[temp1a][i];
            }

wait(f);
Digit1=1;
//above turns off last led's segments values

//below empties out the vector values for reuse
for(int i = 0; i<8;i++){
    led[i] = 0;}

 //belows holds row of matrix and assign column value from matrix
 Digit2 = 0;             //turns on digit2 with decimal

 for (int i=0; i<8; i++){
        led[i] = matrixdecimal[temp2a][i];
        }
wait(f);
Digit2=1;
//turns off last led's segments values

//below empties out vector values for reuse
for(int i = 0; i<8;i++){
    led[i] = 0;}

 //belows holds row of matrix and assign column value from matrix
 Digit3 = 0;             //turns on digit3
 for (int i=0; i<8; i++){
        led[i] = matrix[temp3a][i];
        }
 wait(f);
Digit3=1;

//turns off last led's segments values
for(int i = 0; i<8;i++){
    led[i] = 0;}

//belows holds row of matrix and assign column value from matrix
 Digit4 = 0;             //turns on digit4
    for (int i=0; i<8; i++){
        led[i] = matrix[temp4a][i];
        }
wait(f);
```

```
        Digit4=1;
//end finesse of digits

//check if F or C has been selected for next display
    if (display_selection==1){t=tf;}
    else if (display_selection==0){t=tc;}

 } //close for while loop
} //close for main
```

Survey Program May 2017—main.cpp

```
/*Temp_mode_v7 was used for 1st survey to determine offset vs. 3 other thermometers
a one-shot read (push reset button on mbed for another read)
displayed on a terminal monitor via USB link and via a Tri-color LED
temperature is read for about 3 seconds (270 readings).  Blue LED1 lights up during reading then
turns off when temperature is displayed
This version is copy of v5 where I got Ambient temperature working.
THIS VERSION experimented with getting emissivity value.
Unable to find a steady value at 0x04, found another listing p14 of DataSheet, and by...
trial and error found a FFFF value at EEPROM address 0x24 then using the MLX Eval board
I VERIFIED I could change emissivity to 0.95 (0xF332) and read back the new number!!!
uses loopcounter in mlx90614.cpp program to solve moving values back and forth...
main calls *.cpp i2c program and loopcounter will increment in synch with count
0x07 is correct for the address of the read temperature.
0x06 is correct for the address of the ambient temp.
tested hand wave and Ambient didn't change but seen temperature value did.
Added table of Hex values as I was having trouble getting a float emiss to work.
*/

#include "mbed.h"
#include "mlx90614.h"

 /*
Uses Radio shack Full-Color LED part#276-0028
lay LED down pins toward you with flat of lens on the left
Pin Out wiring guide:

CONTROL    LED color        MBED Pin#    LED pin
-------------------------------------------------
FEVER        RED          17          medium length on left
NORMAL       GREEN        18          Short on right
LOW          BLUE         19          Short 2nd from right
Common anode (long pin, 2nd from left) wired in series with 820 ohms resistor
to 3.25V (for testing and control). You write a one to turn off the LED and a 0 to turn it on.
*/

//Temperature indicator LEDs Setup:
DigitalOut FEVER(p17);   //assign names to pins
DigitalOut NORMAL(p18);  //assign names to pins
DigitalOut LOW(p19);     //assign names to pins
DigitalOut myled(LED1);  //displays I2C wait
I2C i2c(p28,p27);        //set up pins for I2C sda,scl
Serial pc(USBTX,USBRX);  //serial usb config for terminal display program
```

```
MLX90614 IR_thermometer(&i2c);  //C++ call to write i2c address to variable i2c
float temp = 0;          //temperature in degrees C
float temp1;             //dummy variable
float temp2;             //dummy variable
float hitemp = 0;        //loop to determine highest temperature read
int count = 0;           //flag for # of temp reading...
float Normal = 0.0;        //Normal temperature at 36", per equation on spreadsheet plot
"Normal vs. Fever"
float OFFSET = 0.0;      //OFFSET correct to get Oral temperature
float Ambent = 0.0;      //storage variable for Ambient temperature
//float emiss = 0.0;       //storage variable for emissivity value
//int emiss;
float Oral = 0.0;        //storage variable for oral temperature once Offset is added in
//int modex;               //switch used to change address for ambient and emissivity reading
float SST =0.0;          //a way to recover the actual skin surface temperature read
float ZeroAdj = 0.3;     //amount I recall this sensor is off from WALD Black Body reading.
Need to double check
//float temp_thermo =0.0 ;
/*change these value above to the correct distance chosen in lines 56 & 57
if distance is 36", Normal is 20.44, OFFSET is 7.6 theoretical
if distance is 24", Normal is 33.50, OFFSET is 3.5 theoretical
if distance is 12", Normal is 36.01, OFFSET is 1.0 theoretical
*/

int main() {

   FEVER = 1;          //turns off tri-color LED red
   NORMAL = 1;         //turns off tri-color LED green
   LOW = 1;            //turns off tri-color LED blue
   myled =1;           //signal testing begins loop to determine highest temperature read by
the sensor

//the following loop is used to go get data from from the i2c bus for the address used
     while (count<270) {
       if (IR_thermometer.getTemp(&temp)) {

           if (temp>hitemp){hitemp=temp;}   //sets temperature to highest in sample so far as
reading progress
              count ++;
              //printf(" %u \r\n", count);
               }
           }

   myled = 0;                  //signal testing completed
   //Normal = 29.44;           //Normal temperature at 36", per equation on spreadsheet plot
"Normal vs. Fever" is 29.44
```

```
   OFFSET = 4.5;                    //OFFSET to change distance reading to oral temperature
reading
   hitemp=hitemp-.18;          //gradient adjust for 90614DCI dependancy on VDD per data
sheet page 32 and LPC1768 Vout 3.3 value (.3*.6=.18)
   hitemp=hitemp + ZeroAdj;      //adds in zero adjustment
   SST = hitemp;                //stores corrected skin surface temperature

//below here the temperature reading uses the offset
   Oral = hitemp+OFFSET; //offset to get to oral temperature
    //printf("Temperatures %5.2F C | %5.2F F | %5.2F SST \r\n", Oral, Oral*1.8+32, SST);

//loop to get Ambient temperature in C ambient temperature is accounted for in
mlx90614.cpp using print function over there
   while (count==270) {
      if (IR_thermometer.getTemp(&temp)) {
         if (temp>Ambent){Ambent=temp;}
         count++;
         //printf(" %u Ambent loop \r\n", count);
         }
     }

//   Ambent = Ambent-.18+ZeroAdj;   //added correction not seen during this last loop into
mlx90614.cpp fetch routine

//loop to get emissivity value
   while (count==271) {
      if (IR_thermometer.getTemp(&temp)){
          if (temp1>0){temp2=temp1;}
            count++;
            //printf(" %u emiss loop \r\n", count);
         }
     }

//print out routines
         printf("| OFFSET %5.2F \r\n", OFFSET);
         printf("Temperatures %5.2F C | %5.2F F | %5.2F SST \r\n", Oral, Oral*1.8+32,
SST);

         //turning on the LEDs
         if(Oral < 35.0) {
            FEVER = 1;
            NORMAL = 1;
            LOW = 0;          //sets tri-color LED to BLUE
            printf("Your temperature is below the NORMAL temperature range \r\n");
            printf("\r\n");
            }
```

```
   else if(Oral > 38.0){
      FEVER = 0;           //Sets tri-color LED to RED
      NORMAL = 1;
      LOW = 1;
      printf("Your temperature is above the NORMAL temperature range \r\n");
      printf("\r\n");
      }
   else {
      FEVER = 1;
      NORMAL = 0;   //if it ain't hot or cold, it's normal turns LED to GREEN
      LOW = 1;
      printf("Your temperature is in the NORMAL temperature range \r\n");
      printf("\r\n");
         }
printf("IMT program: Temp_mode-v7 Log Ready, IP patent protected \r\n");
printf("\r\n");
}
```

Program Fetches Sensor Data/Calculates Temperature —MLX90614.cpp

//This is the fetch routine via i2c the data from the sensor
//This arrangement of all the reference addresses tied to 0x07 get printouts as decimal numbers
//need to get the correct address for emissivity. Just about got it, data sheets say emissivity address is

```
#include "mlx90614.h"

MLX90614::MLX90614(I2C* i2c,int addr){

   this->i2caddress = addr;
   this->i2c = i2c;
   }

   int Loopcount;

bool MLX90614::getTemp(float* temp_val){

   char p1,p2;
   float temp_thermo;
   bool ch;
   int emiss;  //working
   //float emiss1;
   //enter ZeroAdj value below in printout for Ambient temperature

//start i3c routine
   i2c->stop();                    //stop i2c if not ack
   wait(0.01);
   i2c->start();                   //start I2C
   ch=i2c->write(i2caddress);           //device address with write condition

   if(!ch)return false;              //No Ack, return False

   if(Loopcount<270){
      ch=i2c->write(0x07);           //device ram address where Tobj value is present: 0x07
      if(!ch)return false;           //No Ack, return False
      }
   if(Loopcount==270){
      ch=i2c->write(0x06);               //address to take ambient temperature 0x06
      if(!ch)return false;
      }
   if(Loopcount==271){
```

```
      ch=i2c->write(0x24);                    //address to get emissivity value 0x24 verified
4/17/2017
      if(!ch)return false;
      }

   i2c->start();                        //repeat start
   ch=i2c->write(i2caddress|0x01);        //device address with read condition
   if(!ch)return false;                  //No Ack, return False

   p1=i2c->read(1);     //Tobj low byte
   p2=i2c->read(1);     //Tobj high byte
   //p3=i2c->read(0);   //PEC, an error correction code is being ignored

   i2c->stop();                         //send i2c stop

//end i2c routine

   Loopcount=Loopcount+1;     //attempt to keep count in mlx90614.cpp the same as in
main.cpp...every call to i2c routine increments Loopcount

   //printf ("Tobj low byte is: %X and P2 : %X \r\n",p1,p2);

   temp_thermo=((((p2&0x007f)<<8)+p1)*0.02);       //pushing High byte + low byte to
make 4 digit hex #, conversion of hex values to Kevin temperature reading...typecast
convert HEX to decimal Float.

   *temp_val=temp_thermo-273.15;                    //Convert kelvin to degree Celsius

   //convert i2c reading to ambient temperature
   if(Loopcount==271){
     *temp_val = ((p2&0x007F)<<8)+p1;  //attempting to get emissivity value in HEX

     //printf ("Tobj low byte is: %X and P2 : %X | *temp_val %5.2F \r\n",p1,p2,
*temp_val);
     printf ("Ambient temp %5.2F C ",temp_thermo-273.12-.18+0.3);
      }

   if(Loopcount==272){
     emiss = (((p2&0xFFFF)<<8)+p1);  //attempting to get emissivity value as a float
     //emiss1 = emiss/0xffff;
     //printf ("Tobj low byte is: %X and P2 : %X | \r\n",p1,p2);
     printf ("| emissivity:%X ",emiss);
      }
 /* conversion of HEX to emissivity
  0xFFFF       1.00
  0xFD6F        0.99
```

```
  0xFAE0        0.98
  0xF850        0.97
  0xF5C1        0.96
  0xF332        0.95
  0xF0A2        0.94
  0XEE13        0.93
 */
   return true;                       //load data successfully, return true
}
```

Temperature Survey—Volunteer Data

Table 34 Temperature Survey—Volunteer data

	A	B	C	D	E	F	G
1	Pace IRB survey 1060760-1						
2	Date:	2-May					
3	Locationl	Pace, 163 Williams Street, NYC, NY					
4	Investigator: Tim Johnson, Dr. Lixin Tao						
5							
6	Subject IC	Age	Sex	height	weight	BMI	Time
7	1	20	m	74	210	27.0	noon
8	2	21	m	74	180	23.1	
9	3	20	m	66	160	25.8	
10	4	23	m	72	230	31.2	
11	5	18	m	69	129	19.0	
12	6	28	m	68	158	24.0	
13	7	24	m	68	154	23.4	
14	8	19	m	68	170	25.8	1pm
15	9	21	f	63	140	24.8	
16	10	21	f	64	124	21.3	
17	11	21	f	65	122	20.3	
18	12	21	m	71	225	31.4	
19	13	25	f	67	170	26.6	
20	14	22	f	63	130	23.0	2pm
21	15	26	f	64	120	20.6	
22	16	21	f	60	135	26.4	
23	17	24	f	61	110	20.8	
24	18	24	m	69	135	19.9	
25	19	26	m	69	170	25.1	
26	20	24	f	66	120	19.4	
27	21	20	m	67	193	30.2	
28	22	21	m	67	193	30.2	3pm
29	23	22	m	72	134	18.2	
30	24	21	m	72	170	23.1	
31	25	21	f	64	136	23.3	
32	26	20	m	70	176	25.3	
33	27	20	f	70	165	23.7	
34	28	21	f	67	170	26.6	
35	29	26	m	72	170	23.1	
36	30	27	m	73	165	21.8	
37	31	69	m	70.5	156	22.1	5pm
38	32	60	f	62	170	31.1	
39	33	70	m	70	198	28.4	
40	34	74	f	63	145	25.7	
41	35	32	m	59	160	32.3	
42	**Averages:**	**27.8**	**21 m/14 f**	**67.4**	**159.8**	**5 "obese"**	
43		22.2667					

Temperature Survey—Device Readings & Offset Calculation

Table 35 Device Readings & offset calculation

	A	B	C	D	E	F	G	H	I	J
1		Note: temperatures greater than 38 C (101.4) are a fever							Zero Adj=	0.00
2									**current offset=**	**3.00**
3		Normal ranges between 35C (95 F) to less than 38 C (101.4 F)							gradient adj=	0
4									**New Offset =**	**3.70**
5	Temperature Readings				Thermowand SST			Average		
6	Temdot F	TempaDot	CVS oral	Proxmity	Close-up	36"	roll-off	Commer'l	-Close-up	Revised Oral
7	98.8	37.11	36.8	36.5	35.01	30.97	4.04	36.80	1.79	34.67
8	98.8	37.11	36.8	36.8	35.25	31.91	3.34	36.90	1.65	35.61
9	98.8	37.11	36	36.8	35.77	33.29	2.48	36.64	0.87	36.99
10	97.8	36.56	36.4	36.5	34.41	32.45	1.96	36.49	2.08	36.15
11	98.8	37.11	36.3	36.7	34.83	33.33	1.5	36.70	1.87	37.03
12	98.6	37.00	36.8	36.7	35.27	33.37	1.9	36.83	1.56	37.07
13	97.8	36.56	36.7	36.6	35.53	32.97	2.56	36.62	1.09	36.67
14	96.8	36.00	36.7	36.9	35.9	32.53	3.37	36.53	0.63	36.23
15	96.8	36.00	36.7	36.6	35.09	33.13	1.96	36.43	1.34	36.83
16	97.6	36.44	36.1	36.7	35.43	33.43	2	36.41	0.98	37.13
17	99.8	37.67	37.4	37	36.37	33.77	2.6	37.36	0.99	37.47
18	97.8	36.56	36.2	36.5	34.95	33.17	1.78	36.42	1.47	36.87
19	98.8	37.11	36.6	36.7	35.49	33.81	1.68	36.80	1.31	37.51
20	98	36.67	37	36.8	34.93	32.09	2.84	36.82	1.89	35.79
21	97.8	36.56	37.1	36.7	35.35	33.05	2.3	36.79	1.44	36.75
22	97.4	36.33	36.8	36.8	35.29	32.83	2.46	36.64	1.35	36.53
23	97.8	36.56	36.4	36.9	35.51	32.45	3.06	36.62	1.11	36.15
24	98	36.67	37	36.8	35.43	33.37	2.06	36.82	1.39	37.07
25	98.8	37.11	36.7	36.8	35.51	33.37	2.14	36.87	1.36	37.07
26	98.4	36.89	36.2	36.8	35.73	32.47	3.26	36.63	0.90	36.17
27	96.8	36.00	37	36.7	35.13	33.03	2.1	36.57	1.44	36.73
28	96.4	35.78	36.5	36.7	35.25	32.37	2.88	36.33	1.08	36.07
29	96.6	35.89	36.4	36.9	36.11	32.77	3.34	36.40	0.29	36.47
30	98.8	37.11	37	37	36.11	33.49	2.62	37.04	0.93	37.19
31	99.2	37.33	37	36.7	35.23	32.25	2.98	37.01	1.78	35.95
32	98.8	37.11	36.8	36.6	34.85	32.81	2.04	36.84	1.99	36.51
33	98.8	37.11	36.9	36.6	35.39	33.29	2.1	36.87	1.48	36.99
34	97.8	36.56	36.8	36.7	35.05	32.55	2.5	36.69	1.64	36.25
35	96.8	36.00	36.4	36.9	35.97	33.79	2.18	36.43	0.46	37.49
36	98.8	37.11	37.1	37	36.09	33.19	2.9	37.07	0.98	36.89
37	97.8	36.56	36.5	36.5	34.45	32.59	1.86	36.52	2.07	36.29
38	98.4	36.89	36.2	36.6	35.55	33.87	1.68	36.56	1.01	37.57
39	98.8	37.11	36.8	36.7	35.93	33.13	2.8	36.87	0.94	36.83
40	96.2	35.67	36.4	36.5	35.01	33.37	1.64	36.19	1.18	37.07
41	99.2	37.33	37	37	35.63	33.69	1.94	37.11	1.48	37.39
42	**98.1**	**36.70**	**36.7**	**36.7**	**35.39**	**32.97**	2.37676	**36.70**	**1.31**	**36.67**
43							2.42429			

Emissivity Survey—Volunteer information

Personal datum					Fitzpatrick		F
ID	Age	Sex	Height	Weight	skin-tone	Photo ?	p
1	25	M	71	160	4 or 5	Yes	
2	20	M	67	175	1	Yes	
3	19	F	67	190	5	Yes	
4	21	M	71	165	1	Yes	
5	19	F	63	100	4	Yes	
6	19	M	64	112	2	No	
7	21	M	67	210	5	Yes	
8	20	M	67	114	4 or 5	Yes	
9	22	F	62	150	4	No	
10	21	M	69	185	4	Yes	
11	24	F	64	127	4	Yes	
12	18	M	67	160	6	Yes	
13	36	M	72	230	6	No	
14	19	F	65	175	1	Yes	
15	33	M	70	155	2	Yes	
16	27	M	70	150	4	Yes	
17	19	M	59	170	2	Yes	
18	20	F	65	125	2	Yes	
19	21	M	70	150	3	Yes	
20	19	M	71	200	5	Yes	
21	20	M	73	285	1	Yes	
22	19	F	62	94	4	Yes	
23	22	M	67	165	1 or 2	Yes	
24	22	M	72	160	2	Yes	
25	19	M	66	152	4	Yes	
26	20	F	67	130	2	Yes	
27	25	M	65	180	4	Yes	
28	19	F	62	112	3	Yes	
29	19	F	57	110	4	Yes	
30	20	F	65	115	4	Yes	

Emissivity Survey—Data Collected

subject #	CVS temp	emiss used	SST	Adjusted	subject #	CVS temp	emiss used	SST	Adjusted
21	36.3	1.000	30.56	34.26	14	36.7	0.990	33.58	37.66
21	36.3	0.973	32.2	36.88	14	36.7	0.999	33.46	37.21
22	36.3	0.972	31.02	35.69	17	36.7	0.957	33.24	38.53
22	36.3	0.989	31.66	35.75	17	36.7	0.981	33.44	37.83
22	36.3	1.000	31.44	35.16	17	36.7	0.988	33.24	37.38
22	36.3	0.975	31.32	35.91	17	36.7	0.933	34.08	38.06
22	36.3	0.967	31.68	36.56	18	36.7	0.967	33.94	38.89
4	36.4	0.975	33.54	38.16	18	36.7	0.969	33.7	38.55
4	36.4	0.984	33.72	38.02	18	36.7	0.982	33.44	37.8
4	36.4	0.976	34.16	38.78	18	36.7	0.998	34.02	37.8
4	36.4	0.985	33.7	37.95	24	36.7	0.975	32.56	37.15
4	36.4	0.991	33.86	37.91	24	36.7	0.973	32.1	36.77
7	36.4	0.975	33.12	37.74	24	36.7	0.980	32.82	37.24
7	36.4	0.975	33.06	37.67	24	36.7	0.974	32.4	37.05
7	36.4	0.971	33.44	38.21	24	36.7	0.966	32.62	37.56
7	36.4	0.958	32.92	38.17	24	36.7	0.959	32.68	37.86
27	36.4	1.000	32.84	36.54	24	36.7	0.975	32.58	37.18
1	36.5	0.963	32.68	37.71	24	36.7	0.980	32.64	37.05
2	36.5	0.927	32.58	38.94	24	36.7	0.989	32.74	36.84
2	36.5	0.951	32.62	38.11	24	36.7	0.997	32.78	36.6
2	36.5	0.966	29.46	34.27	24	36.7	0.992	32.42	36.4
2	36.5	0.970	32.64	37.44	25	36.7	0.993	33	36.95
2	36.5	0.974	32.8	37.44	25	36.7	0.989	33.06	37.18
2	36.5	0.981	32.46	36.84	25	36.7	0.999	33.06	36.8
3	36.5	0.989	33.48	37.6	25	36.7	0.990	32.64	36.71
3	36.5	0.985	33.32	37.58	29	36.8	1.000	33.12	36.82
3	36.5	0.994	32.88	36.81	30	36.8	1.000	29.16	32.88
5	36.5	0.987	32.98	37.17	30	36.8	0.999	32.04	35.77
10	36.5	0.985	32.76	37	30	36.8	0.990	31.94	36
12	36.5	1.000	32.86	36.56	30	36.8	0.995	31.54	35.42
12	36.5	0.999	32.94	36.69	30	36.8	0.976	32.9	37.47
11	36.6	0.967	33.96	38.9	30	36.8	0.980	32.14	36.57
11	36.6	0.985	34.04	38.32	30	36.8	0.978	31.3	35.77
11	36.6	0.994	34.04	37.95	30	36.8	0.978	32.38	36.87
11	36.6	1.000	33.68	37.38	17	36.9	0.998	33.48	37.24
11	36.6	1.000	33.16	36.86	17	36.9	0.998	33.04	37.82
15	36.6	0.977	32.56	37.11	26	36.9	0.960	32.96	38.12
15	36.6	0.982	32.64	36.98	26	36.9	0.979	33.14	37.63
16	36.6	0.977	32.56	37.1	26	36.9	0.973	32.9	37.59
16	36.6	0.980	32.54	36.98	26	36.9	0.967	32.9	37.82
19	36.6	0.977	32.38	36.91	26	36.9	0.959	33.36	38.6
20	36.6	0.968	32.64	37.52	26	36.9	0.978	32.98	37.5
20	36.6	0.987	31.94	36.11	26	36.9	0.984	32.8	37.09
20	36.6	0.987	31.8	35.95	26	36.9	0.991	32.36	36.39
20	36.6	0.982	31.68	36.01	26	36.9	0.987	33.62	37.79
20	36.6	0.980	29.42	33.79	26	36.9	0.993	32.52	36.46
20	36.6	0.986	31.9	36.08	26	36.9	0.994	32.64	36.57
20	36.6	0.997	32.4	36.2	26	36.9	0.990	33.24	37.3
20	36.6	1.000	32.26	35.96	26	36.9	0.991	33.14	37.16
20	36.6	1.000	31.8	35.51	26	36.9	0.994	33.26	37.17
20	36.6	1.000	32.04	35.75	26	36.9	0.992	31.28	35.25
23	36.6	0.960	31.66	36.78	26	36.9	0.992	33.5	37.5
23	36.6	0.970	32.04	36.83	28	37	0.999	32.96	36.71
23	36.6	0.973	31.72	36.35	28	37	0.990	32.2	37.27
6	36.7	0.987	32.92	37.11	28	37	0.993	32.62	36.59
8	36.7	0.960	32.6	37.74	28	37	0.986	31.08	35.26
8	36.7	0.949	32.18	37.7	28	37	0.979	33.06	37.55
8	36.7	0.940	32.46	38.33	28	37	0.969	32.96	37.79
8	36.7	0.984	33.9	38.22	28	37	0.976	33.08	37.67
8	36.7	0.983	31.2	35.48	28	37	0.981	32.82	37.2
9	36.7	0.983	33.64	37.96	28	37	0.984	33.26	37.56
9	36.7	0.995	33.28	37.16	28	37	0.989	32.34	36.42
13	36.7	0.999	33.26	36.99	28	37	0.986	33	37.23
					28	37	0.985	32.76	36.99

Ambient Temperature Readings

Two sample sessions were undertaken to detect ambient air temperature using the infrared sensor. In each sampling, the last reading is taken with the hand of the operator quickly passing thru the field of view of the sensor to verify that the sensor is taking valid readings and recording the temperatures seen. This also demonstrate the ability of the sensor to detect rapid changes of temperature.

In the first sampling, Table 36, the sensor is about 10 feet away from the air conditioner with the sensor pointed off into the room space with the air conditioning not blowing air into the room.

A second sampling, Table 37, is undertaken almost immediately at the same location pointing into the same direction only this time the air conditioning blower is on. Stirring of the air can be felt by the operator during this sampling session.

These two samples show what the ambient temperature is like when the sensor is taking readings with the air conditioner blower turned off and turned on.

In Table 36, the temperature varies 33.71 °C to 33.87 °C (92.68 °F to 92.97 °F). A difference was noticed in the ambient temperature of 0.16 °C (0.29 °F) due to the air movement.

In Table 37, the temperature varied from 33.61 °C to 33.73 °C (92.97 °F to 92.50 °F). A difference was noticed in the ambient temperature of 0.10 °C (0.47 °F) due to the air movement. Overall, there was a cooling trend in the room of approximately 0.10 °C when the air conditioning was blowing air.

The ambient air temperature is also a limiting factor for detecting human temperature. Here is how that can occur. As the infrared sensor moves further away from a calibrated heat source the lower the reading will be. At some distance from the source, the heat from the source has dissipated to a point where the heat source is in equilibrium with the ambient air. At this distance and beyond, the infrared temperature readings are essential ambient air temperature readings. The way to check if your readings are the subject's temperature readings and not the ambient air is to turn the sensor away from the subject slightly and take an ambient air temperature reading. If the ambient air temperature is at least a degree lower than the subject's temperature, then the subject's temperature reading is a valid reading. This can occur in offices and rooms that are heated to the extent that the room temperature approaches the lower cut-off for the normal human temperature 35 °C (95 °F). Since the ambient temperature can vary by location, date, and time, this information should be verified at the beginning of every infrared temperature measurement session.

A different ambient temperature is used in deriving the sensed reading. This is done within the body of the smart sensor by the process for detecting a reading. Suffice it to say that the ambient temperature within the smart sensor is different from the ambient temperature of the room the sensor is placed.

Table 36 Ambient air temperature air conditioning off

Tera Term Web 3.1 - COM3 VT

File Edit Setup Web Control Window Help

```
The ambient temperature is 33.71 C and 92.68 F

The ambient temperature is 33.77 C and 92.79 F

The ambient temperature is 33.73 C and 92.71 F

The ambient temperature is 33.77 C and 92.79 F

The ambient temperature is 33.73 C and 92.71 F

The ambient temperature is 33.75 C and 92.75 F

The ambient temperature is 33.77 C and 92.79 F

The ambient temperature is 33.77 C and 92.79 F

The ambient temperature is 33.75 C and 92.75 F

The ambient temperature is 33.75 C and 92.75 F

The ambient temperature is 33.77 C and 92.79 F

The ambient temperature is 33.81 C and 92.86 F

The ambient temperature is 33.85 C and 92.93 F

The ambient temperature is 33.77 C and 92.79 F

The ambient temperature is 33.81 C and 92.86 F

The ambient temperature is 33.87 C and 92.97 F

The ambient temperature is 33.85 C and 92.93 F

The ambient temperature is 41.89 C and 107.40 F
```

Table 37 Ambient air temperature air conditioning on

Tera Term Web 3.1 - COM3 VT

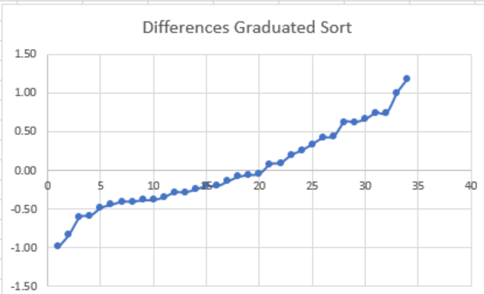
File Edit Setup Web Control Window Help

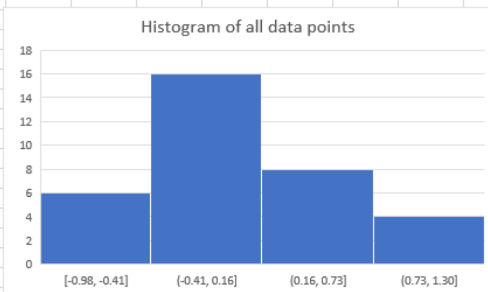
```
The ambient temperature is 33.73 C and 92.71 F

The ambient temperature is 33.67 C and 92.61 F

The ambient temperature is 33.69 C and 92.64 F

The ambient temperature is 33.65 C and 92.57 F

The ambient temperature is 33.67 C and 92.61 F

The ambient temperature is 33.67 C and 92.61 F

The ambient temperature is 33.71 C and 92.68 F

The ambient temperature is 33.67 C and 92.61 F

The ambient temperature is 33.67 C and 92.61 F

The ambient temperature is 33.67 C and 92.61 F

The ambient temperature is 33.61 C and 92.50 F

The ambient temperature is 33.65 C and 92.57 F

The ambient temperature is 33.73 C and 92.71 F

The ambient temperature is 33.63 C and 92.53 F

The ambient temperature is 33.67 C and 92.61 F

The ambient temperature is 33.65 C and 92.57 F

The ambient temperature is 41.77 C and 107.19 F
```

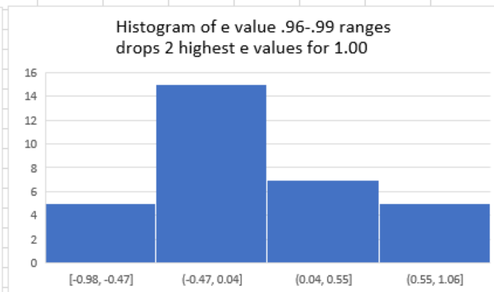
Spreadsheet Simulation of Automatic Emissivity Control

AR8 =IF(T8>37, 0,((T8/37.4))^(0.25))

	W	X	Y	Z	AA	AB
6	Proximity	ThermoWand		difference	sort differences	
7						
8	36.80	35.62		1.18	-0.98	
9	36.80	37.00		-0.20	-0.82	
10	36.50	36.16		0.34	-0.60	
11	36.70	37.04		-0.34	-0.58	
12	36.70	37.08		-0.38	-0.48	
13	36.60	36.68		-0.08	-0.44	
14	36.90	36.24		0.66	-0.40	
15	36.60	36.84		-0.24	-0.40	
16	36.70	37.14		-0.44	-0.38	
17	37.00	37.48		-0.48	-0.38	
18	36.50	36.88		-0.38	-0.34	
19	36.70	37.52		-0.82	-0.28	
20	36.80	35.80		1.00	-0.28	
21	36.70	36.76		-0.06	-0.24	
22	36.80	36.54		0.26	-0.20	
23	36.90	36.16		0.74	-0.20	
24	36.80	37.08		-0.28	-0.14	
25	36.80	37.08		-0.28	-0.08	
26	36.80	36.18		0.62	-0.06	
27	36.70	36.74		-0.04	-0.04	
28	36.70	36.08		0.62	0.08	
29	36.90	36.48		0.42	0.10	
30	37.00	37.20		-0.20	0.20	
31	36.70	35.96		0.74	0.26	
32	36.60	36.52		0.08	0.34	
33	36.60	37.00		-0.40	0.42	
34	36.70	36.26		0.44	0.44	
35	36.90	37.50		-0.60	0.62	
36	37.00	36.90		0.10	0.62	
37	36.50	36.30		0.20	0.66	
38	36.60	37.58		-0.98	0.74	
39	36.70	36.84		-0.14	0.74	
40	36.50	37.08		-0.58	1.00	
41	37.00	37.40		-0.40	1.18	
42		**36.74**	Average	0.00	=Sum of differences	
43		0.16232	Correlation			
44	of a sample (n-1) for reading fr			0.52526	Standard Deviation	
45	nterval for 95% for accuracy of			0.10047		







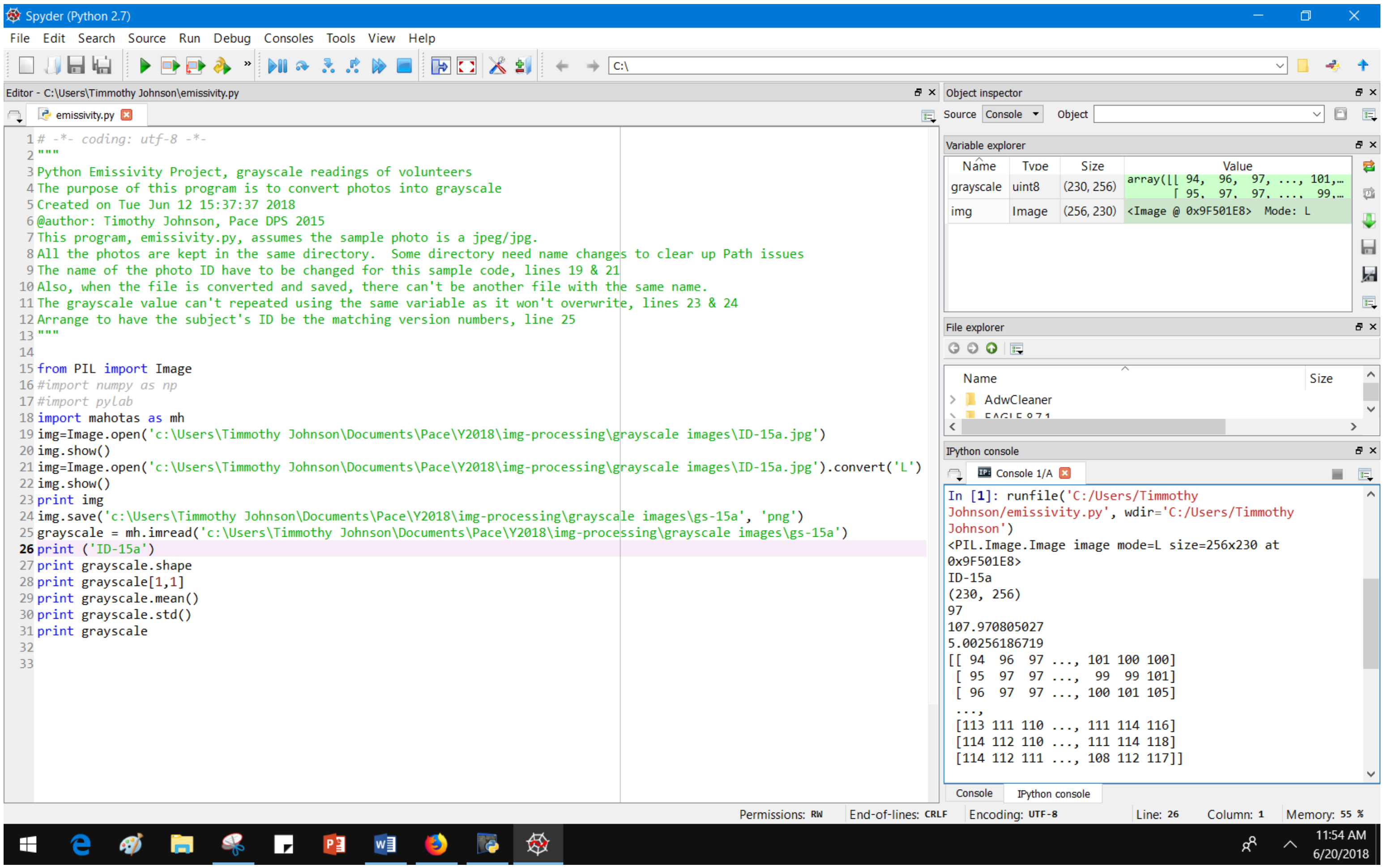
	AL	AM	AN	AO	AP
6	Compensation Table based on e of convenience				
7	T	e	lower lim	e^(1/4)	ΔT= T-Te¼
8	-100	0.96	-0.99	0.9898	-1.02
9	-75	0.97	-0.47	0.9924	-0.57
10	3	0.98	0.04	0.9949	0.0153
11	120	0.99	0.55	0.9975	0.3
12	1	1	1.06	0	1
15	Simulation of automatic emissivity control				
16	T	e	lower lim	e^(1/4)	ΔT= T-Te¼
17	35.5	0.96	-0.99	0.9898	0.3621
18	36	0.97	-0.47	0.9924	0.2736
19	36.5	0.98	0.04	0.9949	0.18615
20	37	0.99	0.55	0.9975	0.0925
21	37	1	1.06	0	0

	AR	AS	AT	AU
6	ΔT	Revised 36" with e		diff w/prox
7				
8	0.9879	36.61		0.18961
9	0	37.00		-0.2025
10	0.99162	37.15		-0.6541
11	0	37.04		-0.3425
12	0	37.08		-0.3825
13	0.99517	37.68		-1.0777
14	0.99217	37.23		-0.3347
15	0.99625	37.84		-1.2387
16	0	37.14		-0.4425
17	0	37.48		-0.4825
18	0.99652	37.88		-1.379
19	0	37.52		-0.8225
20	0.98915	36.79		0.00836
21	0.99571	37.76		-1.0582
22	0.99422	37.54		-0.7367
23	0.99162	37.15		-0.2541
24	0	37.08		-0.2825
25	0	37.08		-0.2825
26	0.99176	37.17		-0.3743
27	0.99558	37.74		-1.0381
28	0.99107	37.07		-0.3736
29	0.99381	37.48		-0.5763
30	0	37.20		-0.2025
31	0.99025	36.95		-0.2527
32	0.99408	37.52		-0.9166
33	0	37.00		-0.4025
34	0.99231	37.25		-0.5548
35	0	37.50		-0.6025
36	0.99666	37.90		-0.8991
37	0.99258	37.30		-0.7951
38	0	37.58		-0.9825
39	0.99625	37.84		-1.1387
40	0	37.08		-0.5825
41	0	37.40		-0.4025
42		37.3256	Averages	-0.5844
44		**0.32949**	**StanDev**	0.37047
45		0.06302	Excel's confidence interval for 95	

Notes on using the Spreadsheet Simulation of Automatic Emissivity Control

1. Temperature data is entered in columns W and X for the two different thermometers: CVS proximity and the experimental sensor called “Thermowand”.
2. Column Z uses a difference formula to develop the distance the two thermometers are “off” from each other.
3. Column AA sorts column Z’s data to provide an order to the differences
4. A line graph based on column AA data is produced automatically by Excel graph selection functions
5. A histogram graph based on Column AA data is produced by Excel graph selection functions
6. A VLOOKUP table titled, “Simulation of automatic emissivity control”, based on formulas from Table 8 is custom designed using upper/lower limits of the histogram to determine the rows average temperature seen (1st column of the VLOOKUP table). The columns of the histogram become the emissivity rows of the VLOOKUP table.
7. The emissivity to be used in a correction is put automatically in column AR
8. Values from column AR are used to calculate a corrected temperature value in column AS, “revised 36” with e”
9. The effect of emissivity inclusion with temperature is seen in the average value in cell AS42 and standard deviation in AS44.
10. Evaluation is based on the comparison between cells X42 and X44 (before) with AS42 and AS44 (after emissivity is included).

Screenshot of Spyder IDE for Python 2.7



Color Temperatures

Temperature	Source
1700 K	Match flame, low pressure sodium lamps (LPS/SOX)
1850 K	Candle flame, sunset/sunrise
2400 K	Standard incandescent lamps
2550 K	Soft white incandescent lamps
2700 K	"Soft white" compact fluorescent and LED lamps
3000 K	Warm white compact fluorescent and LED lamps
3200 K	Studio lamps, photofloods, etc.
3350 K	Studio "CP" light
5000 K	Horizon daylight
5000 K	Tubular fluorescent lamps or cool white/daylight compact fluorescent lamps (CFL)
5500 – 6000 K	Vertical daylight, electronic flash
6200 K	Xenon short-arc lamp[3]
6500 K	Daylight, overcast
6500 – 9500 K	LCD or CRT screen
15,000 – 27,000 K	Clear blue poleward sky
These temperatures are merely characteristic; there may be considerable variation	

Above source: https://en.wikipedia.org/wiki/Color_temperature

White points of standard illuminants[24][25][26]

Name	CIE 1931 2°		CIE 1964 10°		CCT (K)	Hue	RGB	Note
	x_2	y_2	x_{10}	y_{10}				
A	0.44757	0.40745	0.45117	0.40594	2856			Incandescent / Tungsten
B	0.34842	0.35161	0.34980	0.35270	4874			{obsolete} Direct sunlight at noon
C	0.31006	0.31616	0.31039	0.31905	6774			{obsolete} Average / North sky Daylight
D50	0.34567	0.35850	0.34773	0.35952	5003			Horizon Light. ICC profile PCS
D55	0.33242	0.34743	0.33411	0.34877	5503			Mid-morning / Mid-afternoon Daylight
D65	0.31271	0.32902	0.31382	0.33100	6504			Noon Daylight: Television, sRGB color space
D75	0.29902	0.31485	0.29968	0.31740	7504			North sky Daylight
E	1/3	1/3	1/3	1/3	5454			Equal energy
F1	0.31310	0.33727	0.31811	0.33559	6430			Daylight Fluorescent
F2	0.37208	0.37529	0.37925	0.36733	4230			Cool White Fluorescent
F3	0.40910	0.39430	0.41761	0.38324	3450			White Fluorescent
F4	0.44018	0.40329	0.44920	0.39074	2940			Warm White Fluorescent
F5	0.31379	0.34531	0.31975	0.34246	6350			Daylight Fluorescent
F6	0.37790	0.38835	0.38660	0.37847	4150			Lite White Fluorescent
F7	0.31292	0.32933	0.31569	0.32960	6500			D65 simulator, Daylight simulator
F8	0.34588	0.35875	0.34902	0.35939	5000			D50 simulator, Sylvania F40 Design 50
F9	0.37417	0.37281	0.37829	0.37045	4150			Cool White Deluxe Fluorescent
F10	0.34609	0.35986	0.35090	0.35444	5000			Philips TL85, Ultralume 50
F11	0.38052	0.37713	0.38541	0.37123	4000			Philips TL84, Ultralume 40
F12	0.43695	0.40441	0.44256	0.39717	3000			Philips TL83, Ultralume 30

Above source: https://en.wikipedia.org/wiki/Standard_illuminant

References

[1] Adafruit, *Raspberry Pi 3 Model B*. Online https://www.adafruit.com/product/3055. Accessed 8/14/2017.

[2] A. Ali, Manipulating Images with the Python Imaging Library, 9/15/2015. Online: https://www.sitepoint.com/manipulating-images-with-the-python-imaging-library/. Accessed 06/05/2018.

[3] S. Asadian, et al, *Accuracy and precision of four common peripheral temperature measurement methods in intensive care patients*, Medical Devices, 9, 301-308. Online www.ncbi .nlm.nih.gov/pmc/articles/PMC5012839. Accessed 3/12/2017.

[4] ASTM, *Standard Specification for Infrared Thermometers for Intermittent Determination of Patient Temperature*. Online https://www.astm.org/Standards/E1965.htm. Accessed 8/14/2017.

[5] M. Atesmen, *Everyday Heat Transfer Problems: Sensitivities to Governing Variable*, ASME Press, New York, NY 10016, USA, 2009.

[6] E. Buhr, S. Yoo, J. Takahashi, *Temperature as a Universal Resetting Cue for Mammalian Circadian Oscillators*, *Science*, 2010; 330 (6002): 379. Online: http://science.sciencemag.org/content/330/6002/379. Accessed 8/4/2017.

[7] CADTH (Canadian Agency for Drugs and Technologies in Health), Non-Contact Thermometers for Detecting Fever: A Review of Clinical Effectiveness, 2014. Online https://www.cadth.ca/non-contact-thermometers-detecting-fever-review-clinical-effectiveness. Accessed 5/1/2017.

[8] Chemguide: Helping you to understand Chemistry, *Beer-Lambert Law*. Online http://chemguide.co.uk/analysis/uvvisible/beerlambert.html. Accessed 8/5/2017.

[9] C. Chin, et al., *Remote temperature monitoring device using a multiple patient-coordinator set design approach*, ROBOMECH Journal (2015) 2:4, DOI 10.1186/s40648-015-0027-x, online: https://robomechjournal.springeropen.com/articles/10.1186/s40648-015-0027-x. Accessed 8/11/2017.

[10] A. Clark and others, Pillow>Handbook>Tutorial, online documentations. Online: https://pillow.readthedocs.io/en/5.1.x/index.html. Accessed 6/1/2018.

[11] J. Craig, G. Lancaster, S.Taylor, P. Williamson, R. Smyth, *Infrared ear thermometry compared with rectal thermometry in children: a systematic review*, Lancet 2002 Aug 24; pp603-9. Online: https://www.ncbi.nlm.nih.gov/pubmed/12241932. Accessed 4/28/2017.

[12] D. Crawford, N. Greene, S. Wentworth, *MHRA 04144 Thermometer Review: UK Market Survey 2005*, Clinical Engineering Device Assessment and Reporting, Cardiff Medicentre, University Hospital of Wales. Medicine and Healthcare, 2005.

[13] Delta T, *Infrared Basics*, Delta T technical papers. Online: http://www.deltat.com/pdf/Infrared%20Energy,%20Emissivity,%20Reflection%20%26%20Transmission.pdf. Accessed 8/11/2017.

[14] K. Dix, *The Elusive Enemy: Airborne Pathogens in Healthcare Facilities*, Infection Control Today: Clinical Update, Aug. 1, 2005. Online: http://www.infectioncontroltoday.com/articles/2005/08/infection-control-today-clinical-update.aspx#. Accessed 8/11/2017.

[15] S. Dodd, G. Lancaster, J. Craig, R. Smyth, P. Williamson, *In a systematic review, infrared ear thermometry for fever diagnosis in children finds poor sensitivity*, J Clin Epidemiol, 2006 Apr; 59(4);354-7. Online: https://www.ncbi.nlm.nih.gov/pubmed/ 16549256. Accessed 3/26/2017.

[16] Editors of Encyclopedia Britannica, *Diode*, Encyclopedia Britannica. Online: https://www.britannica.com/technology/diode. Accessed 8/5/2017.

[17] Explorable.com, *Statistical Correlation: Coefficient of Correlation*. Online: https://explorable.com/statistical-correlation. Accessed 7/30/2017.

[18] Farlex, The Free Dictionary, *Luma and Color difference Signals*. Online: https://encyclopedia2.thefreedictionary.com/YUV. Accessed 6/1/2018.

[19] Farlex, The Free Dictionary, *YUV/RGB conversion formula*. Online: https://encyclopedia2.thefreedictionary.com/YUV%2fRGB+conversion+formulas. Accessed 6/26/2018.

[20] Food and Drug Administration, *Product Classification*. Online: https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfpcd/classification.cfm?ID=2477. Accessed 8/14/2017.

[21] D. Fournet, et al., *A method for whole body human skin temperature mapping*, Academia.edu, Sept 6, 2012. Online: https://www.academia.edu/33521517/A_method_for_whole_body_human_skin_temperature_mapping. Accessed 8/11/2017.

[22] K. Giuliano, A. Giuliano, S. Scott, E. MacLachian, E. Pysznik, S. Elliot, D. Woytowicz, *Temperature measurement in critically ill adults: a comparison of tympanic and oral methods*. Am J Crit Care, 2000 Jul;9(4);254-261. Online: https://www.ncbi.nlm.nih.gov/pubmed/10888148. Accessed on 3/26/2017.

[23] C. Gordon, *2012 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics*. Technical Report NATICK/15-007. Natick MA: U.S. Army Natick Soldier Research, Development and Engineering Center. Online: https://en.wikipedia.org/wiki/Interpupillary_distance. Accessed 9/05/2017.

[24] D. Grosz, *What is a Thermopile?,* wiseGEEK. Online: http://www.wisegeek.org/what-is-a-thermopile.htm. Accessed 8/4/2017.

[25] P. Hanst, L. Hanst, T. Steven T. *Gas Measurement in the Fundamental Infrared Region*, "Air Monitoring by Spectroscopic Techniques", edited by Markus W. Sigrist. Chemical Analysis Series, Vol. 127. ISBN 0-147-55875-3. John Wiley & Sons. 1994.

[26] Hershel Infrared Website, *What is Infrared Heat?,* Online: https://www.herschel-infrared.com/how-it-works/what-is-infrared-heat/. Accessed 8/4/2017.

[27] Hyperphysics, *Stefan-Boltzmann Law*, Georgia Institute of Technology. Online: http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/stefan.html. Accessed 8/13/2017.

[28] S. Jefferies, M. Weatherall, P. Young, R. Beasley, *A systematic review of the accuracy of peripheral thermometry in estimating core temperatures among febrile critically ill patients*, Crit Care Resusc, 2011 Sept;12(3);194-9, PubMed US National Library of Medicine NIH. Online: https://www.ncbi.nlm.nih.gov/pubmed/21880009. Accessed 3/26/2017.

[29] R. Kaplan, T. Johnson, R. Schneider, S. Krishnan, *A Design for Low Cost and Scalable Non-Contact Fever Screening System*, 2011 ASEE Annual Conference & Exposition, Vancouver, Canada, June 25-29, 2011.

[30] N. Latman, P. Hans, L. Nicholson, K. Lewis, A. Shirey, *Evaluation of clinical thermometer for accuracy and reliability*, Biomed Instrum Technol 2001 Jul-Aug;35(4):259-65, PubMed US National Library of Medicine National Institutes of HealFFFth. Online https://www.ncbi.nlm.nih.gov/pubmed/11494651. Accessed 3/26/2017.

[31] H. Levitt, *Temperature measurement in paediatric*, Paediatric & Child Health, v.(5), p. 273-275, July-August 2000. Online: https://www.cps.ca/en/documents/position/temperature-measurement. Accessed 3/23/2018.

[32] Lumen Learning, *Radiation*. Online: https://courses.lumenlearning.com/physics/chapter/14-7-radiation/. Accessed: 8/4/2017.

[33] P Mackowiak, *A critical appraisal of 98.6 degrees F, the upper limit of the normal body temperature, and other legacies of Carl Reinhold August Wunerlich,* JAMA, 1992 Sep 23-30; 268(12): 1578-80. Online: https://www.ncbi.nlm.nih.gov/pubmed/1302471. Accessed 8/12/2017.

[34] Mayo Clinic Staff, *First Aid: Fever*, Mayo Clinic Patient Care and Health Info. Online: http://www.mayoclinic.org/first-aid/first-aid-fever/basics/art-20056685. Accessed 3/20/2017.

[35] Melexis, *Data Sheet MLX90614, Rev. 6*, Sept. 20, 2010. Online: www.melexis.com. Accessed 5/15/2017.

[36] Mbed, “mbed LPC1768”, 2018. Online: https://os.mbed.com/platforms/mbed-LPC1768/. Accessed 2/15/2018.

[37] L. Michalski, K. Eckersdorf, J. Kucharski, J. McGhee, *Chapter 1. Temperature Scales and Classification of Thermometers*, Figures 1-8, Temperature Measurement, 2nd Ed., Wiley Online Library, published 26 April 2002. Online: https://onlinelibrary.wiley.com/doi/10.1002/0470846135.ch1. Accessed 5/8/2017.

[38] M Montalto, F. Davies, N. Marijanovic, A. Meads, *Skin Surface temperature: a possible new outcome measure for skin and soft tissue infection*, Australian Family Physician, Sept. 2013, pp653-657. Online: http://www.racgp.org.au/afp/2013/september/skin-surface-temperature/. Accessed 8/4/2017.

[39] J. Odell, *Introduction to contact regulation thermography*, Biological Health Group formerly Eidam Diagnostics Corporation. Online: http://www.eidam.com/Products/Articles/Intro_CRT_Odell.pdf, 2010. Accessed 8/4/2017.

[40] Palmer-Wald website, Product Specifications. Online: http://www.palmerwahl.com/product_home.php?cat=26&catl=&line=504&itm=5941. Accessed 4/8/2017.

[41] S. Perkins, *Lab creates new, unexpected type of “firenadoes”*, Science News for Students, 9/6/2016. Online: https://www.sciencenewsforstudents.org/article/ lab-creates-new-unexpected-type-firenadoes. Accessed 4/27/2017.

[42] L. Piang. A. Ahmad, *Mathematical Modelling and Simulation of Heat Dispersion Due to Fire and Explosion*, Journal Teknologi, 37(F) Dis. 2001: 15-26, (Ed. note: formula 9). Online: http://eprints.utm.my/1442/1/JT37F%5B2%5D.pdf. Accessed 4/4/2017.

[43] Python Software Foundation. Online: https://pypi.org/. Accessed 6/20/2017.

[44] T. Roderick, *Understanding Emissivity—its only skin deep*, Think Thermally®Online, Winter, 2007. Online: https://www.thesnellgroup.com/storage/fck/File/thinkthermally/ThinkThermally_2007_Winter.pdf. Accessed in 2015.

[45] G. Roelofs, *PNG The Definitive Guide*, O’Reilly and Associates, Sebastopol, CA. 1999. Online: http://www.libpng.org/pub/png/book/chapter08.html#png.ch08.div.5.3. Accessed 5/10/2018.

[46] J. Rustemeyer, J; Radtke, A. Bremerich, *Thermography and thermoregulation of the face*, Head and Face Medicine 2007, 3:17. Online: http://www.head-face-med.com/content/3/1/17. Accessed 11/14/14.

[47] P. Raybaut, Spyder (the Scientific PYthon Development EnviRonment), 2009©. Online: https://www.spyder-ide.org/. Accessed 6/20/2018.

[48] M. Sircus, *Low Body Temperature Symptoms and Causes—And how to treat it*. Article published 1/21/2016. Online: http://drsircus.com/light-heat/low-body-temperature-symptoms-causes-treat/. Accessed 5/5/2017.

[49] J. Suzdaltsev, *Why Scientists Are Creating Fire Tornadoes*, online video D-News. Online: https://www.youtube.com/watch?v=1HsuhS2XdY4. Accessed 4/27/2017.

[50] Texas Instrument, *Simiconductor Manufacturering: How a Chip is Made*. Online http://www.ti.com/corp/docs/manufacturing/howchipmade.shtml. Accessed 8/5/2017.

[51] The Engineering Toolbox, *Units of Heat—BTU, Calorie, Joule*. Online: http://www.engineeringtoolbox.com/heat-units-d_664.html. Accessed 8/7/2017.

[52] N. Trefethen, *icalculator:Body Mass Index*. Online: www.icalculator.com. Accessed 5/3/2017.

[53] Virtual Amrita Labs, *Thermocouple—Seebeck Effect*, Amrita University. Online: http://vlab.amrita.edu/?sub=1&brch=194&sim=351&cnt=1. Accessed 8/5/2017.

[54] WebMD, *Fever: First aid*, Medical Reference from Healthwise, Inc. Online: http://www.webmd.com/first-aid/body-temperature. Accessed 3/20/2017.

[55] Wikipedia, 68—95—99.7 Rule, Online: https://en.wikipedia.org/wiki/68%E2%80%9395%E2%80%9399.7_rule. Accessed 7/29/2017.

[56] Wikipedia, *Beer-Lambert law*. Online: https://en.wikipedia.org/wiki/Beer_Lambert_law. Accessed 8/7/2017.

[57] Wikipedia, *Emissivity*. Online: https://en.wikipedia.org/wiki/Emissivity. Accessed 5/8/2017.

[58] Wikipedia, *Fitzpatrick Scale*. Online; https://en.wikipedia.org/wiki/Fitzpatrick_scale. Accessed 11/9/2017.

[59] Wikipedia, *Grayscale*. Online: https://en.wikipedia.org/wiki/Grayscale. Accessed 6/26/2018.

[60] Wikipedia, *Infrared*. Online: https://en.wikipedia.org/wiki/Infrared. Accessed 8/5/2017.

[61] Wikipedia, *Phonons: Acoustical and optical*. Online: https://en.wikipedia.org/wiki/Phonon#Acoustic_and_optical_phonons. Accessed 8/5/2017.

[62] Wikipedia, *Pyrometers*. Online: https://en.wikipedia.org/wiki/Pyrometers. Accessed 5/8/2017.

[63] Wikipedia, *Quantization: Rounding*. Online: https://en.wikipedia.org/wiki/Quantization_(signal_processing). Accessed 8/5/2017.

[64] Wikipedia, *Radiant flux*. Online https://en.wikipedia.org/wiki/Radiant_flux. Accessed 8/7/2017.

[65] Wikipedia, *Standard illuminant*. Online: https://enwikipedia.org/wiki/Standard_illuminant. Accessed 9/12/2017.

[66] Wikipedia, *Stefan-Boltzmann Law*. Online: https://en.wikipedia.org/wiki/Stefan%E2%80%93Boltzmann_law. Accessed 8/8/2017.

[67] Wilson Temperature Syndrome. Online: http://www.wilsonssyndrome.com/low-body-temperature/. Accessed 5/5/2017.

[68] L Wong, *Temperature of a Healthy Human (Body Temperature)*. Online: https://hypertestbook.com/facts/1997/LenaWong. Accessed 8/10/2017.

[69] R. Zhao, Geoffrey Vallis, *Parameterizing mesoscale eddies with residual and Eulerian schemes, and a comparison with eddy-permitting models,* Ocean Modelling 23 (2008) 1–12. Online: https://www.gfdl.noaa.gov/bibliography/related_files/rz0801.pdf. Accessed 4/24/2018.

[70] D. Zhu, T. Sifleet, T. Nunnally, Y. Huang, *Analog to Digital Converts*, Georgia Institute of Technology. Online: http://ume.gatech.edu/mechatronics_course/ADC_F08.pdf. Accessed 8/5/2017.