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Computational Clothing and Accessories

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1. INTRODUCTION

Wearable computers are fully functional, self-powered, self-contained computers that allow the user to access information anywhere and at any time (Mann, 1996; Mann, 1997a; Barfield and Baird, 1998; Bass, Kasabach, Martin, Siewiorek, Smailagic, and Stivoric, 1997). Until just recently,

FIG. 15.1. Wearable device from the late 1980s—a multimedia computer with a 0.6-inch CRT, invented and worn by Steve Mann (http://wearcomp.org/ieeecomputer/r2025.html).

wearable computers consisted of fairly obtrusive computer displays, CPUs, and input devices, worn on the user's body (Figure 15.1). However, due to advances in microelectronics, developments in networking, and growing interest from the public, designers of wearable computers are beginning to focus on the issue of making these systems look more like clothing and less like computers. For example, in the area of visual displays, a covert eyeglass-based display was built in 1995 (Mann, 1997a,b). Others later built an eyeglass-based display in 1997 (Spitzer, Rensing, McClelland, and Aquilino 1997) that was intended for eventual commercialization. Beginning in 1982, Eleveld and Mann began to experiment with the design of computers built directly into clothing, and the notion of flexible computational garments was developed (Mann, 1997a,b). Others have more recently experimented with the idea of flexible clothing based computing (Post and Orth, 1997).

To emphasize the attempt to integrate computing into clothing, we use the term "computational clothing" to refer to clothing that has the ability to process, store, retrieve, and send information. These capabilities will allow clothing and clothing accessories to function as standalone computers, to react to sensors in the environment, or to link to the

World Wide Web and other networked systems. Most importantly, computational clothing will allow users to access the functionality associated with modern computational devices while conforming to traditional fashion trends.

Networked clothing will represent an especially important development in personal information technology. Applications previously implemented with networked clothing include devices that serve the function of turning on the lights of a room and adjusting and controlling the heating and cooling in the room (Mann, 1997c). Future proposed applications also include performing medical tests on the wearer (Lind, Jayaraman, Rajamanickam, Eisler, and McKee, 1997). On the issue of collecting physiological data, the early work of Mann during the 1980s (Mann, 1997a,c) illustrates an attempt to integrate biosensors into wearcomps that detect the user's physiological state. The more recent work of Picard and Healey (1997) attempts to correlate physiological states with emotion. Most importantly, by actually embedding computer technology into clothing, people can have continual access to resources without the inconvenience and obtrusiveness of carrying computational devices around separately. Thus, clothing with computational capability will facilitate a form of human-computer interaction comprising small body-worn computers (e.g., user-programmable devices integrated into clothing) that are always on and always ready and accessible. The "always ready" capability of computational clothing will lead to a new form of synergy between human and computer, characterized by long-term adaptation through constancy of user interface (Mann, 1997a).

As noted, before the general public will accept computers as everyday apparel, the computers will need to behave like and feel like actual clothing. For this reason, it will be important for designers to consider information from a wide variety of sources when designing computational clothing. For example, information about textiles and fabrics, microelectronics, human interface design, networking, power sources, and cultural fashion trends will need to be considered when designing computational clothing. The purpose of this chapter is to present information from these diverse areas in the context of the design and use of computational clothing. The material presented in this chapter represents a starting point for those interested in designing clothing with computational capability—what we present is an overview of several related areas that impact the design of computational clothing. We expect significant advances to be made on this topic in the next five to ten years.

2. SYSTEM DESCRIPTION AND GENERAL CAPABILITIES

Many of the current research directions in the design and use of computational clothing can be traced to the early 1960s when Ivan Sutherland (1968) from MIT first developed a see-through display that allowed graphics to be superimposed over a real-world scene. In addition, the ideas associated with ubiquitous computing have also contributed to developments in computational clothing. What better way to access computing resources anywhere and at any time than to be wearing them on your body? In this regard, advances in microelectronics and wireless networking are making ubiquitous computing a reality. However, as noted previously, before the general public will be seen wearing a computer, components of the wearable computer (e.g., the CPU housing unit, input and output devices, etc.) will have to look far more like clothing or clothing accessories than the commercial wearable computer systems available now (Barfield and Baird, 1998).

As indicated by Mann (1997c), clothing with computational capability will consist of a computer that is subsumed into the personal space of the user, controlled by the user, and will have both operational and interactional constancy (i.e., will always be on and will always be accessible). Most notably, since computational clothing will be worn by the user as everyday apparel, the user will always be able to enter commands and execute a set of such entered commands, and the user will be able to do so while walking around or doing other activities. The issue of how to design computational clothing so as to both fit the user's apparel and to become an accepted component of the user's apparel is a current and challenging design problem (Figure 15.2).

The most salient aspect of computers, in general (whether computational clothing or not), is their reconfigurability and their generality (e.g., that their functions can be made to vary widely, depending on the instructions provided for program execution). With computational clothing, this is no exception; that is, the wearable computer clothing is more than just a wristwatch or regular eyeglasses. Computational clothing will have the full functionality of a computer system but, in addition, will also be inextricably intertwined with the wearer. This is what will set computational clothing apart from other wearable devices that are more in the area of computational (or digital) accessories, such as wristwatches, regular eyeglasses, wearable radios, etc. Important aspects of computational clothing will be discussed next in terms of basic modes of operation and fundamental attributes.

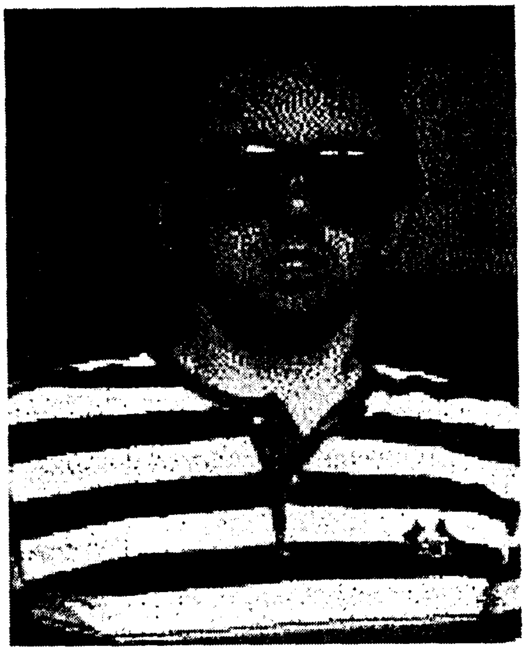


FIG. 15.2. A recent, nearly undetectable, prototype wearable computer consisting of eyeglasses, a handheld control, and a computer worn in back under the shirt, invented and worn by Steve Mann, http://wearcomp.org/ieeecomputer/r2025.htm.

- Photographic memory: When using a camera as a component of the system, the user will be able to experience perfect recall of previously collected information.
- Shared memory: In a collective sense, two or more individuals may share in their collective information of the other, so that one may have a recall of information that one need not have experienced personally.
- Connected collective intelligence: In a collective sense, two or more individuals may collaborate while one or more of them is doing another primary task.
- Personal safety: In contrast to a centralized surveillance network built into the architecture of the network, with computational clothing the surveillance will be built into the architecture (clothing) of the individual.
- Tetherless operation: Computational clothing will afford mobility, essentially the freedom from the need to be connected by wire to an electrical outlet or communications line.
- Synergy: The goal of clothing with computational capability is to produce a synergistic combination of human and machine, in which the human performs tasks that it is better at, while the computer

performs tasks that it is better at. Over an extended period of time, computational clothing will begin to function as an extension of the mind and body and will no longer be treated as if it is a seperate entity. This intimate and constant bonding is such that the combined capabilities of the resulting synergistic whole will exceed the sum of either. Mann (1998) calls synergy, in which the human being and computer become elements of each other's feedback loop, Humanistic Intelligence (HI).

In addition to the above points, there are three operational modes representing the interaction between human and computer associated with computational clothing:

1. Constancy: The computer aspect of computational clothing will run continuously and will always be ready to interact with the user. Unlike a hand-held device, laptop computer, or PDA, it does not need to be opened up and turned on prior to use.
2. Augmentation: Traditional computing paradigms are based on the notion that computing *is* the primary task. In contrast, with computational clothing, computing is *not* the primary task. The assumption behind a user wearing a computer as clothing is that the user will be doing something else at the same time as doing the computing. Thus the computer should serve to augment the human's intellect, or augment the senses.
3. Mediation: Unlike hand-held devices, laptop computers, and PDAs, computational clothing will encapsulate us. It doesn' t necessarily need to completely enclose us, but the concept allows for a greater degree of encapsulation than traditional portable computers. There are two aspects to this encapsulation:
   - 3a. Solitude: Clothing with computational capability can function as an information filter, allowing the user to block out material he/she might not wish to experience, whether it be offensive advertising or simply a desire to replace existing media with different media.
   - 3b. Privacy: Mediation allows us to block or modify information leaving our encapsulated space. In the same way that ordinary clothing prevents others from directly seeing our bodies, computational clothing may, for example, serve as an intermediary for interacting with untrusted systems.

The privacy aspects of computational clothing are especially interesting and germane to design. Although other technologies, such as desktop computers, can help us protect our privacy with programs such as Pretty Good Privacy (PGP), the Achilles heel of these systems is the space between us and them. It is generally far easier for an attacker to compromise the link between us and the computer (perhaps through a so-called Trojan horse or other planted virus) than it is to compromise the link between our computer and other computers. Thus computational clothing can be used to create a new level of personal privacy because it can be made much more personal (e.g., so that it is always worn, except perhaps during showering, and therefore less likely to fall prey to covert attacks upon the hardware itself). Moreover, the close synergy between the human and computers will make it harder to attack directly (e.g., as one might peek over a person's shoulder while they are typing, or hide a video camera in the ceiling above their keyboard). Furthermore, the wearable computer can take the form of undergarments that are encapsulated in an outer covering or outerwear of fine conductive fabric to protect from an attacker looking at radio frequency emissions. The actual communications between the wearer and other computers (and thus other people) can be done by way of outer garments, which contain conformal antennas, or the like, and convey an encrypted bitstream.

3. GENERAL CHARACTERISTICS OF CLOTHING

To better understand how to design clothing with the capabilities that we attribute to computer systems it is relevant to review the basic principles associated with clothing in general. Clothing is often referred to as a "portable environment" or as a "second skin". Furthermore, clothing has three different aspects, which include the physiological, social-psychological, and cultural. Each of these areas should be considered in the design of computational clothing.

Clothing specialists have delineated the main reasons why people wear clothing. These reasons include issues of protection, modesty+privacy, status, identification, and self-adornment and self-expression (Lyle and Brinkley, 1983). In terms of self- expression, witness the current computational devices that change color to reflect the user's mood. People also use clothing as a means to project status, role, and gender, as well as cultural differences. In our view, the fact that future clothing will be programmable will allow the user to change the "cultural" appearance of their clothing as a function of mood or situation.

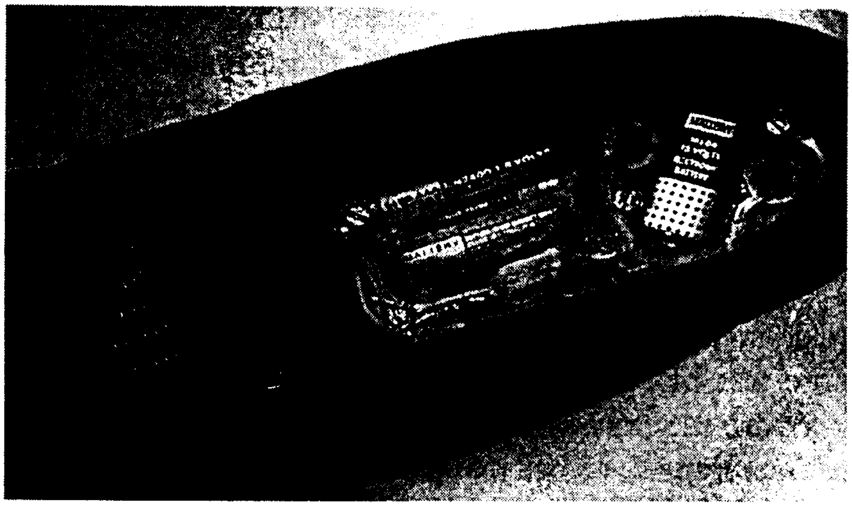


FIG. 15.3. The Eudaemon shoe (Bass, 1985)

It is also interesting to note that people use the term's "clothes" and "clothing" interchangeably. The term "clothing" has a broader and more comprehensive meaning than the term "clothes", which by itself indicates garments or apparels. The term "clothing" refers not only to clothes but also to the accessories that people place on their body. Noncloth items include hats, shoes, handbags, belts, watches, gloves, accessories, glasses, umbrellas, etc. Figure 15.3 shows an early example of a computer integrated into a traditional noncloth item, the shoe (Bass, 1985). This shoe (Eudaemon shoe) used a short-range inductive system to receive signals from a calculator operated by another person and a vibrotactile display as output to the foot. The application for the Eudaemon shoe was to predict the landing location of a roulette ball. Note that this shoe was not a general-purpose computer in the sense that the user could not change its functionality by writing a new program into it, while walking around. It was more like wearable technology than the wearable computing we know and use today, but it nevertheless serves as a good example of useful wearable technology. A more recent shoe with computational capability was developed by Paradiso and Hu (1997). The purpose of their "electronic shoe" was to transmit data about foot position through sensors that were designed to drive music synthesizers and computer graphics in real time. Their shoe is instrumented with pizoelectric pads that measure differential toe pressure and dynamic pressure at the heel, a bidirectional FSR strip that measures sole deflection, and a micromechanical accelerometer used to detect tilt (pitch) and foot velocity. Other sensors include an electronic compass to measure yaw and a magnetic vector sensor to measure bearing (from the Earth's magnetic field). Finally, Paradiso and Hu (1997) indicate that the translational position of the shoes can be measured by use of a scanning laser range finder or directly using sonar.

Even though various types of clothing can be differently classified according to the wearer's lifestyle or viewpoint, clothing is usually divided into four groups. These include business or dress clothing, casual clothing, sports or leisure clothing, and sleepwear or underwear (Erwin, Kinchen, and Peters, 1979). Dress items include suits, dress shirts, ties, jackets, slacks, shoes, and socks for men, and dresses, pants or skirts, blouses, and shoes for women. Casual jacket, T-shirts, slacks, sweaters, and casual shoes belong to the group of casual clothes. More or less, the casual items are unisexual and genderless in terms of style. Active sportswear, cold-weather jackets, pants, and resort wear belong to the sports or leisure clothing category. Pajamas, undershirt, corsets, etc. are examples of sleepwear and underwear. Protective garments for fire fighters, pesticide applicators, hockey players, the military, and surgeons have their own distinct functions. Protective garments are classified into four groups according to the following categories or characteristics of clothing: thermal, chemical, mechanical, and biological (McBriarity and Henry, 1992). In the area of protective clothing for the military, Lind, Jayaraman, Rajamanickam, Eisler, and McKee (1997) have developed a wearable motherboard or what they term "sensate liner" (Figure 15.4). The sensate liner is a form-fitting garment that consists of sensing devices containing a processor and transmitter. The sensate liner textile consists of a mesh of electronically and optically conductive fibers integrated into the normal structure of fibers and yarns used to generate the garment.

In order to discuss the requirements of clothing, it is necessary to discuss the serviceability of clothing. Serviceability is the measure of the clothing products' ability to meet consumer's needs. Serviceability concepts include: aesthetics, durability, comfort, care, safety, environmental impact, and cost (Hatch, 1993; Kadolph and Langford, 1998). Serviceability concepts for clothing will need to be considered when designing computational clothing. Aesthetics refers to the attractiveness or appearance of clothing. Aesthetic appeal is becoming a more important criterion for clothing than ever before (see Figures 15.18-15.23). In addition, color, texture, and luster of fabrics and even silhouette, style, and coordination of outfits are very critical factors in choosing garrnents. Finally, durability denotes how the product withstands use.

The meaning of comfort in relation to clothing is as follows: Generally, comfort can be defined as freedom of discomfort and pain. It is a neutral state. When comfort is discussed, the relationships among the type of

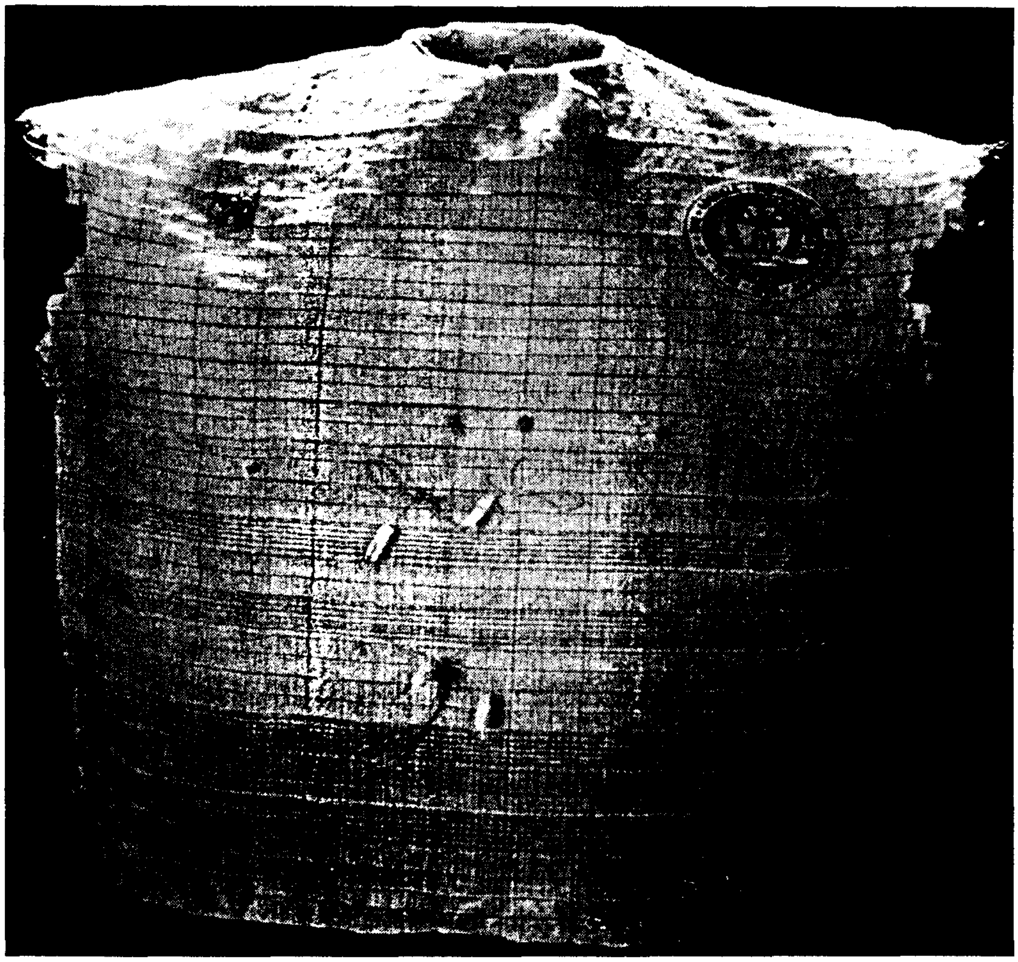


FIG. 15.4. Sensate liner developed by Lind, Jayaraman, Rajamanickam, Eisler, and McKee (I 997) at the Georgia Institute of Technology (http://vishwa.tfe.gatech.edu/gtwm/gtwm.html).

clothing, characteristics of the person, and characteristics of the environment have to be considered. Comfort can be divided into several components as follows: Comfort relates to the way in which clothing affects heat, moisture, and air transfer as well as the way in which the body interacts with clothing. This aspect of comfort is referred to as "thermophysiological comfort." In addition, comfort is related to the issue of how consumers actually feel when clothing comes into contact with the skin. This is referred to as "sensorial or neurophysiological comfort." Finally, "comfort" is related to the ability of clothing to allow freedom of movement, reduced burden, and body shaping as required. This is "body-movement comfort." One of the later sections of this chapter will focus on the issue of wearability as a function of body movement. Each of these aspects of comfort will be discussed in more detail below given their importance for the design of computational clothing.

Awareness of clothing usually leads to an expression of discomfort such as too hot, too cold, too cool, and too wet. In general, clothing is considered thermally comfortable when there is no need to take off or put on additional clothing and the fabric is not sensed as wet or humid. Thermophysiological comfort depends on the clothing microclimate developed between the body skin and inner layer of clothing. In order to be comfortable "thermophysiologically," the clothing microclimate should lie in the range of 35 ± 2 deg C temperature, $50 \pm 10\%$ relative humidity, and 25 ± 5 m/s air velocity. Attainment of a comfortable thermal and wetness state involves transport of heat and moisture through a fabric. Fabric has its own insulative ability, water vapor permeability, absorbency, wickability, and other properties related to thermal comfort. It is also interesting to note that some unpleasant sensations, such as prickliness, itchiness, inflammation, roughness, and warm and cool sensations, are produced when clothing irritates the sensory receptors and nerve endings in the skin. It is generally agreed that there are three categories of sensory nerves, that cover haptic sensations: the pain group, the touch group (pressure and vibration), and the thermal group (warmth and coolness). In the context of the haptic modality, static charged fabrics cling to the body, resulting in an uncomfortable feeling. Charged fabrics may lead to shocks when the wearer touches a metal object. These side effects are due to the electrical nature of the textiles and the skin.

People must be able to move around in the apparel items they wear. Discomfort may result when clothing restrains movement, creates a burden, or exerts pressure on the body-this aspect of clothing design is particularly relevant to computational clothing. Textile materials must be flexible and elastic. Also, when people move, their skin stretches and recovers, and so fabric must elongate to accommodate body movements and then must be able to recover. Generally, fabrics with less than 15% elongation values are referred to as rigid fabrics, and fabrics with more than 15% elongation are stretch fabrics. Tailored clothing requires 15 to 25% elongation, whereas sportswear requires about 20 to 35% elongation. Finally, active wear needs 35 to 50% elongation for comfort.

Garment weight also contributes to comfort and discomfort because it determines the burden the wearer must carry. Garment weight mainly depends on the amount of fiber in the garment and with computational clothing the added weight resulting from the devices worn on the body. For example, some commercial wearable computers can weigh between 5 and 9 kilograms and devices worn by soldiers can add another 66 kilograms of weight to the soldiers clothing. In this'context, the average weight of men's garments totals up to 3.8 kilograms and that of women's clothing about 2.3 kilograms. The weight of clothing may also result in pressure being applied to the skin. Clothing pressure depends on the garment design and fit and the stretchability of fabric. These variables determine the amount of pressure exerted on the body that results from clothing. Pressures of less than 60 grams per square meter exerted by clothing on the body are considered to be comfortable. Pressures of from 60 to 100 grams per square meter are considered uncomfortable and pressures over 100 grams are not tolerable. As another design consideration for computational clothing, the pressure exerted by clothing on the body becomes greater as the curvature of the body increases. In addition, safety, care, environmental impact, and cost are important factors for serviceability.

Clothing is made of textile fabrics, which are materials characterized as planar structures consisting of yarns or fibers. Using these materials, clothing is constructed into three-dimensional forms. Clothing is formed by cutting appropriately shaped pieces from fabrics and sewing them together. The major components of textile fabrics are fibers, yarns, fabrics, and colorants and chemicals. Fibers are tiny substances, which have a length at least 100 times its diameter. This large ratio between length and diameter enables fibers to be spun into yarns or made into fabrics. Many different types of fibers such as cotton, polyester, nylon, wool, silk, acrylics, olefin, and linen are used as sources of textile fabrics. Whether they are natural or man-made, fibers differ from each other in their chemical nature, in other words, in polymeric substance. For example, cotton consists of a polymeric substance that is a cellulose, whereas wool is a protein consisting of amino acids.

Yarns are continuous strands of textile fibers suitable for weaving, knitting, or intertwining to form textile fabrics. Fabrics have yarns interlaced at right angles, or interlooped horizontally or in zigzag form. Some fabrics do not have yarns and are made from some arrangement of fibers. These are so-called woven, knitted, and nonwoven fabrics. Fabrics are highly porous. Much of the thermophysiological comfort is provided by the porous structure of the fabric. Colorants and chemicals constitute a substantial portion of the finished and dyed textile fabrics. One or more chemicals are used to improve the fabric's properties. Colorants are used to modify the perceived color of fabrics or to impart color to colorless fabrics.

Apparel is made of patterned fabrics sewn together by thread. Appareal sometimes has inner and outer fabrics and at the same time, in the center of these two layers, an interfacing fabric. A variety of materials and techniques are employed in constructing well-made and functional closures.

These depend on the type and design of the garment, the fabric, and the location of the opening in the fabric. Closure utilizes a wide use of zippers. There are three ways to insert zippers: invisible applications, lapped applications, and centered applications. In addition to buttonshooks, fabric loops and velcro fasteners are easily used. Couture techniques such as stitch, knot, covered snap, covered cords, braided belt, tassels and fringes, and embroidery stitches are frequently chosen to enhance the garment and emphasize its beauty, individuality, and quality. Nylon was first produced by Carothers in 1935, and synthetic fibers such as polyester, polypropylenes, and acrylics were discovered during the 1950s. Now new materials of high functionality and high performance are designed and produced according to the nature of their utilization. Some of these materials are discussed in this chapter as possible fabrics suitable for computational clothing. The static charge of synthetic fabrics, due to their low water content, causes many problems, such as fabric cling, electric shock, and dust adsorption. It is therefore necessary to utilize electroconductive fabrics in the design of computational clothing. This is because electroconductive fabrics are good not only for the protection of the digital circuits but also for the safety of the wearer. Recent developments in the design of electroconductive fibers are to use carbon black as the core component and conjugate-spin as a nylon filament. The carbon black is used so that electroconductive static charges are not built up on the clothing surface. The specific resistivity of the fabric made of the conjugate spinning process using the carbon black is 10^3–10^5 $\Omega\cdot$cm, whereas the specific resistivity of ordinary nylon fabric is 10^{11}–10^{13} $\Omega\cdot$cm and that of cotton fabric is 10^8–10^9 $\Omega\cdot$cm, which means that for cotton fabric static is not a problem during daily wear.

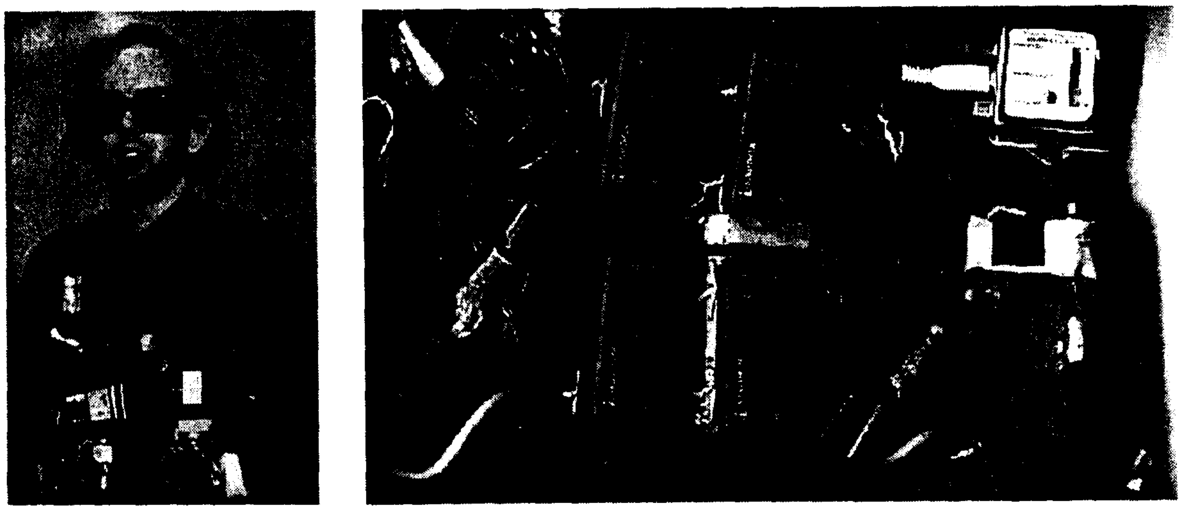
There are some fabrics that control the microclimate temperature automatically. If the wearer feels hot, the fabric absorbs the excess heat, and vice versa. This intelligent fabric is made possible by using some phase-change material as a finishing agent. Phase-change material absorbs and preserves the optical energy of the sun; it releases heat when the material is cooled, and it absorbs heat when the material is heated. Materials such as polyethylene glycol (PEG) and zirconium carbide compounds are typical phase-change materials. PEG was first adopted for use in fabrics and used for winter sportswear. Zirconium carbide was used in the form of particles in polyamide and polyester fibers. The particles are enclosed within the core of synthetic fibers. The garment made of this fiber absorbs solar visible radiation, which is released in the clothing. Furthermore, sweat absorbent fabric serves as a functional fabric for sportswear. To be comfortable and functional, the fabric used for sportswear needs to have the capability to absorb moisture and sweat. If athletes wear conventional clothing during sporting events, the effect is that they will feel hot and thus sweat sufficiently to result in wet garments. In this case the fabric will stick to their body, and behaviorally they will try to detach the "sticked fabric" from their body. Nowadays, sportswear is also used as leisure clothing, which considerably extends its scope. Sweat absorbed fabric consists of polyester fiber, which has a hollow center, and with a large number of micropores at the surface of the polyester fiber. The micropores on the surface are homogeneously distributed throughout the surface and some run through into the hollow part. Sweat is immediately absorbed through the pores and diffused into the hollow center; the result is that the fiber surface is kept dry. The hollow center acts like a reservoir for sweat.

4. COMPUTATIONAL CLOTHING DESIGN CHARACTERISTICS

Essentially, for clothing to have computational capability, digital circuits must be integrated into the clothing. There are many ways that circuits may be integrated into clothing. As an example, when polymers are extruded through spinnerets as hollow fiber, wires could be centered in the fiber. In addition, conjugate spinning can also utilize chips or wires as one or two components in the polymer solution. When yarns are manufactured, wrapped yams can be made such that the wires are the core part of the yarn and the ordinary polymer filaments are wrapped around the core part. Another method to integrate digital devices with clothing is to make metallic yam, for example, yams made of silver or gold. Computer chips and polymer solutions may be put together into sheet form and then split plotted into thin yam. This procedure offers a way to form metallic yarns of materials such as silver, gold, and aluminum. When weaving fabrics, wire itself can be core-spun or wrapped and can be used as warp yarns or filling yams in constant intervals. This process is similar to the electroconductive fabric process where carbon black yarns are used as warp and as filling yarns in some interval. In addition, wires can be used as embroidery yams onto conventional fabric surface. Moreover, other couture methods can be adopted as a possible way to include wires containing digital circuits or wireless networking. Computer chips can also be integrated into various forms of closures that exist now with clothing, such as zippers, hooks, or metallic buttons. According to the end-use, various types of clothing like underwear, sportswear, casual wear, or work clothes could be developed into wearable clothing. For formal wear, underlining fabric and interfacing are the possible targets for integrating digital circuits into clothing.

The issue of how to integrate computing capability into clothing has been investigated for over twenty years. Some of what has been learned in past efforts is relevant to current implementations of computational clothing. For example, the wearable signal processing apparatus of the 1970s and early 1980s was quite cumbersome, so an effort was directed by Steve Mann and other researchers toward not only reducing the size and weight but, more importantly, reducing the undesirable and somewhat obtrusive appearance. The designer discovered that the same apparatus could be made much more comfortable by bringing the components closer to the body, which had the effect of reducing both the torque felt bearing the load, as well as the moment of inertia felt in moving around. This effort resulted in version of a wearable computer invented by Steve Mann called the "Underwearable Computer" shown in Figure 15.5.

Typical embodiments of the underwearcomp shown in Figure 15.5 resemble an athletic undershirt (tank top) made of durable mesh fabric, upon which a lattice of webbing is sewn. This facilitates quick reconfiguration in the layout of components and rerouting cabling. Note that in this system, wire ties were not needed to fix cabling, as it was simply run through the webbing, which held it in place. All power and signal connections were standardized, so that devices could be installed or removed without the use



(a) (b)

FIG. 15.5. The "underwearable" signal processing hardware: (a) as worn by Steve Mann, (b) close-up showing webbing for routing of cabling.

of any tools (such as a soldering iron) by simply removing the garment and spreading it out on a flat surface. Some more recent related work by others (Lind, Jayaraman, Rajamanickam, Eisler, and McKee, 1997), also involves building circuits into clothing, in which a garment is constructed as a monitoring device to determine the location of a bullet entry (see Figure 15.4). Conductive materials have been used in certain kinds of drapery for many years for appearance and stiffness, rather than electrical functionality, but these materials can be used to make signal processing circuits, as depicted in Figure 15.6. Simple circuits like this suggest a future possible direction for research in the design of computational clothing.

(a) (b)

FIG. 15.6. some simple examples of cloth that has been rendered conductive. (a) Cords on early headsets, telephones. etc. often felt more like rope than wire. (b) A recent generation of conductive clothing made from bridged-conductor two-way (BC2) fabric. Although manufactured to address the growing concerns regarding exposure to electromagnetic radiation, such conductive fabric may be used to shield signal processing circuits from interference. Signal processing circuits worn underneath such garments were found to function much better due to this shielding. This outerwear functions as a Faraday cage for the underwearable computing. The notion that cloth be rendered conductive, through the addition of metallic fibers interwoven into it, is one thing that makes possible clothing that serves as an RF shield (Fig 15.5(b)), manufactured to address response to the growing fear of the health effects of long-term exposure to radio-frequency exposure. However, it may also be used to shield signal processing circuits from outside interference or as a ground plane for various forms of conformal antennas sewn into the clothing.

Another characteristic of computational clothing is that the clothing may be "smart." Smart clothing is inspired by the need for comfortable signal processing devices that can be worn for extended periods of time and can provide the wearer a level of intelligence to assist in performance of tasks. Smart clothing is made using either of the following two approaches: additive or subtractive. In the additive approach, the process begins with ordinary cloth by sewing fine wires or conductive threads into the clothing to achieve the desired current-carrying paths. In the subtractive approach, the process begins with conductive cloth, which is cut away in certain places, to leave behind the desired pattern, or with conductive cloth in which the conductors are insulated, and the insulation is removed in only certain locations. Smart clothing has been proposed as a form of existential media (Mann, 1997b) (Figure 15.7). Existential media defines new forms of social interaction through enhanced abilities for self-expression and self-actualization, as well as through self-determination. The aspects of existentialism pertaining to existential media are best understood through a reading of Frank1 (1994). Examples of smart clothing include internet-connected shoes that allow one to run with a jogging partner located in some distant place, but connected via the network. Viewpoints might also be shared using the "eye-to-eye" glasses (where a portion of each runner's visual field comes from the other runner (Mann, 1994)).

5. DESIGN FOR WEARABILITY

In the sections that follow, we present material that bridges the obtrusive wearable computers of the present with the fashionably integrated wearables of the future. The information in the following sections was developed based on a wearability study conducted by Interaction Designers at Carnegie Mellon University. The team's thesis is that despite visions of smart textiles and computational clothing in the future, there will still be a need for the solid forms of today's computers to be integrated comfortably with the human body.

Networked and computational clothing may be available in the near future because of our ability to place circuits into fibers and weaves. There are however going to be parts of wearable computers (power supplies for example) that are not going to be easily made of fabric. These parts will always be solid forms, but they need not be plastic bricks. To solve the problems of integrating solid and flexible three-dimensional forms with the human body, the design team at Carnegie Mellon University has developed

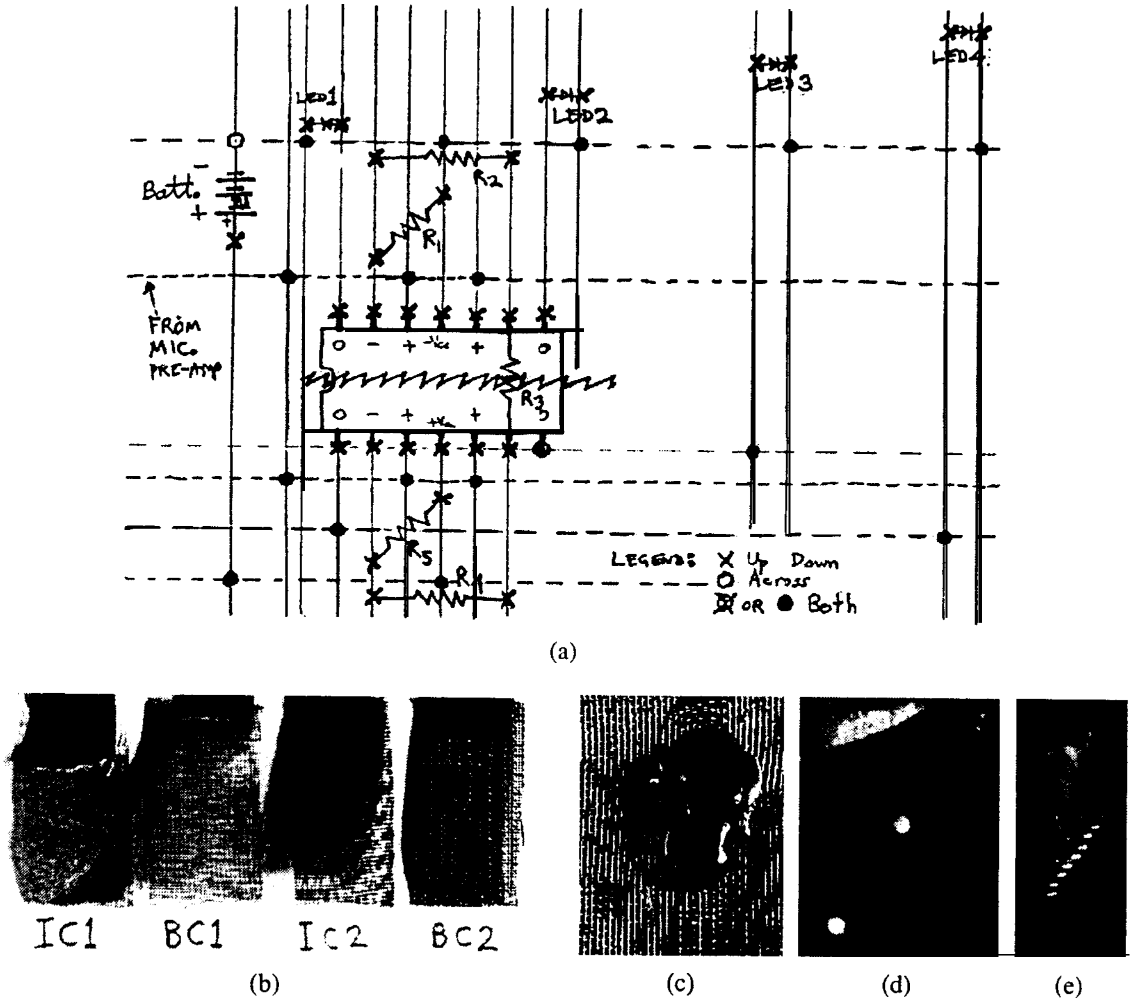


FIG. 15.7. Signal processing with "smart clothing". (a) Portion of a circuit diagram showing the new notation developed to denote four LED indicators and some comparators. The "X" and "O" notation borrows from the tradition of depicting arrows in and out of the page (e.g., "X" denotes connection to top layer, which is oriented in the up-down direction, while "0" denotes connection to bottom "across" layer). The 'sawtooth" denotes a cut line where enough of the fabric is removed so that the loose ends will not touch. Optional lines were drawn all the way from top to bottom (and dotted or hidden lines across) to make it easier to read the diagram. (b) Four kinds of conductive fabric. (c) Back of a recent article of smart clothing showing a solder joint strengthened with a blob of glue). Note the absence of wires leading to or from the glue blob, since the fabric itself carries the electrical current. (d) Three LEDs on type-BC1 fabric, bottom two lit, top one off. (e) A signal processing shirt with LEDs as its display medium. This apparatus was made to pulse to the beat of the wearer's heart as a personal status monitor, or to music, as an interactive fashion accessory.

"Design for Wearability." Design for Wearability is a tool that helps designers of wearable computers create forms that work well with any size adult human body. The basis for this tool is a set of design guidelines that describe how to make a wearable form.

5.1 Wearable Forms

In the following sections we present a set of three-dimensional forms for the human body that employ design guidelines for wearability. These forms outline the ideal envelope for dynamic wearability. The creation of these forms is based on an iterative process based on extensive field and laboratory experience designing wearable computers from CMU researchers. The general methodology was to make two-dimensional drawings and three-dimensional foam models and then to apply the models to human bodies. In addition, user studies were conducted for two purposes: (1) to better understand the complex curves of the body and (2) to verify that the developed forms were indeed wearable on the dynamic human form.

Each of the above thirteen guidelines listed in Table 15.1 is key to making a wearable computer into something that is really wearable. Given use of these guidleines, the user's comfort and freedom of movement are preserved. In the view of CMU researchers, wearable computing should be a positive and empowering experience, not one of discomfort or with cyborg connotations. The CMU team has employed the first six of those

TABLE 15.1
Guidelines for Wearability

1. Placement (where on the body it should go)
2. Form Language (defining the shape)
3. Human Movement (consider the dynamic structure)
4. Proxemics (human perception of space)
5. Sizing (for body size diversity)
6. Attachment (fixing forms to the body)
....
7. Containment (considering what' s inside the form)
8. Weight (as its spread across the human body)
9. Accessibility (physical access to the forms)
10. Sensory Interaction (for passive or active input)
11. Thermal (issues of heat next to the body)
12. Aesthetics (perceptual appropriateness)
13. Long-Term Use (effects on the body and mind)

guidelines and created a reference set of wearable forms to be used in the development of wearable computers. While all the above guidelines are important, we will only focus on the first six guidelines. The latter seven design guidelines are not easily generalizable since they are much more dependent on the context and constraints of a specific design problem.

Guideline 1 Design for dynamic wearability requires unobtrusive placement on the human body. Placement is determined by editing the extensive human surface area with the use of criteria. Criteria for placement can vary with the needs of functionality and accessibility; however, it is important to work within the appropriate areas (indicated below) for the dynamic human body. The criteria used for determining placement for dynamic wearability are:

- areas that are relatively the same size across adults,
- areas that have low movement/flexibility even when the body is in motion, and
- areas that are larger in surface area.

Applying these criteria results in the most unobtrusive locations for placement of wearable objects on the human body. These are depicted in Figure 15.8.

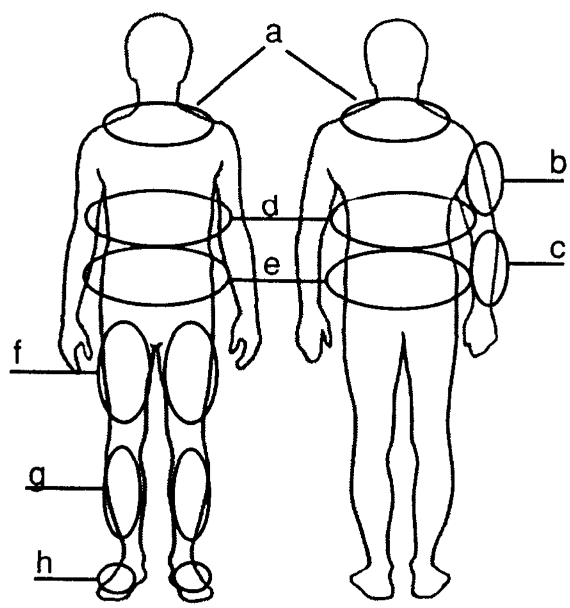


FIG. 15.8. The general areas found to be the most unobtrusive for wearable objects are: (a) collar area, (b) rear of the upper arm, (c) forearm, (cl) rear, side, and front ribcage, (e) waist and hips, (f) thigh, (g) shin, and (h) top of the foot (from Gemperle, Kasabach, Stivoric, Bauer, and Martin, 1998).

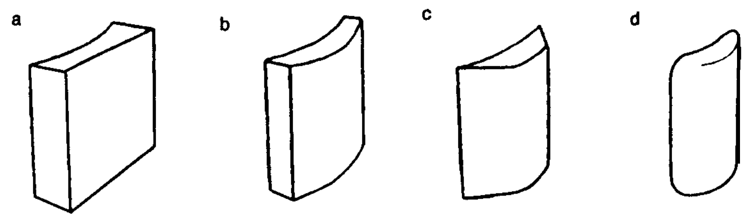


FIG. 15.9. Combining elements of concavity (a) against the body, convexity (b) on the outside surfaces of the form, tapering (c) as the form extends off the body, and (d) radii softening up the edges to create a humanistic form language (from Gemperle, Kasabach, Stivoric, Bauer, and Martin, 1998).

Guideline 2 Design for the human body also requires a humanistic form language. This works with the dynamic human form to ensure a comfortable, stable fit. Humanistic form language includes forrning a concavity on the inside surface touching the body, to accept human convexities. On the outside surface, convexity will deflect objects in the environment, thereby avoiding bumps and snags. Tapering of the form' s sides will stabilize the form on the body. Radiusing all edges and corners creates a safe, soft, and wearable form. These steps are illustrated in Figure 15.9, taking a simple block to a wearable form. The humanistic form language not only makes forms wearable, it adds structural ruggedness that is crucial in an active environment.

Guideline 3 Human movement provides both a constraint and a resource in the design of dynamic wearable forms. Human movement is useful in determining a profile or footprint for wearable forms, as well as to shape the surface of forms. Consider the many elements that make up any single movement. Elements include the mechanics of joints, the shifting of flesh, and the flexing and extending of muscle and tendons beneath the skin. The photographs in Figure 15.10 illustrate how much the form of the body changes with simple motion. Allowing freedom for these movements can be accomplished in one of two ways: by designing around the more active areas of the joints or by creating spaces on the wearable form into which the body can move. For example, the torso is a good place to put a wearable, but the arms need to have full freedom to swing around the side and front of the torso. In addition, the torso needs the full ability to twist and bend. These movements can help sculpt the surface of the form.

Guideline 4 Design for human perception of size. The brain perceives an aura around the body that should be considered when determining the distance a wearable form should project from the body. The

FIG. 15.10. Even through simple motions, our bodies change significantly (from Gemperle, Kasabach, Stivoric, Bauer, and Martin, 1998).

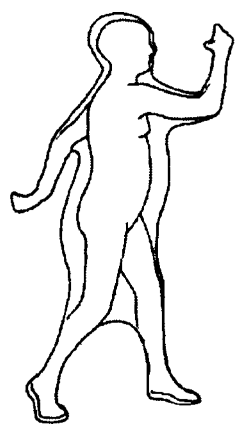


FIG. 15.11. Aura around the human body that the brain will perceive as part of the body (from Gemperle, Kasabach, Stivoric. Bauer, and Martin, 1998).

understanding of these layers of perception around the body is referred to as proxemics (Hall, 1982). Forms should stay within the wearer's intimate space, so that perceptually they become a part of the body. The intimate space is illustrated in Figure 15.11 and can be between 0 and 5 inches off the body. Compromises are often necessary but a general rule of thumb is to minimize thickness as much as possible. This increases safety and comfort, both physical and perceptual. A good example to observe is when a young American football player first dons shoulder pads and immediately starts bumping into people and door ways because of the extra bulk.

Guideline 5 Size variation provides an interesting challenge when designing wearable forms. Both the build of a body and the ways in which it will gain and lose weight and muscle are important. Wearables must be designed to fit as many types of users as possible. Allowing for these size variations is achieved in two ways. The first is the use of static anthropometric data, which detail point to point distances on different sized bodies (Tilley, 1993; McCormick and Sanders, 1982) (Figure 15.12). The second is consideration of human muscle and fat growth in three dimensions. Fitting these changing circumferences can be achieved through the use of solid rigid areas coupled with flexible areas. The flexible areas should either be located between solid forms as joints or extending from the solid forms as wings.

Guideline 6 Comfortable attachment of forms can be created by wrapping the form around the body, rather than using single point fastening systems such as clips or shoulder straps (Figure 15.13). As in guideline 5,

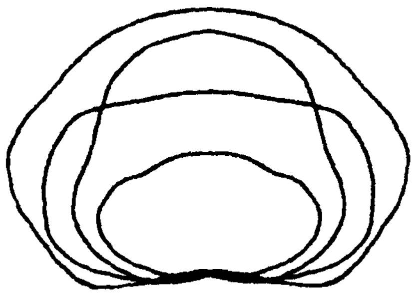


FIG. 15.12. Torso cross sections of various sized bodies show how sizes vary (from Gemperle, Kasabach, Stivoric, Bauer, and Martin, 1998).

FIG. 15.13. Single point attachment of a common pager or portable stereo is unstable and perceptually separate from the body (from Gemperle, Kasabach, Stivoric, Bauer, and Martin, 1998).

it is also important to have attachment systems that can accommodate various physical sizes. Design for stable, solid, and comfortable attachment draws on the clothing and outdoor equipment industries. Design for size variations in attachment systems can be obtained in two simple ways. The first is through adjustability (e.g., straps that can be extended as seen on backpacking equipment). The second is through the use of standardized sizing systems from the clothing industry.

Guideline 7 Designing wearable objects generally requires the object to contain materials such as digital technology, water, food, etc. While some of these things are malleable in form, there are many constraints that these "insides" bring to the outer form.

Guideline 8 The weight of a wearable should not hinder the body's movement or balance. The human body bears its own extra weight on the stomach, waist, and hip area. Placing the bulk of the load there, close to the center of gravity, and minimizing as it spreads to the extremities is the rule of thumb.

Guideline 9 For any wearable it is important to consider the sort of accessibility necessary to render the product most usable. Extensive research exists in the areas of visual, tactile, auditory, or kinesthetic access on the human body. Simple testing should be conducted to verify the accessibility of specific wearables.

Guideline 10 Sensory interaction, both passive and active, is a valuable aspect of any product. It is important to be sensitive to how one interacts with a wearable-something that exists on one's body. This interaction should be kept simple and intuitive.

Guideline 11 There are three thermal aspects of designing objects for the body: functional, biological, and perceptual. The body needs to breathe and is very sensitive to products that create, focus, or trap heat.

Guideline 12 An important aspect of the form and function of any wearable object is aesthetics. Culture and context will dictate shapes, materials, textures, and colors that perceptually fit the users and their environment (Craik, 1994). For example, CMU researchers created a wearable computer for an airplane repair situation, depicted in Figure 15.14. Using the heavy leather of the traditional tool belt, it is possible to increase the comfort and acceptance by the repair technicians.

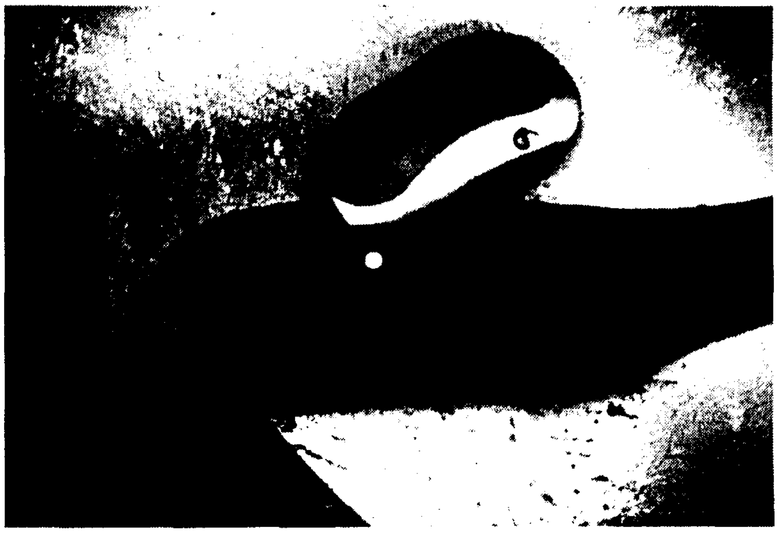


FIG. 15.14. Navigator 2 wearable computer for aircraft maintenance engineers integrates a humanistic form language with attachment guidelines, placement guidelines (small off the back), and aesthetic, perceptual, and sensory informed use of materials (from Gemperle, Kasabach, Stivoric, Bauer, and Martin, **1998).**

Guideline 13 The long-term use of wearable computers has an unknown physiological effect on the human body. As wearable systems become more and more useful and are used for longer periods of time, it will be important to test their effect on the wearer's body.

The Design Guidelines alone cannot convey all significant aspects of designing for wearability. They communicate a means to consider all the issues involved when creating wearable forms. The design guidelines for dynamic wearability as presented in conjunction with the development of a family of wearable forms is presented next.

5.2 Dynamic Wearable Forms

In the following material a set of three-dimensional forms for the human body that employ design guidelines for wearability are presented. These forms outline the ideal envelope for dynamic wearability. The first design object was to generate data defining the complex convex curves of the determined placement areas. The goal was to not only define but also to further understand those curves and how they changed with bodies of different sizes and shapes. For this goal, a set of tools were developed, depicted in Figure 15.15. With this flexible tool, the CMU team was able to map the arcs of several parts of the body-the collar area, triceps, forearm, ribcage, thigh, and shin-and to both compare and measure the arcs from

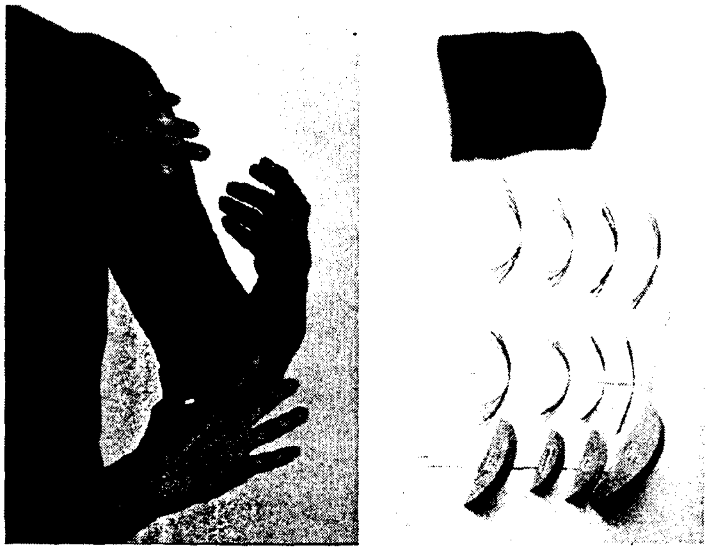


FIG. 15.15. A shapeable tool used to map the arc of the triceps. Different peoples arcs are then mapped together to create an average concavity and width dimension to apply to wearable designs (from Gemperle. Kasabach, Stivoric, Bauer, and Martin, 1998).

various bodies. This allowed the CMU team to determine an appropriate radius/spherical section for the concave inside of the forms, as well as the starting point and length of the flexible areas for each form.

In addition, a usability study was performed to test the comfort level and freedom of movement allowed by the forms that were designed. Thus far, ten people have tested the wearability of these forms. These test subjects were chosen to represent extreme diversity in body shape and size. The subjects were required to perform a series of simple activities, once in their regular clothing and once with the full set of wearable forms on their bodies, over their clothing. The activities included walking, carrying a box, bending, squatting to lift a box, reaching, climbing, and sitting. Subjects were also asked to rate their freedom of movement and comfort levels during each activity and for each area of their bodies. Each of the forms worn by the test subjects was developed by applying design guidelines as outlined previously. Beginning with placement in acceptable areas on the body and the humanistic form language, human movements in each individual area were considered. Each area was unique; thus some study of the muscle and bone structure was required along with common movement. Perception of size was also studied for each individual area. The general principles for size variations were applied and customized for each unique area. A preliminary data analysis indicated that levels of comfort and freedom of movement appeared nearly identical with or without the pods.

FIG. 15.16. Example of spandex pockets placed on the body for use with wearable computers (from Gemperle, Kasabach, Stivoric, Bauer, and Martin, 1998).

The attachment system designed for testing with the forms was minimal spandex that stretched around the body. Spandex pockets held each of the forms close to the body. The image below (Figure 15.16) depicts the attachment system on our model. One additional constraint in developing these pods was that they must be able to house electronic componentry. As a result, all of the forms were between 3/8″ and 1" thick and we anticipate that flexible circuits could fit comfortably into the 1/4″ thick flex zones.

Descriptions of each of the dynamic wearable forms with photos, charts, and maps of the body and the unique details of the individual areas are too extensive to list here. This chapter will detail the neck area to illustrate the work.

5.3 Dynamic Wearable Forms around the Neck

The three-dimensional forms that were developed are referred to as "pods." A group of pods strung together are "pod sets." Around the neck there is a pod set consisting of four pods. Two pods rest on the front of the body and two on the back. Each individual pod is made up of three parts: two thin solid forms with a flexible material sandwiched between them. The flexible material extends beyond the solid pod structure, serving as a flex zone. On the neck the flex zone creates a collar that encircles the neck and connects all four pods. The two pods on the front of the body sit just below the collar bone, on the pectoral muscle and above the breast.

The two pods on the back of the body sit on the large triangular muscle that connects the shoulders to the neck, the trapezius. Placement of four neck pods allows for all movement of the shoulders, arms, and head. The flex zone connecting these four pods flexes to accommodate the various different torso depths and chest and trapezius arcs. Pods on the chest follow the curves defined by the first and second ribs below the collar bone. The trapezius pods have a top profile determined by the curve where the neck meets the shoulders and a bottom profile determined by the movement space for the shoulder blades and the spine. These pods on the shoulder area are designed to move and float over the movement of the trapezes (shrugged shoulders). The pods on the chest extend 1/2 inch off the body and are 4 by 2 inches. The pods on the shoulder extend 3/4 inch off the body and are 2.3 by 3.4 inches. The neck and chest pods are contained in a collar that encircles the neck and holds them in place. These pods can also be attached by containing them in a minimal vest structure that supports pods on the rest of the torso (Figure 15.17.)

By making dynamic wearability constraints explicit, it is hoped that designers will treat wearability requirements as concretely as technological constraints and match them to users' functional requirements in the early

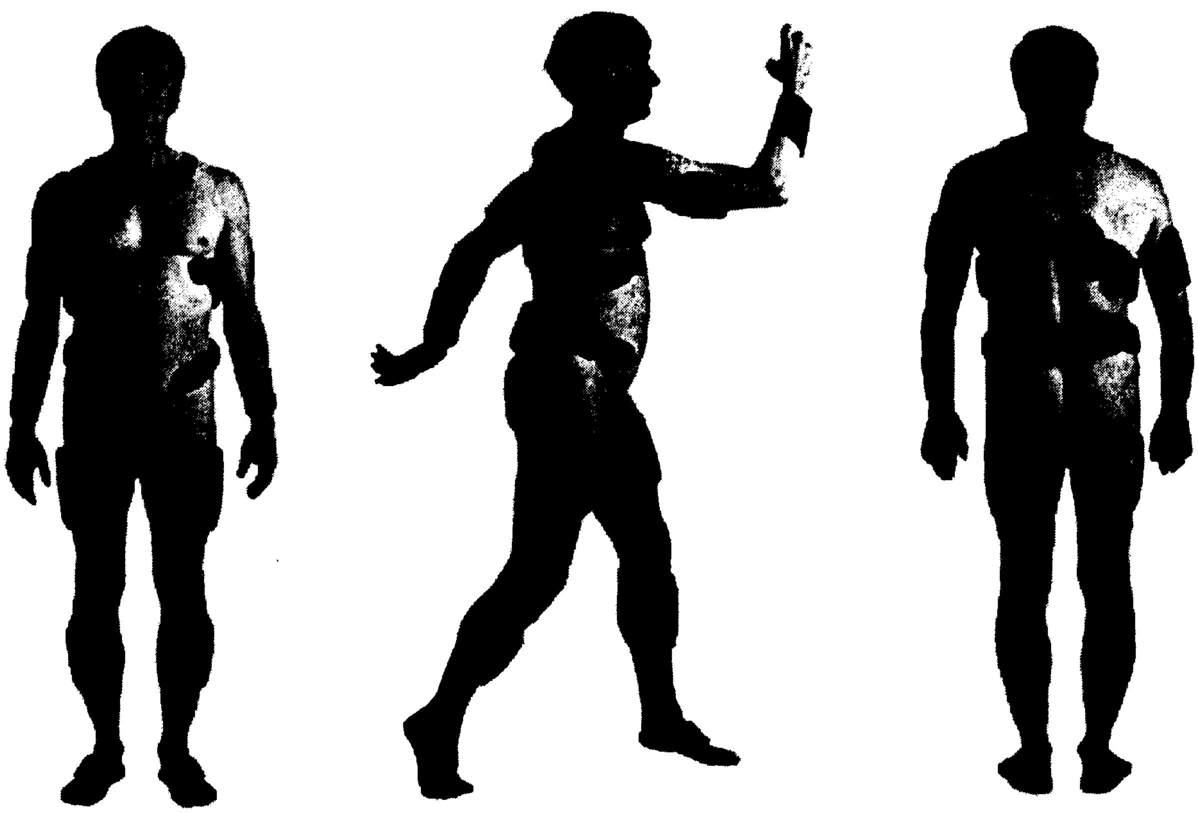


FIG. 15.17. Additional example of spandax pockets placed on the body for use with wearable computers (from Gemperle, Kasabach, Stivoric, Bauer, and Martin, 1998).

stages of the design process. The CMU team plans to extend this research to include accessibility for different activities, weight distribution, thermal concerns, interaction issues, material preferences, and long-term effects to the body while using these wearables. In summary, the following hold:

- Static, anthropometric data exist; however, dynamic understanding and measurements of the human body do not. The CMU team has collected information that has aided designers in development of wearable systems. This Design for Wearability Study discussed above represents a start at putting this information together, organized, in one place, to be useful as a set of guidelines and a resource for designers that need to integrate issues of wearability into a design.
- The design guidelines discussed in this section of the chapter illustrate steps to take into consideration when designing something to exist on the human body. This set of guidelines presents a method of thinking about and understanding a wearable and its' wearability.
- Wearable technology should not compromise but enhance people. It is possible to create a wearable piece of digital technology that feels good. Design for wearability and the wearable forms provide both proof and process for this.

6. CURRENT COMPUTATIONAL ACCESSORIES

In addition to the clothing that people wear every day, there are many types of fashion accessories that make people's outfits. Many of these accessories, such as watches, belts, and hats, are worn everyday as part of a person's outfit and are quite commonplace. Examples of these include miniature cellular phones worn as necklaces or pagers strapped to belts. The common trend in each of these types of fashion accessories is that not only are accessories being used today as fashion icons, but they are also being designed to serve a specific purpose. By embedding digital technology into these accessories, the metaphor for computational clothing is expanded into complete computational outfits. This not only expands the functionality of a person's computational apparel but also allows for an increased fashion sense and individuality that only accessories can create. When looking at computational accessory technology, it is helpful to partition the technology into three classifications since the devices in each of these categories are similar in design and purpose. The accessory categories for current technology include watches, personal communication devices, and personal aids.

6.1 Watches

Wristwatches are perhaps the most common fashion accessory for both men and women. They have been around for decades and were originally simple mechanical devices intended solely to indicate the time. However, as time passed and watches became more and more popular, they began to become fashion accessories as well. Currently Seiko has developed the 16-bit processor powered Ruputer Pro digital watch. This watch not only has all the features of common digital watches (time. data, stopwatch, and alarm), it also contains a full featured PDA and a game unit. The watch contains 2 megabytes of onboard flash memory, is Windows 95 linkable, and has all of the organizer functions of a Palm Pilot. In addition to this functionality, the Ruputer Pro will soon have infrared communication abilities with other Ruputers that would allow its users to play games. Another popular watch manufacturer, Swatch Telecom, is developing a digital watch that contains a cordless phone. Further in the future, Swatch is planning a version of the watch that not only tells time but will also function as a mobile cellular telephone. A similar venture by Timex and Motorola has yielded the Beepwear. This is a full-featured digital watch that also includes a full-featured pager. Users are able to receive complete text messages from both pages and voice mail. The watch alerts the user of new messages by either beeping or flashing. Finally, one of the most developed and sophisticated versions of the digital watch is the Casio Data Bank. This watch comes in a variety of styles and utilizes a touch screen interface. The touch screen not only displays the time and date but also has eight selectable icons that activate features such as a scheduler, which includes a calendar to remind the wearer of important dates, and a tele-memo, which stores 200 pages of names, phone numbers, addresses, appointments, and notes. The Casio Data Bank digital device also includes a business and executive mode that allow users to link companies to names and perform index searches of the data.

6.2 Personal Communications Devices

The second category of digital accessories consists of devices whose purpose is interpersonal communication. These devices include cellular phones, pagers, and mobile email devices, to name a few. While these devices are relatively new, compared to the digital watch, they are no less gaining widespread popularity as their costs decrease and their functionality increases. As these devices are becoming more lightweight and portable, more people are beginning to carry them as part of their everyday outfits. In some instances they are even beginning to wear these devices like fashion accessories. The most compelling example is that people are beginning to wear their cellular phones around their necks like necklaces. Designers of these technologies are aware of these trends and are starting to design their devices with this in mind, Their goals are to make these devices as common as everyday accessories.

Motorola, who has influenced the way people carry their cellular phones with their StarTAC line, has developed a new series of cellular phones that will be the smallest in the United States when they begin shipping. The new Motorola V series will weigh only 2.7 ounces and have up to 160 minutes of talk time. This device is only millimeters thicker than its actual battery and is able to be easily worn around the neck or clipped onto a belt. Also from Motorola is the Smart Pager SP1300. This device is the world's first electric organizer and pager to use a completely graphical user interface (GUI). The device consists of an all-touch-screen LCD control pad with 1 MB of onboard memory. It can also be hooked up to a PC to share and synchronize data. Another innovative personal communication device is the Accent developed by Phillips. This device attaches to a cellular phone and acts as an address book, email in-box, and fax machine. The device consists of a touch screen that allows all of these features to be accessed easily. The device also allows users to look up friends names and then automatically dial their numbers.

Finally, the most complete mobile personal communications system is the Kenwood RadCam. This device is the first walkie-talkie device to transmit not only sound but pictures. The RadCam is simply hooked up to a radio transmitter and the user can then send a live picture taken by the user to another person.

6.3 Personal Aids

The next category of devices can best be described as personal aids. They are also called personal digital assistants or PDAs. These are mobile devices that more and more people are starting to use and carry regularly. These devices are most often used as personal organizers, schedulers, notepads, and contact managers. There are a wide variety of these products on the market from a number of manufacturers. One example of such technology is the Cassiopeia E-10 from Casio. This small hand-held device performs all of the functions stated above plus has an optional modem for sending and receiving email and features voice recording. The E- 10 provides all this functionality in a lightweight 3" x 5" device that fits in the palm of your hand. It features a 4" backlit screen and can be controlled with one hand. These types of PDAs are generally controlled by touch screens, pens, or buttons, and many of them have full-blown operating systems or are at least compatible with Widows 95 systems for data sharing.

Another personal assistant type system is the Garmin StreetPilot. This portable device uses global positioning satellite (GPS) technology to give the user real-time position and map data from wherever they are. Users can use data cards with the device to pull up detailed street maps and directions to destinations they enter. The device also tells users where the location of the nearest businesses, attraction, shopping, or food stores are. With this device, users should never be lost in a new city or not know how to get to shopping or food services.

Another emerging technology that people will be carrying in the near future are Subscriber Identity Module (SIM) smartcards. These are credit card size modules that can be connected to a cellular phone that allow it to become essentially a network computer. The smartcards contain user information and storage for electronic commerce transactions. With e-commerce becoming more and more popular as Internet technology develops, these smartcards will allow users to purchase items from anywhere at anytime. The key issues in this emerging technology include electronic payment techniques, data compression, and optimization and encryption of transactions. With over 150 million estimated cellular phone users worldwide by the year 2000, this technology is expected to become a $300 billion industry by the year 2002 according to the U.S. Commerce Department.

Along similar lines, Akyman Financial Services (AFS) of Australia has developed the AFS-800 wireless electronic funds transfer terminal. This hand-held device is an Electronic Funds Transfer at Point of Sale (EFTPos) system that allows retailers to guarantee fund transfers from customer bank accounts to merchants. Traditionally these types of terminals were only available in stores as credit card/debit card readers. However, this new technology contains user credit and debit card information, payment authorization functions, and person-to-person or smartcard-to-computer links. This will allow users to pay vendors and other users electronically and from anywhere at anytime.

Finally, Audible has designed a hand-held portable device called the Mobile Player that is able to play audio from the Internet and listen to it anywhere. The Mobile Player weighs less than 3.5 ounces and is able to store up to 2 hours of spoken audio. It also comes with a docking system that allows the user to transfer audio through a PC serial port. The device works by the user downloading audio programs from Audible's web site. They can then playback their selections how and when they want. The system includes a one-touch bookmarking system, the ability to fast-forward, reverse, pause, and skip from program to program easily, prompts that let you know exactly where you are in each program, and a rechargeable battery.

The military is currently working on the development of the Personal Information Carrier (PIC) or digital dog tag. The PIC is a small electronic storage device containing medical information about the wearer. While old military dog tags contained only five lines of information, the digital tags may contain volumes of multimedia information including medical history, X rays, and cardiograms. Using hand-held devices in the field, medics would be able to call this information up in real time for better treatment. A fully functional transmittable device is still years off, but this technology once developed in the military, could be adapted to civilian users and provide any information, medical or otherwise, in a portable, nonobstructive, and fashionable way. Another future device that could increase safety and well being of its users is the nose-on-a-chip developed by the Oak Ridge National Lab in Tennessee. This tiny digital silicon chip about the size of a dime, is capable of "smelling" natural gas leaks in stoves, heaters, and other appliances. It can also detect dangerous levels of carbon monoxide. This device can also be configured to notify the fire department when a leak is detected. This nose chip, which should be commercially available within two years, is inexpensive, requires low power, and is very sensitive. Along with gas detection capabilities, this device may someday also be configured to detect smoke and other harmful gases. By embedding this chip into worker uniforms, name tags, etc., this could be a lifesaving computational accessory.

In addition to the future safety technology, soon to be available as accessories are devices that are for entertainment and security. The LCI computer group is developing a Smartpen that electronically verifies a user's signature. The increase in credit card use and the rise in forgeries, has brought with it the need for commercial industries to constantly verify signatures. This Smartpen writes like a normal pen but uses sensors to detect the motion of the pen as the user signs his or her name to authenticate the signature. This computational accessory should be available in 2000 and would bring increased peace of mind to consumers and vendors alike.

Finally, in the entertainment domain, Panasonic is creating the first portable hand- held DVD player. This device weighs less than 3 pounds and has a screen about 6" across. The color LCD has the same 16:9 aspect ratio of a cinema screen and supports a high resolution of 280,000 pixels and stereo sound. The player can play standard DVD movies and has a 2 hour battery life for mobile use.

7. COMPUTATIONAL ACCESSORIES IN THE FUTURE

In addition to the clothing that people wear every day, there are many types of fashion accessories that complete one's outfit. Many of these accessories, such as watches, belts, hats, and jewelry are quite commonplace. By embedding digital technology into these accessories, the metaphor for computational clothing is expanded into other realms of fashion and wearables. This not only expands the functionality of a person's computational apparel but also allows for an increased fashion sense and individuality that only accessories can create. When looking at future computational accessories it is helpful to separate them into classifications of functionality. The accessory classifications, for both current and future conceptual digital accessories, are personal communications, personal organization, personal entertainment, and personal body monitoring. Both current computational accessories and future concepts for computational accessories can be found in each of these classifications.

In the past fifty years designers have spent considerable time and energy speculating about what the future will hold, with particular interest in the future relationship between people and computers. Conceptualizing future computational accessories has become a booming industry that is driving the development of new mobile and wearable computers. Often the realm of designers and fine artists, conceptual computational accessories focus as much on functionality as they do on both fashion and human-computer interaction. Some exciting places to look for conceptual computational accessories include, for example, Philips Vision of the future ongoing project, the Industrial Designers Society of America, IDEA awards concept category, the LG electronics design competition, and various design schools and firms around the world.

In the context of computational accessories and wearables of the future, students at Carnegie Mellon University were recently asked to spend a semester developing concepts for future digital accessories-with style and attitude. Below is an outline of some of their projects.

- Snuggers (Figure 15.18), a concept created by Kat Cohen, is a wearable personal reminder designed expressly for preteens with that urge for independence.
- The Occhio concept (Figure 15.19), designed by Ignacio Filipino, is a fashionable virtual view monocle display.

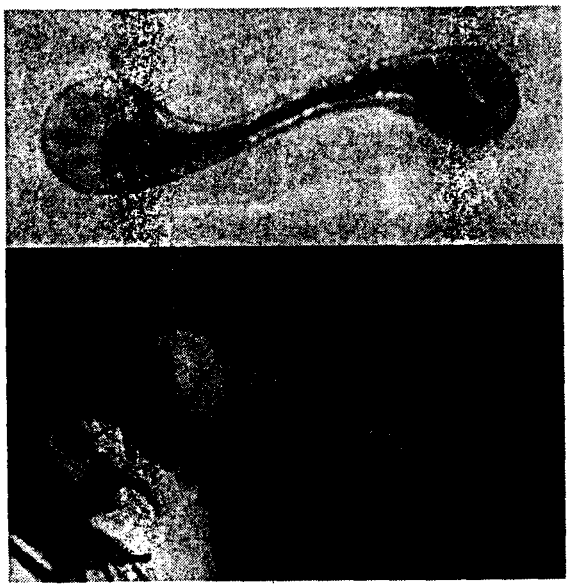


FIG. 15.18. "Snuggers" a wearable **device, by Kat Cohen, CMU.**

FIG. 15.19. "Occhio" wearable device, by Ignacio Filipino. CMU.

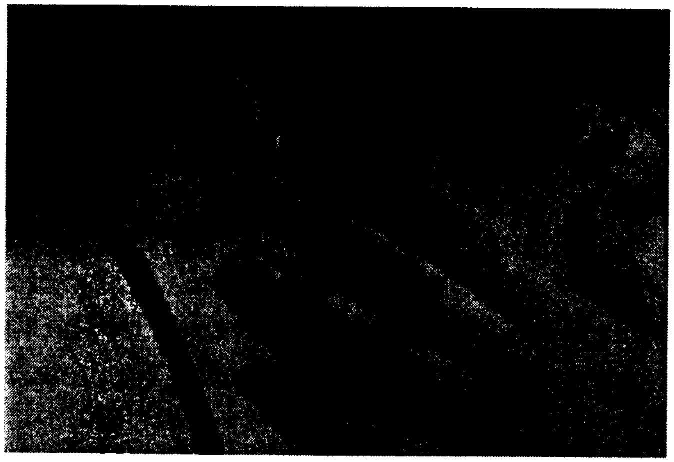


FIG. 15.20. "Kneph" wearable device, by Elizabeth Geuder, CMU.

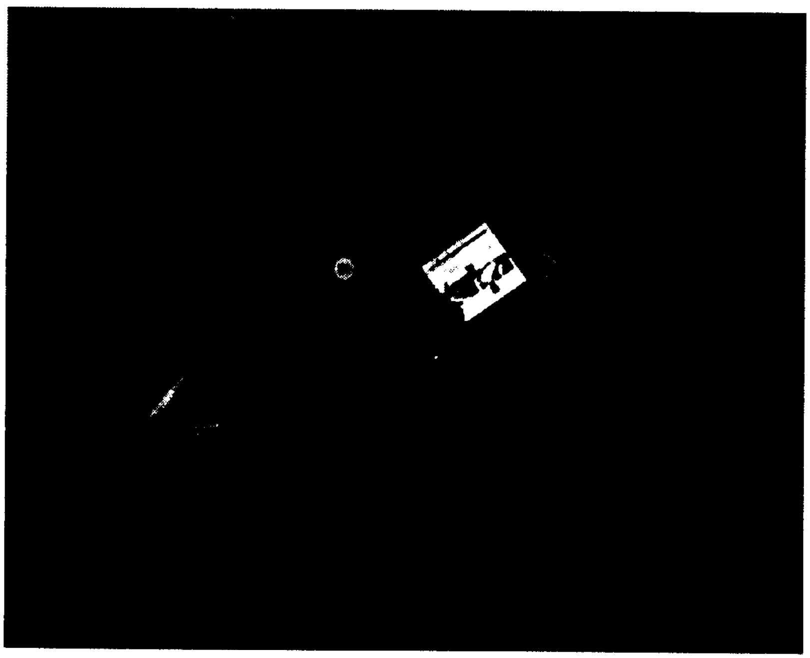


FIG. 15.2 1. Wearable digital jewel pops, by Magnaniis. CMU.

- The Kneph neck jewel (Figure 15.20), created by Elizabeth Geuder, is a wearable personal recording device for creative endeavors.
- Nicole Magnaniis' wearable digital jewel pops open into a hand-held display (Figure 15.21).
- Jocelyn Pollackís' wrist worn personal assistant (Figure 15.22) can be easily removed and used as a phone.
- The Optra (Figure 15.23), created by Michael Benvenga, is a series of four wearable projectors that together allow the display of various sized information.

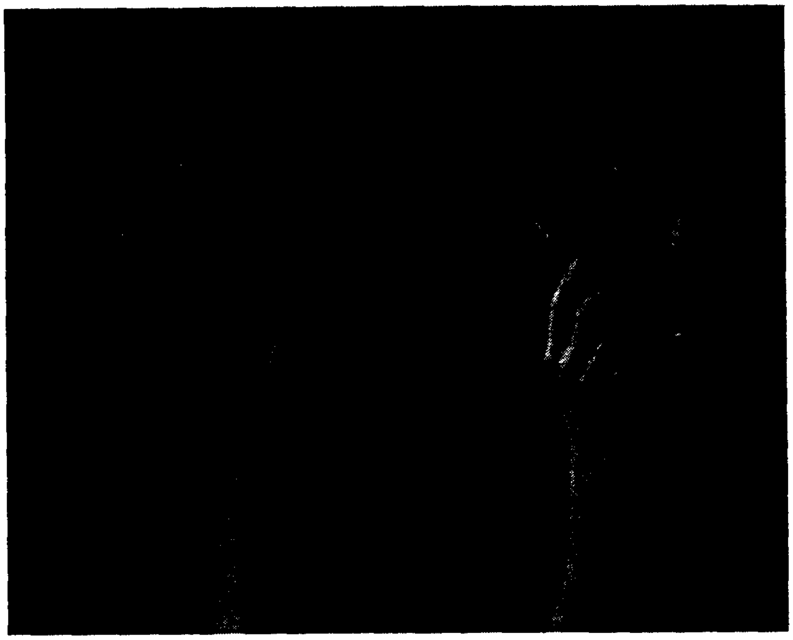


FIG. 15.22. Wrist worn personal asssitant, by Jocelyn Pollackis, CMU.

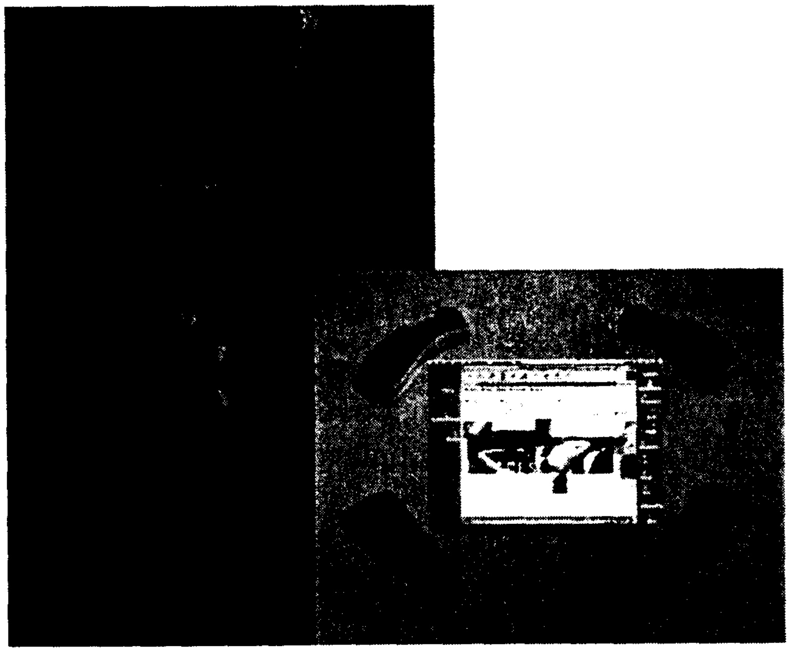


FIG. 15.23. "Optra" wearable device, by Michael Benvenga, CMU.

8. SUMMARY

As the number and complexity of wearable computing applications continues to grow, there will be increasing needs for systems that are: faster, lighter, and have higher resolution displays. Better networking technology will also need to be developed to allow all users of wearable computers to have high bandwidth connections for real-time information gathering and collaboration. In addition to the technology advances that make users need to wear computers in everyday life, there is also the desire to have users want to wear their computers. In order to do this, wearable computing needs to be unobtrusive and socially acceptable. By making wearables smaller and lighter, or actually embedding them in clothing, users can conceal them easily and wear them comfortably.

To summarize, in this chapter we presented concepts related to the design and use of computational clothing and clothing accessories. As shown in this chapter, there are many application areas for this technology such as medicine, manufacturing, training, and recreation. Computational clothing will allow a much closer association of information with the user. By embedding sensors in the wearable to allow it to see what the user sees, hear what the user hears, sense the user's physical state, and analyze what the user is typing, an intelligent agent may be able to analyze what the user is doing and try to predict the resources he or she will need next or in the near future. Using this information, the agent may download files, reserve communications bandwidth, post reminders, or automatically send updates to colleagues to help facilitate the user's daily interactions. This intelligent wearable computer would be able to act as a personal assistant, who is always around, knows the user's personal preferences and tastes, and tries to streamline interactions with the rest of the world.

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