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Wearable Computers

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1. Introduction

Wearable computers are fully functional, self contained portable computers that are worn on the user's body [1]. One of the main goals of wearable computers is to allow users to access computational resources whenever and wherever they are in the environment. This generally requires four standard system components: (1) a computer unit which is able to store, retrieve, and process digital information, (2) an output display device to view the information, (3) input devices to access and manipulate the information, and (4) a wireless network. The computer unit houses the CPU, motherboard, hard drive, memory, and all other components necessary to process and output information and data. In terms of computational resources, the processing power and storage capability of PC-based wearable computers are generally comparable to that of laptop technology.

There are an increasing number of applications, both in the workplace as well as in everyday life, where people require almost constant access to computing resources. While many of the applications that require computers also provide them, such as ATM machines, credit card scanners, and fax machines, people often carry (or wear) their own personal digital devices. Some of these devices are standard consumer products that are widespread throughout society, such as laptop computers, cellular phones, pagers, PDA's, and "digital" watches. In addition, these portable digital devices are becoming smaller, lighter, less obtrusive, and are providing user's longer use without the need to be recharged. They are even beginning to be integrated with people's daily outfits when they leave the house [2]. For example, phones are worn around the neck, "digital" watches are strapped to a wrist, pagers are clipped to a belt, and even wearable computers are worn under or over clothing (*Figures* 1 and 2). Since the main goal of "wearable" computational devices is to provide the user access to information whenever and whereever they are in the environment, to this end they need to be portable, reliable, and unobtrusive. However, in many respects, today's fashion culture is still unaccustomed to seeing people wearing digital devices and would generally consider such an individual "different" [2]. Therefore, in order for manufacturers of portable digital devices to sell them to the general public (and for digital clothing to be accepted by the general public), the devices worn must be visually unobtrusive while maintaining their functionality; they must also be integrated into the clothing style of the user.

This paper is also concerned with the topic of computational clothing (sometimes referred to as digital or electronic clothing) and digital accessories that people wear with their clothing or carry around with them. The design and use of computational clothing is a

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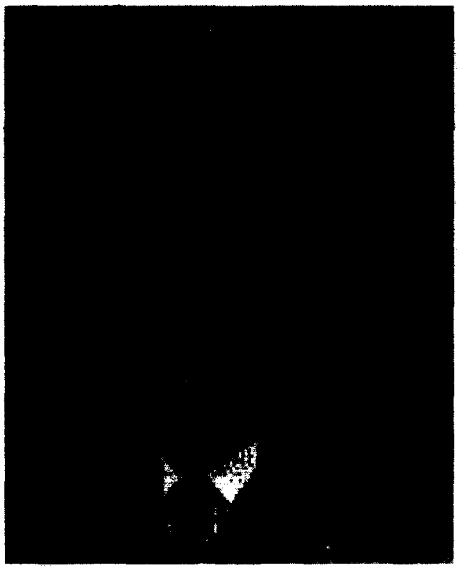

Figure 1. Wearable device from the late 1980s-a multimedia computer with a 0.6-inch CRT, invented and worn by Steve Mann, http://wearcomp.org/ieeecomputer/r2025.htm.

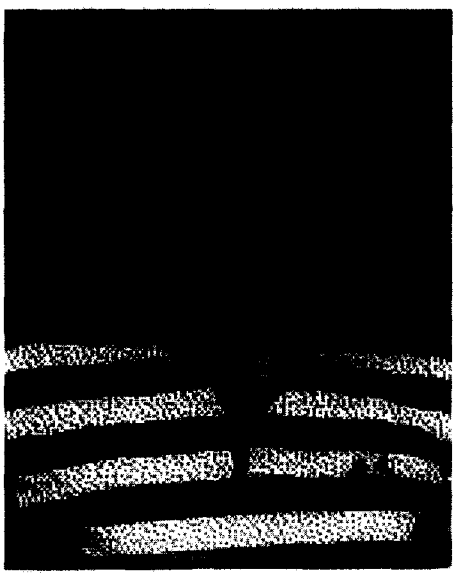

Figure 2. A recent, nearly undetectable, prototype wearable computer consisting of eyeglasses, a handheld control, and a computer worn in back under the shirt, invented and worn by Steve Mann, http://wearcomp.org/ieeecomputer/r2025.htm.

topic of recent interest to researchers in computer science, engineering, textiles and clothing, and human interface design. Much of the current research directions in this area can be traced to the early 1960's when Ivan Sutherland from MIT first developed a see-through display which allowed graphics to be superimposed over the environment. 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, 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.

One of the primary display devices for wearable computers is a head-mounted display (HMD). Currently, there are three main application areas for HMDs, these include virtual reality, augmented reality, and wearable computers. These three application areas are summarized below.

Virtual reality – With virtual reality, a participant uses an HMD to experience an immersive representation of a computer-generated simulation of a virtual world. In this case, the user does not view the real world, and is connected to the computer rendering the scene with a cable, typically allowing about 3~4 meters of movement.

Augmented reality – With augmented reality, a participant wears a see-through display (or views video of the real world with an opaque HMD) which allows graphics or text to be projected in the real world [3,4]. As with the virtual reality experience, the user is connected to the computer rendering the graphics or text with a cable, again allowing about 3~4

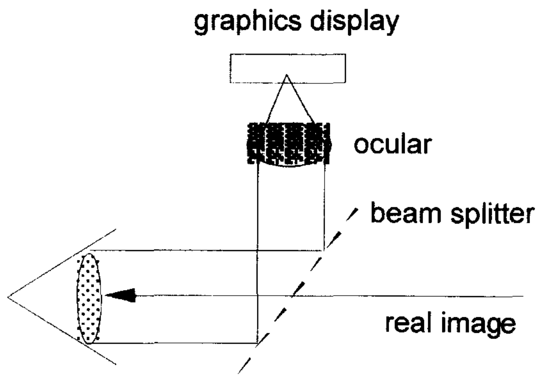

Figure 3. Schematic diagram of a see-through display. The display includes an ocular which magnifies the displayed image which is then projected onto the retina.

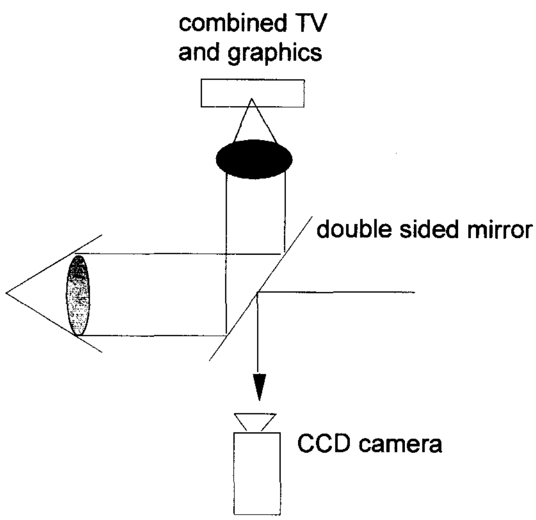

Figure 4. Schematic diagram of a video-based/ opaque HMD system.

meters of movement.

Wearable computers – With wearable computers, the user actually wears the computer, and as in virtual or augmented reality, wears the visual display (hand-held or head-mounted, although the focus in this paper is HMD-based systems). The wearable computer may be wirelessly connected to a LAN or WAN, thus allowing information to be accessed whenever and wherever the user is in the environment. With an appropriate input device (s), the user may also be able to manipulate virtual objects in the environment.

For augmented reality displays, there are main two ways to superimpose graphics over the real world. An image representing each of these procedures is shown below.

Table 1 summarizes some of the capabilities of wearable computers in comparison to virtual and augmented reality systems. As noted, wearable computers allow hands free operation of real objects as does augmented reality displays. However, because virtual reality displays are completely immersive, the user cannot directly see his hands which makes manipulation of real objects difficult. Of course, with appropriate input devices, manipulation of virtual objects can occur. The see-through display capability which allows text or graphics to be projected within the real world are unique to augmented reality and wearable computer systems. However, all three application areas, virtual reality, augmented reality, and wearable computers, can use non see-through or opaque displays. With augmented reality and wearable computers, an opaque HMD (monocular or binocular) can show live video with computer-generated text or graphics overlaid over the video. In terms of range of motion, wearable

Table 1. Comparison of wearable computers with augmented and virtual reality systems

Display attribute	Type of system		
	Wearable computer	Augmented reality	Virtual reality
Hands Free Operation	Yes	Yes	No
See-Through Display	Yes	Yes	No
Opaque Display	Yes	Yes	Yes
Amount of Disk Space	Limited	Extensive	Extensive
Range	Mobile	3-4 meters	3-4 meters
Network	Wireless	Land based	Land based

computers allow complete freedom of movement around the environment, while augmented and virtual reality systems provide a range of motion within the real world confined to that of the length of the cable connecting the display hardware to the rendering platform. The ability to be wirelessly networked is an important characteristic of a wearable computer compared to augmented reality and virtual reality systems, this capability, for example, allows the world wide web to be accessed anywhere and at any time.

Wearable computer systems can also be thought of as personal information devices [5]. With a wearable computer, the user expects his interface to be accessible continually and unchanging, unless specified otherwise. With experience, the user personalizes his system to ensure appropriate responses to everyday tasks. As a result, the user's wearable computer system becomes a mediator for other computers and interfaces, providing a familiar, dependable interface and set of tools complementing the abilities the wearable computer infrastructure provides (more processor power, additional sensing, *etc.*). With sophisticated user models and corresponding software agents, such an interface can be extended to recognize and predict the resources needed by the user [6].

There are several dimensions by which wearable computers can be evaluated. Two of which include the level of mobility provided by the computing system and the level of scene fidelity. The level of scene fidelity refers to the quality of the image provided by either the virtual reality display, real world, or augmented world. Obviously, real world experiences results in the most mobility, and the greatest level of scene fidelity. Essentially, human's carry their sensors with them as they move around the environment, and experience the world with the resolution provided by these biological sensors. Wearable computers also allow a high degree of mobility, but not quite that associated with the real world experience. For example, currently we cannot swim with wearable computers although our biological sensors easily allow this range of mobility. Furthermore, the weight of wearable computers further adds to their lack of mobility. Wearable computers allow a high degree of scene fidelity because the real world is viewed either directly with see-through optics or via live video. However, the level of scene fidelity may be less than that associated with augmented reality because wearable computers currently do not have the rendering capability of workstations that are often used (*e.g.*, SGIs) to render graphics for augmented reality environments. Furthermore, augmented reality displays are limited in range to that associated with the length of the cable connecting the display to the rendering engine. Finally, virtual reality in its present form is often low on scene fidelity and low on mobility within the real world.

2. Design Issues

Display technology, input and output devices, power supplies, and image registration techniques are all important aspects of wearable computers. The following sections briefly discuss these topics. Although wearable computer displays, wireless communications, and data storage technology are becoming efficient enough to allow unobtrusive power supplies, the desire for faster CPUs and higher bandwidth will continue to contribute to the need for more power with wearable computers. Standard power supplies used by wearable computers are usually lithium-ion based battery packs that are worn on the body and connected to the computer. Their charges can generally last for 2~4 hours before recharging is necessary. However, developments in several areas, such as lithium-ion polymer batteries (which may allow 11 hours of usage before recharging), and harnessing human motion as a power source.

2.1. Image Registration

When creating a wearable computer system which can be used to augment the environment with text of graphics, an important visual requirement is that the computer-generated imagery register at some level of accuracy with the surroundings in the real world [7]. For example, a medical application where computer-generated images are overlaid onto a patient, accurate registration of the computer generated-imagery with the patient's anatomy is crucial [8,9]. In terms of developing scenes for "mobile" augmented reality (*i.e.*, wearable computers), the problem of image registration, or positioning of the synthetic objects within the scene in relation to the real objects is both a difficult and important technical problem to solve.

Image registration is an important issue regardless of whether one is using a see-through or a video-based HMD to view the augmented reality environment. With applications that require close registration, accurate depth information has to be retrieved from the real world in order to carry out the necessary calibration of the real and synthetic environments. Without an accurate knowledge of the geometry of both the real-world and computer-generated scene, exact registration is not possible. To properly align video and computer-generated images with respect to each other, several frames of reference must be considered. Janin, Mizell, and Caudell [7] (using a HMD) and Lorensen and colleagues [9] (using a screen based system) have discussed issues of image calibration in the context of different frames of reference for augmented reality. In Lorensen's medical example, two coordinate systems were necessary, a real-world coordinate system and a virtual-world coordinate system. Alignment of the video and computer-generated imagery was done manually. Lorensen pointed out that this procedure worked well when anatomical features of the patient were easily visible. Janin and colleagues [7] presented another technique that can be used to measure the accuracy with which virtual images are registered with real world images. This method involves the subject aligning a crosshair, viewed through a HMD, with objects of known position and geometry in the real world. Because this crosshair is not head tracked it moves with the users head, this allows the vector from the position tracker to the real world object to be measured. The alignment procedure is done from multiple viewing positions and orientations, and as reported by Janin and colleagues, allows a level of accuracy in terms of projection errors of 0.5", the approximate resolution of the position sensor. Although these methodologies work reasonably well for systems that have a limited range of mobility, much more research needs to be done before accurate registration of images using wearable computer systems can occur.

2.2. Optics

Another important design issue for wearable computers using video-based systems is related to the optics of the CCD camera and the optics of the HMD. The focal length of a camera is the distance between the near nodal point of the lens and the focal plane, when the focus of the lens is set to infinity. There are two nodal points in a compound lens system. The front nodal point is where the rays of light entering the lens appear to aim. The rear nodal point is where the rays of light appear to have come from, after passing through the lens. Camera lenses which may be used to design augmented reality scenes using wearable computers may vary in the field of view. For example, a typical wide angle lens has a 80 degree field of view, a standard lens a 44 degree field of view and a typical telephoto lens a 23 degree field of view. The use of a zoom lens that has the capability to change from wide angle to telephoto views of the scene is desirable for video-based wearable computers as this allows the viewer to match the field of view of the real-world scene to the field of view of the computer-generated scene. In addition, depth of field, described as the distance from the nearest to the furthest parts of a scene which are rendered sharp at a given focusing setting is another important variable to consider for augmented reality displays. Depth of field increases as the lens is stepped down (smaller lens aperture), when it is focused for distant objects, or when the lens has a short focal length. In some cases it may be desirable to have a large depth of field when using a video-based wearable computer in order to maximize the amount of the scene that is in focus. Other important variables to consider when designing a video-based system that displays stereoscopic images includes the horizontal disparity (horizontal offset) of the two video cameras, and the convergence angle of the two cameras. Some basic information on these variables is provided by Milgram, Drascic, and Grodski [10] who used video cameras to create a stereo real world image superimposed with a stereo computer-generated pointer.

Furthermore, if the video of the real world is to appear as if viewed through the users eyes, the two CCD cameras must act as if they are at the same physical location as the wearers eyes. Edwards *et al.* [11] tried several different camera configurations to find the best combination of these factors for augmented reality displays. They determined that the inter-pupilary nodal distance is an important parameter to consider for applications which require close to medium viewing distances for depth judgments and that off-axisness is hard to get used too when objects are close to the viewer. Placing the cameras in front of the wearers eyes may result in accurately registered video and computer-generated images, but the image of the outside world seen through the HMD will appear magnified and thus closer than they actually are.

2.3. Input Devices

In conjunction with the output devices, effective input devices are necessary to allow the user to seamlessly interact with the virtual text or images being presented. The input devices that have evolved for use with wearable computers are very diverse and always changing to accommodate user needs. Recent growth in the popularity of wearable computers has sparked an increasing interest in the design and evaluation of input devices.

In the real world environment, the user is often using one or both hands to perform a task, therefore, the input devices used with wearable computers need to be designed with this requirement in mind. Appropriate input devices need to be utilized to allow the user to efficiently manipulate and interact with objects. For data entry or text input, body mounted keyboards, speech recognition software, or hand held keyboards are often used. Devices like IBM's Intellipoint, and track balls, data gloves, and the Twiddler are used to take the place of a mouse to move a cursor to select options or to manipulate data. One of the main advantages of using a wearable computer is that they allow the option of hands free use. When complete hands free operation is needed, speech recognition, gesture based, EMG based, and EEG based devices are a few ways for the user to interact with the computer in a completely hands free manner. Other input devices such as hand held keyboards, wrist keyboards, or track pads allow the user to input data when complete hands free use is not necessary.

For some wearable computer applications, another effective tool in providing the user with a realistic experience is allowing them to receive tactile feedback to provide a direct physical perception of objects [12,13]. This directly couples input and output between the computer and user. Tactile and force feedback acts as a powerful addition to augmented reality simulations for problems that involve understanding of 3D structure, shape, or fit, such as in assembly tasks [14]. The common factors considered in the design of these input devices is that they all must be unobtrusive, accurate, and easy to use on the job.

3. Application Areas

3.1. Digital Clothing

An emerging method of combining today's portable digital technology with cultural fashion trends is actually integrating the devices into clothing [15] while at the same time conforming to traditional fashion trends [2]. By actually embedding digital technology into clothing, people are able to have continual access to their digital resources without the inconvenience and obtrusiveness of carrying them around separately.

Clothing is often referred to as a 'portable environment' or as a 'second skin'. No matter how one refers to clothing, clothing clearly has three different aspects, these include the physiological, social-psychological, and cultural. Each of these areas need to be considered in the design of digital clothing and accessories. In addition, clothing specialists have delineated the main reasons why people wear clothing. These reasons include issues of protection, modesty, status, identification, and self-adornment and self-expression [16]. In terms of self expression, witness the current digital 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.

It is also interesting to note that people use the terms "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. Non-clothe items include hats, shoes, handbags, belts, watches, gloves, accessories, glasses, umbrellas, *etc.*

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 [17]. 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. They are classified into four groups according to the following categories or characteristics of clothing: thermal, chemical, mechanical, and biological [18]. Furthermore, in order to discuss the requirements of clothing, it is also 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 [19,20]. Serviceability concepts along with knowledge of digital technology will both need to be considered when designing digital clothing. Aesthetics refers to the attractiveness or appearance of clothing. Aesthetic appeal is becoming a more important criteria for clothing than ever before. In addition, color, texture, and luster of fabrics and even silhouette, style, and coordination of outfits are very critical factors in choosing garments. 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 relationship between the type of clothing, characteristics of the person, and characteristics of the environment has to be considered. Comfort can be divided into several components as follows. Comfort relates to the way in which clothing effects 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 so called "body-movement comfort". Each of these aspects of comfort will be discussed in more detail below given their importance for the design of digital clothing.

Awareness of clothing usually leads to an expression of discomfort such as too hot, too cold, 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 33 ± 2 ℃ temperature, $50\pm10\%$ relative humidity, and 25 ± 5 m/sec 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. Therefore, it is necessary to select appropriate textile materials in the design of digital clothing.

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, which cover haptic sensations, that is, 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 digital clothing. Textile materials must be flexible and elastic. Also, when people move, their skin stretches and recovers, thus 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 digital clothing the added weight resulting from the digital devices worn on the body. For example, some commercial wearable computers can weigh between 5~9 kilograms and digital 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 digital 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, fibbers differ from each other in their chemical nature, in other words, in polymeric substance. For example, cotton consists of a polymeric substance which 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. "Apparel" 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 buttons-hooks, 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.

Since Nylon was first produced by Carothers in 1935, synthetic fibers such as polyester, polypropylenes, acrylics, *etc.*, were discovered during the 1950's. 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 paper as possible fabrics suitable for digital clothing. The static charge of synthetic fabrics, due to their low water content, causes many problems such as fabric cling, electric shock, dust adsorption, *etc.* It is therefore necessary to utilize electroconductive fabrics in the design of digital 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 surface of clothing. The specific resistivity of the fabric made of the conjugate spinning process using the carbon black is $10^3 \sim 10^5$ Ω cm. The specific resistivity of ordinary nylon fabric is $10^{11} \sim 10^{13}$ Ω cm. Whereas that of cotton fabric is $10^8 \sim 10^9$ Ω cm, which in this case hardly makes static 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. If wearer feels cold, vice versa, the fabric releases heat to the human body. 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, and releases heat when the material is cooled, and 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 by an after treatment technique developed by Vigo [21] and used for winter sports wear like ski-wear. 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, sports wear finds also is 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.

3.2. Ways to Integrate Digital Circuits/Electronics to Clothing

Computers are generally composed of five basic components/functions. These include input, output, wiring, power (battery), and the main CPU unit. Although it depends on the specific computer component, concepts of clothing as outlined in this paper should be incorporated with any computer parts that are visible or invisible. As an example, when polymers are extruded through spinnerets as hollow fiber, wires could be centered in the fiber. Conjugate spinning can also utilize chips or wires as one or two components in the polymer solution. When yarns are manufactured, wrapped yarns 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 yarn, for example, yarns made of silver or gold. Computer chips and polymer solutions may be put together into sheet form and then split plotted into thin yarn. This procedure is a way to form metallic yarns such as silver, gold and aluminum. When weaving fabrics, wire itself in a core-spun or wrapped form of wire, and can be used as warp yarns or filling yarns in constant intervals. This 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 yarns 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 metalic buttons. According to the end-use, various types of clothing like underwear, sportswear, casual wear or work clothes could be developed into wearable computer-clothing. For formal wear, underlining fabric and interfacing are the possible targets for integrating digital circuits into clothing.

4. Computational Accessories

In addition to the clothing that people wear everyday, 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. Other accessories while not currently considered as standard as a watch, are becoming more popular and are designed to serve a purpose. 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 four 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. The final category which will be discussed in the conclusions section, includes a list of future technology that has potential but has not yet been applied to fashion accessories

4.1. Watches

Wrist watches 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. Swatch is currently waiting to see which cellular technology will become more popular in the US. Currently, the two main players are the Global System for Mobile Communications (GSM) and the universal mobile telephony standard (UMPS), which is currently under development. 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 a 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 with the watch. The touch screen not only displays the time and date, but also has eight selectable icons that activate features such as a scheduler that includes a calendar to remind the wearer of important dates, a tele-memo that store 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.

4.2. Personal Communications Devices

The second category of digital accessories consists of devices whose purpose is interpersonal communication. These devices include cellular phones, pagers, 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 cost decreases and their functionality is increasing. 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 revolutionized 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 US 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 SP 1300. 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.

4.3. 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 everyday. 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"×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 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 US 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 funds transfers from customers 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.

5. Additional Research Directions

5.1. Medicine

One of the more important applications for wearable computers is the visualization of medical information projected onto a patient. Currently, MRI and CT images are viewed independent of the patients body. The use of augmented reality displays will allow MRI and CT images to be superimposed over the patients anatomy which may assist in tasks such as the planning of surgical procedures. Researchers from the Department of Computer Science at the University of North Carolina, Chapel Hill, have pioneered the development of medical augmented reality. For example, Fuchs and Neuman [22] investigated the use of three-dimensional medical images superimposed over the patient's anatomy for non-invasive visualization of internal human anatomy. Specifically, in their application, a physician wearing a HMD viewed a pregnant woman with an ultrasound scan of the fetus overlaid on the woman's stomach. Walking around the patient allowed the doctor to observe the fetus in 3D perspective and with reference to the mothers body.

Other researchers, such as Lorensen and colleagues [9], and Gleason and colleagues [23] at the Surgical Planning Laboratory of Brigham and Woman's Hospital and Harvard Medical School have also investigated the use of augmented reality environments for medical visualization. Specifically, Gleason, Kikinis, Black, Alexander, Stieg, Wells, Lorensen, Cline, Altobelli, and Jolesz [23] used three-dimensional images to assist in preoperative surgical planning and simulation of neurosurgical and craniofacial cases. They built an augmented reality display which allowed the surgeon to superimpose three-dimensional images with the surgeon's operative perspective. Surgical simulation provides the ability to interact with the reconstructed virtual objects, such as viewing different surgical approaches or displaying only a limited number of anatomic structures or objects. Gleason *et al.* described the effectiveness of their augmented reality system for intraoperative neurosurgical procedures in the context of 16 cases. From the same research team, Lorensen *et al.* [9] presented a case study which involved the removal of a tumor at the top of a patient's brain. Before making any incisions, the surgical team viewed computer models of the underlying anatomy of the patient's brain surface and tumor, mixed with a live video image of the patient. The combined video and computer image was used to help the surgeon plan a path to the diseased tissue. The video of the patient, enhanced by the computer models, showed the extent of the tumor's intrusion beneath the brain's surface. A future extension of this work could involve a member of the surgical team with a wearable computer located at a remote site also viewing the tumor projected onto the patient and assisting in the diagnosis and planning of the surgical procedure.

5.2. Manufacturing

Very often in a manufacturing environment, jobs are done on the shop floor, in confined spaces, or other areas that require the worker to move around the workspace or facility. However, the workers still need access to information such as assembly instructions, part sheets, or task lists. Traditional paper diagrams or written instructions are not always intuitive or easy to use, and having to carry them around the factory can interfere with the job. This is where the advent of wearable computers are able to provide the necessary functionality and mobility required to effectively use computers to aid in manufacturing tasks. Using wearable computers, workers can project information in the form of text or graphics, in their work environment and interact with the information in a hands free or minimally obtrusive manner.

As one example, engineers at Boeing have implemented wearable computers and augmented reality to aid workers in the assembly of airplanes. Their augmented reality project was designed to display pertinent instructions and diagrams in front of the manufacturing workers, who use the information to work on or assemble components of the aircraft [7]. The wearable computer is used to render wire frame diagrams or text instructions at arm's length in front of the user. The user looks at the piece and they see a diagram or text telling them what to do next and how. One of the main challenges associated with using augmented reality and a wearable computer for this application is accurately registering the user's position relative to the work piece so that the projected diagram stays put whenever the user moves his head. In order to solve this problem, Boeing engineers are working on a real-time videometric tracker. With such a system, a small, head-mounted video camera will select markings on the work piece and will then send appropriate information to the processor which will compute the users position and will display the diagram and text relative to the markings.

5.3. Architecture

Architects frequently present designs by overlaying photographic imagery of present sites with synthetic imagery of proposed buildings. In some cases, full animations are produced showing the proposed building in its intended setting. Instead of modeling the site, a video recording of the site could be made from the environment, recording the position and orientation of the camera. Then, the camera position and orientation could be used to drive an animation of the proposed building. The animation could be composited on top of the video footage [24], saving the animator from having to model the entire setting. For an interactive presentation, the participant would be on the site, wearing a see-through or video-based HMD, looking at the synthetic building as if it were there.

5.4. Face Recognition

One of the traditional goals of computer vision is the identification and tracking of objects by their video images [5]. While this is a difficult problem in general, constrained situations may be addressed with sufficient processing power. Pentland and colleagues [25, 26] have developed face recognition algorithms that can capture a face and compare it against an 8000 face database in approximately one second on a 50 MHz 486 class wearable computer. While aligning the face in order to perform this search is still difficult, taking up to a minute on R4400-based machines, if the search is limited to a particular size and rotation, the alignment step is much more efficient. In the context of a wearable computer, the search may be limited to faces that are within conversational distance. In the current system developed by Pentland and colleagues, the user can further assist the system by centering the head of his conversant on a mark provided by the system. The system can then rapidly compare the face versus images stored in the database. Given the speed of the algorithm developed by Pentland and colleagues, the system can return the closest match, and withhold labeling until its confidence measure reaches a given threshold. Upon proper recognition, the system can overlay the returned name and useful information about the person.

5.5. Intelligent Assistants

As noted, the goal of wearable computers is to provide timely and useful informative to the user. However, it is easy to cross the boundary between information that is actually useful and overwhelming clutter. In order to more effectively assist the user, a wearable computer must model its user's actions, goals, and even emotions. Systems have been developed to track the user's position, visual field, and current interests as revealed by what is being typed [5]. However, a more personal and striking interface may be possible if the user's emotional affect can be sensed as well [27].

It has been shown that emotional affect plays a large part in everyday life [28]. However, until recently, computer interfaces have been unable to recognize user's affect. Wearable computers, which are in continual close contact with their users allow a unique opportunity for affect sensing. Picard discusses ways in which computers might recognize affect [27], as well as a number of potential applications of affective wearable computers. By combining biosensors that can sample a user's temperature, blood pressure, galvanic skin response, foot pressure, and electromyogram with a wearable computer, it is possible to create a model of the user by combining affect and environment sensing as well as pattern recognition techniques similar to that discussed by Orwant [29].

Using the sensor data and the user model, a wearable computer can track the state and actions of its user, and react accordingly. For example, if a user is attending an important business meeting, understanding that the user does not want to be disturbed, the wearable computer should take a message if email is received. However, in the case of an emergency message, the computer should understand enough of the context to alert the user immediately. The computer should also be able to identify urgent or time-critical messages [30] and wait for a break in the conversation to post a message discreetly onto the user's display.

Finally, a user model implemented within a wearable computer system, should know about the user's preferences and thus should be able to predict future actions. This information can be used to allocate resources preemptively. For example, if a user enjoys hard rock music when working on a late night project to keep alert, but prefers classical music during the day to lower stress, the wearable computer can predict what the user may want to listen to next and can download potential selections over a wireless network.

6. Summary

One of the latest fields of research in the area of output devices is tactual display devices [13,31]. These tactual or haptic devices allow the user to receive haptic feedback output from a variety of sources. This allows the user to actually feel virtual objects and manipulate them by touch. This is an emerging technology and will be instrumental in enhancing the realism of wearable augmented environments for certain applications. Tactual displays have previously been used for scientific visualization in virtual environments by chemists and engineers to improve perception and understanding of force fields and of world models populated with the impenetrable objects. In addition to tactual displays, the use of wearable audio displays that allow sound to be spatialized are being developed. With wearable computers, designers will soon be able to pair spatialized sound to virtual representations of objects when appropriate to make the wearable computer experience even more realistic to the user.

Furthermore, 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.

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 5 lines of information, the digital tags may contain volumes of multi-media 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, not obstructive, 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 should be commercially available within 2 years, and 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 workers 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. With the increase in credit card use and the rise in forgeries, is 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 their name to authenticate the signature. This computational accessory should be available in 1999, and would bring increased peace of mind to consumers and vendors alike.

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.

To summarize, in this paper we presented concepts related to the design and use of wearable computers with extensions to smart spaces. For some time, researchers in telerobotics have used computer graphics to enhance remote scenes. Recent advances in augmented reality displays make it possible to enhance the user's local environment with "information". As shown in this paper, there are many application areas for this technology such as medicine, manufacturing, training, and recreation. Wearable computers 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 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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Further Readings

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