Examining Factors Encouraging or Hindering the Adoption of Wearable Technology

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ABSTRACT
Wearable devices have been explored in the literature since the 1990's. However, these devices have not achieved mainstream acceptance. Recently, with the introcduction of smartwatches, wearble devices are again a hot topic. Recent research and industry trends indicate attempts to shift the perception of wearables from novelty clothing items, to functional, on-the-go accessories that enhance daily life [23]. This literature review examines various wearable technologies since the 1990's to understand the physical attributes (such as being lightweight, aesthetically pleasing, invisible and ergonomic), functionality (such as multi-purpose, configurable and responsive) and social implications of these devices that encouraged or hindered their adoptance.

Author Keywords
Wearable technology; HCI

BACKGROUND LITERATURE
The field of wearable computing shares many overlaps with other research areas, such as pervasive computing. Satyanarayanan describes mobile computing as a predecessor to pervasive computing [25]. Another predecessor to pervasive computing is the field of distributed systems, which deals with how computers operate while interconnected. Issues related to communication, fault-tolerance, availability, data synchronization and security dominated this field. The advent of mobile devices (laptops and later, cell phones) added an entirely new dimension to distributed systems and brought out new challenges. For example, mobile devices have limited resources (processing power and memory) due to constraints on size, weight and power consumption. Additionally, since mobile devices are portable, there is no guarantee on the quality of their connection to a network.

Research in wearable computing began gaining traction in the 1990's. Early studies explored applications in fields such as healthcare and military, and were often interdisciplinary in nature, interweaving ideas from augmented reality, virtual environments and pervasive computing [32, 12, 5]. What separated wearables from other technologies was the the close coupling of user and computers. Wearables are designed to be on the body for extended periods of time, forming the user's second skin. As such, thoughtful design and an easy, accessible interface was a key to the success of wearables. With form such a critical component, many designs have been explored throughout the years. An early form factor of wearable devices in the 1990's was a belt. The belt was mounted with computers, for example, the VuMan [27]. Another well-used form was the jacket. Jackets gained popularity as it would allow the device to blend with existing clothing, and jacket designs offered leeway in terms of additional bulk [29]. Watches also provided discreet integration [20]. The ultimate aim of the form factor for a wearable is to make it usable in daily life [28]. E-textiles, or garment integration, garnered interest starting in the 90's. The aim was to incorporate technology into clothing and eventually, technology would be produced to support the garment industry [28]. Early display systems included the Head Mounted Display (HMD). Most of the display systems, such as handhelds, wrist mounted, and body worn displayed were large, cumbersome and heavy. It was not feasible to utilize such displays in daily life [28].

The start of the decade saw major efforts in research to improve system functionality and autonomy, while also developing more intuitive user interfaces [16]. Public and private investment also propelled interdisciplinary research in the field [17]. One significant achievement in the first decade was the meeting of textiles and electronics. Many benefits were achieved by integrating electronic components into textiles. Smart fabrics can touch 90% of skin, they are flexible, comfortable and conform to the skin, and remove the need for sensors to be attached individually, allowing for mass production [16]. A new industry, the first two decades expanded the field of wearable technologies considerably and opened up many areas of study. Current and future research now, must focus on producing systems that can move beyond the research setting into practical use.

CURRENT RESEARCH
This section discusses three popular areas of current wearable technology research: healthcare, commercialization and mainstream acceptance, and the workplace. Positive aspects of wearable design are discussed, as well as hindrances to widespread adoption.

Healthcare
Ubiquitous computing plays an increasingly larger role in healthcare. Current research trends include providing an integrated healthcare and lifestyle framework for the elderly. With one in five citizens predicted to be seniors by 2025, greater

burden will be placed on the healthcare system. Providing the elderly with the means to live unassisted could help reduce this burden [31]. A growing life expectancy is also leading to an increased number of people with health concerns, due to a greater proportion of elderly people. For example, there are currently 35 million people with dementia, and this number is predicted to rise by 65 million in the next twenty years. In the near future, healthcare providers will need to provide care to a large number of vulnerable and high-risk patients [13].

Healthcare-focused research on ubiquitous computing aims to increase the independence of patients suffering from chronic illness. Life-logging, the process of collecting data on one's life such as pictures, audio and movement has many useful applications in healthcare research. One such tool that utilizes life-logging is *miLifeCam* [3]. *miLifeCam* is designed for patients with dementia and composed of an Android Smartphone and a Sony Smartwatch. The smartphone, which can be worn around the neck, takes a picture every 30 seconds, and records the time, location and data from the accelerometer sensor. The application also allows for storing information on other people, such as friends and family. These individuals can then be identified through QR codes, and their names, photo and relationship to the wearer are sent to the smartwatch display. Though the study's participants found the system easy to use, the authors acknowledge that all the participants were young and testing on subjects older than 55 is needed. *miLifeCam* has several design issues that may be problematic for its target demographic. The smartphone must be worn around the neck for the image-capturing to be useful, which may hinder wearer acceptance. The application is composed of a smartphone and smartwatch connected over bluetooth. The technological complexity of the system may make it difficult for patients with dementia to use, and calls for integrated, compact design solutions in the healthcare industry. Additionally, each device has to be charged, which is another burden on users.

Falls are a major source of injury among the elderly. Devices that can detect falls and alert the appropriate persons, such as health care providers or family members, could greatly reduce healthcare costs for the government and for taxpayers. Fall detection systems are a popular area of research [14, 2, 1]. One such fall detection system expands current solutions by integrating telemonitoring [1]. The *eCAALYX* aims to provide a complete solution for the elderly and disabled. The system has components for the home, for mobile use, and for the caretaker site. The mobile component consists of health and mobility sensors that monitor respiratory rate, skin temperature and heart rate, embedded into a smart garment. The garment also monitors falls, mobility, and energy expenditure. Messages are delivered to the caretaker site. The caretaker site is composed of a server containing electronic health records. The site's duties include patient management, data visualization, health agenda and observation pattern management. This woven combination of multiple functions and forms could potentially serve as an integrated solution to assisted elderly living.

Another interesting area of study are semi-autonomous assistive mobile manipulators. Patients with motor impairments often rely on caregivers to complete essential daily activities, such as shaving or brushing hair. Human-robot interaction carries safety risks in this scenario, as these people may find it difficult to stop the robot in case of malfunction of emergency. Wearable assistive devices can aid in making physical robot-human interaction safer by processing cues from the user. These devices can recognize stop signals such as wincing [10]. The study presented the *wouse*, a device that can detect a facial response such as wincing. The *wouse* was used in conjugation with a Willow Garage PR2 robot in preliminary studies. The authors noted the difficulty of detecting slight facial expressions, with the *wouse* recognizing wincing on only two of four patients, as well as hardware limitations. The wouse design was difficult to adapt to real-word situations as some participants noted it felt tight and uncomfortable to wear, and difficult to personalize to each user's face [10].

A less utilized medium of communication is the tongue. Various approaches to Tongue Supported Computer Interaction (TSHCI) have been studies. The tongue has been effectively used in vision replacement systems [22], biofeedback systems, and balance improvement [30]. One approach to TSHCI systems is through a Palatal Tongue Controller (PTC). Using a technique called Electropalatography (EPG), tongue contact with the roof of the mouth is interpreted as a dot matrix. Due to the invasive nature of the system, it has not yet been tested. A less invasive approach utilizes infrared signals that receives emergency signals from patients and sends it to healthcare providers. Challenges facing the commercial use of TSHCI systems is the limited understanding of the functional workings of the tongue, the methods of monitoring tongue movement, and lack of real-world tests. Current TSHCIs involve the user undergoing painful, invasive and expensive surgery. Several design issues in the use of tongues as an HCI medium remain, such as developing a non-obtrusive system, effectiveness of the control strategy, and ease of learning [15]. THCI systems have important applications in the healthcare industry, such as designing assistive devices for individuals with spinal cord injuries and limited sensory function.

People with motor and sensory limiting disabilities such as quadriplegia and paraplegia face considerable difficulty with everyday tasks. Over 270,000 people with spinal cord injuries live in the United States, almost all of whom require care. Many assistive devices provide alternate sensory control mechanisms, such as hand and eye gestures, but often have limitations that make them difficult for sustained use. Such gestures can be used to control appliances and security systems. However, commonly used sensors such as an Electrooculogram (EOG), use wet electrodes that cause skin irritation and generate noisy data, which inhibits long-term use. Further, patients with spinal cord injuries have a wide range of ability, meaning that one sensor will not work with equal effectiveness for all patients. Finger gestures, for example, are not suitable for an individual with complete limb paralysis. Certain devices, such as cameras and game consoles, are composed sensors that require limb movement that may not be possible for individuals with spinal cord injuries. A solution to the current offering of limited assistive devices is a multi-sensor, gesture-based home automation system that can be adjusted to the specific capabilities of patients [21]. The system is composed of multiple wearables that detect both eye and hand gestures with low latency and high accuracy. There is a headband comprised of EOG sensors to capture eye movements. Hand gestures are captured by a glove that contains flex sensors and an accelerator. Three forms of gestures are recognized, eye movement, finger flexing and hand rotation, What distinguishes this system from others is its collection of simple and robust gesture recognition algorithms. Gesture input is transferred to a smartphone that can be used to control home appliances. Testing showed that the system recognized 86% to 97% of gestures.

Current research on wearables in the healthcare industry is in preliminary stages. A large focus of the research is on integration of function and ease of use. Home automation is being integrated with wearables, which is in turn integrated with electronic health records. The vision is to provide one easily accessible, customizable, long-term solution to patients. Studies have been able to provide proof of concepts that could help people who would otherwise require care to live unassisted, or with minimal caregiver support. However, a significant barrier to commercial, mainstream use are the HCI components of the system. Despite existing technology allowing for implementation of the functionality, making systems that are integrated, non-invasive, and feasible for long-term use remains a challenge.

Commercialization and mainstream use

In recent history, commercial wearables generally performed one task. Fitness bands, for example, would monitor heart rate, and Smartwatches would display time. The newest generation of products has shifted from narrow, domain specific functionalities to an integrated assistive device for everyday life. The first major attempt to gain consumer acceptance was with *Google Glass*, a multi-functional headset worn as a pair of glasses, aiming to assist in a multitude of daily activities, from photo taking, to web searching to email checking. *Google Glass* failed to gain commercial acceptance due to a myriad of reasons, a major one related to its social implications. People viewed *Google glass* as an invasion of privacy and many were cautious of people wearing it. The market remains open still for the entry of the"killer app" that will make wearables an essential, everyday tool in the lives of the general public.

Increasing attention demands by mobile devices call for user-intuitive design. A 2015 study discovered that in 75% of cases, people were attentive to mobile messages 12.1 hours a day, on average. These interruptions may arrive at times when the user is engaged in activity requiring visual or auditory attention. As frequent interruptions make it difficult to return to the original task, the study proposed a bounded deferral mechanism. This intelligent notification delivery service notifies user of messages based on its prediction of the user's level of business [7].

Another interesting aspect of the notification process is method of delivery. Vibro-tactile stimulation is a popular means of delivering notifications, particularly when visual and auditory attention is engaged in another task. when messages are received frequently, the user's ability to process all the information is diminished. The location of the embedded tactors has been found to affect user processing ability. The study tested two two possible tactor configurations. In the first, the four tactors were placed around the wrist like a wristwatch. In the other, they were arranged on the top of the wrist like a clock face. With the wristwatch arrangement, participants processed spontaneous notifications 41.6% more than in the clock face arrangement and were better able to maintain attention on their primary task [19]. The results indicate that the spatial density of information affects processing ability and that the design of message delivery products should consider the optimized methods of information delivery that allow user attention to remain on the primary task while still being able to respond to spontaneous notifications.

Important considerations for the design of wearables are comfort levels. Physical and psychological comfort has been studied by earlier research. Social comfort, however, has not received as much attention. With wearables gaining mainstream appeal, the social perception of these devices becomes a key factor to consider from an HCI perspective. Designers must consider two levels of social perception, that of the form itself and of the meaning it communicates (ex. brand, status etc.). Major sources of aversion to the adoption of wearables comes from its visual properties, as well as functionality [8].

Mainstream acceptance of wearables faces several challenges. Current research is moving towards creating a multi-functional device with both comfort in form and style in design that can serve the user in daily life. In other words, researchers and business alike are on the search for the "killer app". Integration with other areas also pose many opportunities. For example, Augmented Reality systems are used in a broad range of domains, such as healthcare, business, military and tourism [6]. Used with wearables, there are many applications in areas such as gaming, gamification, or field simulation training. Traditionally, hardware capabilities significantly limited the design options available to developers. Even today, factors such as battery life dictate both style and functionality. Mobility is also a significant consideration in the design of wearable applications. More so than limitations on the hardware side, a lack of understanding about consumer needs and habits affects design decisions. From a business perspective, researchers have yet to discover solid reasons for the low adoption rate of wearables among consumers. The high price points may be an issue, as it puts wearables out of the reach of most average consumers. Novelty may also be a factor. Due to the newness of wearable devices, many consumers are intrigued by wearables and unsure of what to expect. After some time though, the novelty wears off. Without the functionality or the form to maintain their interest in the device, they stop using it. As of yet, commercial wearable devices have been more a proof of concept than a good designed to generate value from consumers. In the business world, this mindset is changing. Organizations are attempting to create functional devices that are aesthetically pleasing and offer value to to customers. Future years are likely to see a great boom in the area of general, all-purpose wearables designed for the average user.

Workplace

Worker productivity and efficiency is a significant concern for organizations. Ubiquitous computing provides organizations with the means to monitor employees, and for employees to increase productivity and efficiency. Wearables in the workplace pose several challenges from an HCI perspective. First, they must be unobtrusive so as not to disrupt daily activity

One area of wearable research is aimed at workers in safety-critical occupations, such as trackside railway workers. Intelligent systems that can detect oncoming trains and notify workers would benefit those working in this occupation. The Mobile Terminal (MT) is a wireless, real-time, safety critical wearable designed for trackside railway workers [4]. The *MT* interacts with sensors called Trainside Presence Alert Devices (TPADs) that detect oncoming trains. *MTs* are worn by the workers and in addition to relaying real-time information about oncoming trains, they also provide information on safety hazards, such as health problems. As a safety-critical, real time device, *MTs* must meet strict design requirements. They must be resilient in extreme conditions, secure against malicious attack, yet unobtrusive enough to be worn continuously without impeding activity. Message delivery is managed by the topmost, communication layer. Three states supported by the layer are normal, degraded and energy saving. Each state consists of different priority, with normal supporting all regular communication, degraded for high priority safety critical messages, and energy saving for minimizing energy consumption. Two methods of delivering messages are proposed. The first model consists of three levels, first delivering a visual signal, then an acoustic signal if no feedback from the worker is received, then a tactile signal if the acoustic message is not responded to. In the other model, all three signals are provided simultaneously. Visual messages are delivered through LED lights on safety glass and auditory signals through a head mounted display. Future considerations for a safety-critical system like this include assessing its dependability and security, as well as unobtrusively integrating the wearable into the worker's uniform.

Many workplaces are complex, consist of many moving parts, and are safety critical. In such an environment, keeping track of all the pieces and identifying hazards is a complex task. Large, industrial environments are an example of a dangerous, fast-moving workplace with heavy machinery. A proposed method to improve workplace safety utilizes Body Area Networks (BANs) as well as passive RFID tags and sensors [18]. There are two components to this system. The system aims to provide detailed, real time updates on workplace safety aspects in an industrial environment. Specific safety standards, such as the procedures for handling and storing material, are highly important to maintain. Workers are required to wear safety gear that meets stringent industrial standards, such as helmets, gloves and goggles. In a high risk environment, deviations from standard practice could result in injuries or death. Human conducted safety assessments evaluate certain aspects of the workplace, such as machinery location, worker activity, and temperature. Some of these safety assessments can be transferred to a machine. A Body Area Network infrastructure was selected as the communication medium to collect, process and transmit data. Safety items, such as helmets and vests, are integrated with RFID tags and sensors. The BAN can then pick up on information from fixed RFID readers located in the environment. Depending on the specific safety protocols of the workplace, conclusions can be drawn and delivered based on RFID tracking. Sensing information is also collected. RFID tags in a pair of shoes, for example, can detect temperature, or tags in a helmet can detect light. Human assessment is prone to human error and oversight. Sensors integrated both into a worker's uniform and the environment may allow for a far more complete, real time understanding of a safety-critical enviroments' potential threats, therefore reducing incidence rates and improving worker safety.

Workers in harsh environments face extreme situations that can threaten their safety. Wearables can reduce the number of safety critical incidents by scanning the environment for threats and relaying signs of potential danger to the worker. One major requirement for these wearables is that they must be unobtrusive. Smart clothing, then, offers an integrated solution. The petroleum industry requires that some of its workers operate in the arctic. The cold, rough weather conditions can lead to fatigue, and can severely impact physical and cognitive function [9]. One major concern for these workers is the loss of finger and hand dexterity due to the cold. The ability to monitor physiological responses to cold could improve working conditions, as low temperature has considerable impact on worker safety. On the other hand, closing down a plant for brief periods due to weather is high cost. Thus, a system is need that can determine the optimal point in this trade-off so as to keep workers safe at minimum cost. Clothing, integrated with sensors that monitor environmental conditions and physiological responses can be used to achieve these goals. One research group developed a jacket with this functionality. Sensor embedded gloves can be used to provide real time feedback on finger and hand skin temperature. However, in the case of petroleum workers, they often take off their gloves to perform tasks. The sensors were therefore placed in the lower right sleeve of the jacket, a position close enough to the hand to pick up data from it. *IsenseU*, a small, and robust sensor was selected to be integrated into the clothing due to its flexibility. Bluetooth was used as the communication medium. The sensor module provides information on skin temperature, humidity, temperature, and free fall detection. All smart components were integrated into the jacket in a way that minimizes bulk and flows with the natural structure of the jacket. The use of the miniature *IsenseU* allows for non-obtrusive placement of the sensor module. To counteract body heat interference with the outside temperature sensor, parts of the jacket were lined with foil and rubber. Testing showed that the jacket provided accessible information about both external conditions and hand temperatures, while not impeding the normal functions of the participants. Such a sleekly incorporated design could be customized for various high-risk situations and enhance the safety levels of organizations [26].

Wearables can be utilized by many industries and organizations. Despite the varying environments and functional requirements for different groups of workers, several design principles remain at the forefront of them all. The wearable solution must not place extra burden on the worker, it must seamlessly integrate without adding bulk, meet strict organizational and industrial standards, provide useful functionality and must be easily accessible to the worker. Current research trends in the field of wearables in the workplace are aimed at identifying the unique needs of a worker group, and designing a system to meet those needs without requiring significant adjustment on the part of the worker.

FUTURE DIRECTIONS

Wearables are starting to gain traction. Associated with this is a flurry of literature and new ideas emerging in literature. Like most technology, it is difficult to predict the future of wearables. However, some general ideas from existing literature reveal areas that need more research.

An interesting and promising idea has been to have Wearables interact with their immediate environment. The boundary between wearable technology and ubiquitous computing is becoming increasingly blurred, with wearables receiving information from their immediate environment and being able to control surrounding objects and appliances. Future research may not place much distinction between these two fields.

A more controversial idea, drawing largely from Science Fiction is implanted devices. Embedding sensors and computing devices into people could provide a “set and forget” experience. A challenge with current wearable technologies is remembering to put on and charge a smartwatch, glove or some other device. Additionally, embedded devices could provide medical information that would otherwise be difficult to obtain.

From a business standpoint, there are many opportunities to exploit for researchers. Generally, wearable technology was, and largely still is, considered an auxiliary accessory to smartphones. However, wearable technologies have attribute that make them distinctly different from the smartphone industry [11]. In addition to function, wearable also have the potential to serve as fashionable, unique and personalized channels of communications. In terms of form, they have much greater flexibility than other consumer devices, creating significant marketing opportunities. Smartphones greatly revolutionized societal behaviour and patterns. Instead of the television, the news was sought from the smartphone. Physical books, newspapers, magazines, were all places aside for the ease of the localized, accessible solution provided by the smartphone. However, one study argues, the role of wearables is not to drastically alter consumer behaviour. Rather, these technologies should serve to support everyday behaviour [11]. This is one major difference wearable technologies will likely face when they enter the mainstream market. With this radically different positioning, researchers must ensure that wearables are designed as support tools that conform to the user rather than requiring significant adjustment from the user. This positioning will naturally dictate the design and human computer interaction components of the device. For example, smartphones can increase in size and still be accepted by consumers, as they are perceived as a revolutionary technology that must be adjusted to. Wearables however, must seamlessly integrate into the users’ daily life and wearable technology that adds bulk, requires modified behaviour, or has a steep learning curve will likely be rejected.

Regardless of the form and functionality of future devices, key challenges wearable devices will need to overcome concern ease of use of and privacy concerns. Carrying around and keeping multiple devices is a burden most users wish to avoid. The usefulness of such devices needs to be balanced with the ease of use of the device. An ideal wearable is one that you forget that your wearing. More multi-purpose devices such as smartwatches need to distinguish themselves from phones and convince users that the watch provides useful functionality without being an annoyance.

Privacy will continue to be a key issue when it comes to wearable devices. Body Area Networks can generate a plethora of personal information and the safekeeping of this information is still an open problem. This is especially true when these devices are used for medical purposes.

Hardware limitations must be overcome in order to bring wearable technology to the mainstream. One such limitation is the use of sensors [24]. Thus far, one contributing factor to the very limited success of wearable devices that monitor factors such as physical activity, is the constricting range of sensors. In order to correctly collect data on physical activity, the sensors must be used in predetermined locations. For example, one user may prefer to keep their smartphone in their front pocket, while another may prefer to keep it in the back pocket. Therefore, wearable devices can so far be used mainly only in laboratory or highly artificial settings such as in a lab, or clinical studies with very controlled conditions. This impacts the willingness of the user to try out these technologies, and also does not generate accurate data on how the user will interact with the device in real life. In addition to the physical limitations of sensors used in wearable technologies, researchers also realize that they face difficulty in extrapolating user interaction and user preferences in a research setting to real world scenarios. Due to the artificial nature of the testing environments, it is difficult to create a product that will be used by the intended demographic, while generating sustained value, appealing the their aesthetic, and providing an intuitive interface. Hardware limitations with the sensors used in wearable technologies indirectly leads to difficulty with creating a truly user-intuitive interface system. By being unable to observe interaction with the device in daily, real life situations, researchers are unable to find out what user needs and preferences are, and how they can tailor their wearable device to meet those standards. Thus, in order to improve upon all aspects of wearable design from functional performance to design, and to gain mainstream acceptance, future research must discover solutions to the limiting hardware problems [24].

CONCLUSION

Wearable computing is in a critical era. While advancements in function are made, form lags behind. The failure, thus far, to produce a user-intuitive wearable that provides valued functionality while maintaining aesthetic, has prevented wearables from entering into mainstream use. Many promising research studies are currently in the beginning, proof of concept stages, and tend to focus more on establishing functionality rather than considering the human computer interaction aspects of the device. Attempts to be the first, widespread wearable have been unsuccessful, due largely to the novelty factor wearing off with quick speed.

With the potential to revolutionize multiple areas, from healthcare to consumer goods to the workplace, there is much to gain in the field of wearable technology.

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