# Have We Achieved the Ultimate Wearable Computer?

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## Abstract

*This paper provides a provocative view of wearable computer research over the years, starting with the first IEEE International Symposium on Wearable Computers in 1997. The goal of this paper is to reflect on the original research challenges from the first few years. With this goal in mind, two questions can be examined: 1) have we achieved the goals we set out? and 2) how has the direction of research changed in the past fifteen years? This is not a survey paper, but a platform to stimulate discussion.*

## 1. Introduction

The first IEEE International Symposium on Wearable Computers (ISWC) was held in Cambridge, Massachusetts in October 1997. The General Chair, Dan Siewiorek, wrote in his message to the symposium: "*The information processing industry is undergoing a paradigm shift.*" I believe this truly captures the spirit of the first ISWC meeting. I was in attendance at this meeting in 1997, and I distinctly remember many of us feeling we were on the cusp of a new computing revolution. The term *ultimate wearable computer* is employed to describe the collection of the key research goals and directions of the community at large.

The aim of this paper is to look back and reflect on whether we have achieved our ultimate wearable computer fifteen years on from the first ISWC, and to see if the vision has held up over the years. It is not intended to be a comprehensive survey, but a consideration of a number of the key research goals over the fifteen year journey. The discussion is broken down into two main sections, a brief overview of eight major research topics from the early years, and secondly, a discussion of whether we have achieved these goals. These eight topics were chosen by reviewing the first six years of conferences, and by personal judgment determined these were the most active areas. This paper reports on research primarily from the ISWC conferences.

## 2. Major Topics

The major topics to be explored in this paper are as follows: wearable computer system form factors, garment integration, displays, user interaction, case studies and applications, augmented reality, networking, and context awareness. Each of these topics will introduce a succinct insight into the research goals and challenges during the early years.

***Wearable Computer System Form Factors****:* There have been a range of form factors examined for wearable computers [1, 2]. An early form factor for wearable computers was a belt mounted configuration. Starting in the early 1990's, a number of custom belt mounted wearable computers, such as the Vuman [3]. Vest and jacket configurations have been investigated over the years, as they provided a means to better blend in with traditional clothing [4]. The use of rigid framed backpacks allowed for more powerful computing platforms to be deployed outdoors [5]. Wrist watches are another obvious form factor for wearable computers, for example the IBM Smart Watch [6]. *The vision was a set of form factors to allow the use of wearable computers in an everyday setting.*

***Garment Integration:*** The concept of e-textiles was one of the first topics of ISWC. Post and Orth investigated a number of e-textile construction techniques [7]. Over the years, there was an increase in research activities into the integration of electronics into the textiles themselves [8]. A major thread of this research domain was the integration of technology into the clothes we wear. Buechley developed an e-textile construction kit for hobbyists [9]. *The vision was wearable computers would be in our consumer clothing and technology would be developed to support the garment industry.*

***Displays***: In the early years, the Head Mounted Display (HMD) was the predominant wearable display technology, such as the Private Eye Display. Micro-Optical successfully demonstrated a display integrated directly into a pair of eye glasses [10]. Handheld, wrist mounted, and body worn displays were additional forms of displays [11]. These display technologies by and large were employed in an application-specific manner, such as handheld displays to emulate a set of

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binoculars. *I believe the vision of many researchers was the wide spread use of HMD's.*

***User Interaction****:* A vast array of input devices for text entry and cursor control was explored during the early years of ISWC. In the early years some of the main devices were: the Twiddler[1], handheld trackballs, forearm mounted keyboards, and gloves. Two-handed wearable interactions were developed with handheld trackballs, thus extending the usefulness of the original single handed, handheld trackball [12]. A key element of UI was the ability to recognise hand gestures while the user is mobile [13]. Evaluation of user interactions has been a strong suit of this community [14]. *The vision was twofold: firstly the development of appropriate user interactions and secondly bring the power of desktop computing under the control of the user.*

***Case Studies and Applications***: Early prototype systems were examined as possible "killer apps" for the use of wearable computers. The hands-free nature of wearable computing showed promise of improving people's lives and the workplace. An early avionics maintenance aid [15] showed promise for instant refresher training/guidance on tasks that are occasionally performed. Tourist applications were a keen focus of location-based wearable applications [16]. The military has been a driving force behind wearable computing from the beginning, as they demand highly mobile computing where the user must carry all their equipment [17]. *The vision was the wide spread use of wearable computers in many application domains.*

***Augmented Reality***: Augmented Reality (AR) is particularly well suited to wearable computers, as a number of uses of AR require high end computing, often in an extremely mobile fashion. The Touring Machine [5] was the first true outdoor AR system, providing HMD location based information to users via AR labels. Entertainment applications, such as AR-Quake [18], started to appear. The modeling of large structures, such as buildings, leveraged the high level of mobility of wearable computers in large outdoor spaces [19]. *The vision was high quality mobile AR in a usable form factor.*

***Networking***: Networking has been identified as a critical enabling technology for wearable computing. Three major sizes of networks were identified as significant for wearable computing: personal area networks (PAN), room/building size, and global coverage. Post et al. described an early PAN [20]. Research into PAN technologies have led to standards for both Bluetooth and ZigBee [21]. Wireless network technologies (802.11) were adopted as a research tool. The need for global coverage pushed early communication technologies, such paging networks [22]. *The vision was the wearable computer wireless connected to the Internet, the environment, and electronics on the user.*

***Context Awareness***: The investigation by many institutions into context awareness/activity recognition is one of longest and richest areas of research in the entire life of ISWC. An early example is the Wearable Remembrance Agent, an augmented memory system [23]. This wearable remembrance agent is a constantly operating active memory aid that employs the user's location to provide relevant notes to that context. Farringdon et al. [24] developed a sensor integrated jacket. This is an early example of wearable context aware sensing to determine human activities such as sitting, standing, lying down, walking, and running. *The vision was the wearable computer would understand and make use of the user's context, in particular: location, activities, and environment.*

**Table 1. Have we made the technologies of the ultimate wearable computer?**

| Topic | Well below | On track | We are there | Exceeded |
|---|---|---|---|---|
| *Wearable Computer Systems* | | | | ✺ |
| *Garment Integration* | | | ✺ | |
| *Displays* | ✺ | | | |
| *User Interaction* | | ✺ | | |
| *Case Studies & Applications* | | ✺ | | |
| *Augmented Reality* | | ✺ | | |
| *Networking* | | | | ✺ |
| *Context Awareness* | | | ✺ | |

## 3. Discussion

This overview leaves the question: *Have We Achieved the Ultimate Wearable Computer?* I will provide my own scholarly judgment about whether we have achieved the ultimate wearable computer for each of the research topics described. It should be noted that research is still continuing in all eight topics discussed. I have categorized the topics into: 1) *Well below*: The research and products are not up where we envisioned them to be. 2) *On track*: The research is continuing, and it is clear we will meet the goals in the future. 3) *We are there*: The goals have been met. 4) *Exceeded*: The technology is much better than we expected! Table 1 provides reference of how each of these topics is categorized. This section describes my final thoughts on each of these eight research topics.

***Wearable Computer System Form Factors*** **(Exceeded):** This topic has exceeded our expectations. The combination of a number of mature technologies

[1] http://www.handykey.com/

has come together to achieve this goal. The pervasive nature of smart phone technology has placed an enormous amount of computation and graphics power in the pockets of the population. For the development of additional experimental form factors, this has also been achieved through the rapidly growing microprocessor industry. Powerful and flexible microprocessor hardware and software development environments are readily available. No longer are complex electro/mechanical workshops required to prototype unique wearable computer systems.

***Garment Integration*** **(We are there):** Garment integration is not a solved problem, but technology is well on its way to be integrated into everyday clothing. Many of the pieces of the puzzle exist today. There has been a steady growth to the investigations into garment integration. We are there because this field has matured to the point where garments can be made with integrated technology, but this technology has only been employed in a limited fashion in products.

***Displays*** **(Well below):** Displays are the most disappointing of the eight topics. This is not surprising, considering the cost of the development of HMD technology compared to the number of consumer products that require HMD's. The current default display technology is the high quality smart phone display. While not hands-free, they do offer high-resolution mobile displays to users. Current research is focused on topics where a handheld display is appropriate for the end use. The research into new displays is largely focused on tactile or portable projectors. There are possibilities for HMD's in the future[2], and we are ever hopeful!

***User Interaction*** **(On track):** Starting from a wide array of different physical input devices, the wearable computing research community has explored a range of methods to interact with applications. As the technology matured, the user interfaces became more tailored to particular tasks and applications. A number of devices have been developed to fill the role of a generic mouse and keyboard style of interface, and these have been shown to work well for a large number of applications. The most common devices are the Twiddler, hand-held trackball, and forearm mounted keyboards. With the form factor of wearable computers turning to the smart phone, gestural interfaces and the interface of the phone itself are now major thrusts of the current focus for user interface research. Overall, the research community has designed, developed, and validated a range of user interface technologies.

***Case Studies and Applications*** **(On track):** A wide range of applications have been and are continuing to be designed, developed, and evaluated. This process allows researchers to better understand how wearable computing systems can be made into useful tools. While no "killer apps" have been developed, a number of successful commercial products do exist, such as the GPS systems to monitor athletics on sporting fields. Body Media[3] incorporates health monitoring sensors into a wearable form factor. The Nike+ iPod combination[4] is a wearable computing system to provide motivation and keeping track of progress during a workout. I class this topic as *on track*, because the research community expected wearable computing products and applications would be much more prevalent today.

***Augmented Reality*** **(On track):** As previously stated, augmented reality is an ideal application of wearable computing. By its very nature, AR requires high performance mobile computing and graphics. The AR and wearable computer research communities have made steady progress on the major research and technology challenges. The current outcome is a wide array of AR applications available on current smart phone technologies, which provide limited registration of AR information. While this is a great achievement, more research is required to make this a truly wearable system. The smart phone is a great computing and graphics platform, but in the AR context phones are handheld and not wearable devices

***Networking*** **(Exceeded):** This is the other topic that has exceeded the hopes and dreams of the wearable community. From the beginning, researchers have been investigated PAN's, wireless local area networks, and global communication systems. All three are now easily obtainable in commercial components, for example smart phones support all these forms of data communication: 3G for global, 802.11 Wi-Fi for local area, and Bluetooth for PAN. The personal area networks are of particular interest to the wearable community, and wearable researchers have been engaged with the standards community to achieve this goal.

***Context Awareness*** **(We are there):** As mentioned earlier, context awareness research has been from the beginning, and continues to be, one of largest areas of research in our community. The original research was concerning initial low level research questions concerning such topics as: simple activity recognition, location based information presentation, and sensor design. Over the years more complex machine learning techniques were developed and trialed in a wearable setting. Currently there is a vast suite of tools and techniques to allow researchers and developers to build context aware applications. One major notable success is that location based applications and services are commonplace today, such as Google Maps.

[2] http://research.nokia.com/news/12101

[3] http://www.bodymedia.com/

[4] http://www.apple.com/ipod/nike/

## 4. Conclusion

In my opinion, the wearable computing research community has produced a vast array of contributions over the years. While we are not all wearing HMD's, we are plugged into the Internet during our waking hours, thus achieving a stated goal of "always on". The wearable computing research has driven all eight of the major topics discussed in this paper. I believe the true legacy of the wearable computing research community is bridging the gap between many different academic/professional domains, such as electronics, computer science, design, materials, fashion, and energy systems.

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