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DEPARTMENT: WEARABLE COMPUTING

25 Years of ISWC

Time Flies When You're Having Fun

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MUCH has changed in the landscape of wearables research since the first International Symposium on Wearable Computers (ISWC) was organized in 1997. The authors, many of whom were active in this community since the beginning, reflect now 25 years later on the role of the conference, emerging research methods, the devices, and ideas that have stood the test of time—such as fitness/health sensors or augmented reality devices—as well as the ones that can be expected still to come, like everyday head-worn displays.

Wearables research used to revolve around lab-grown prototypes that were often created from scratch by young PhD students that experimented with small and modular hardware components, imagining new user-centered applications. Fast forward to 2009: iOS and Android touchscreen smartphones are commonplace, with over 100M being sold each year, equipped with applications similar to those prototyped more than a decade earlier, such as context-based web search and navigation; smartphones have become indispensable. What else has changed in this research community? Time for a look back at the past two and a half decades.

AN EVOLUTION IN RESEARCH PRACTICES

As research into wearable systems has grown and evolved, several trends have emerged in how researchers adopt new processes to create new wearable systems and applications. A methodology that has served the ISWC community well these 25 years is called time travel: Individual researchers decide what functionality they want; implement it as best as possible; experiment; and then iterate.

From Roll Your Own Hardware to Apps

Wearable computers were such a new hardware concept in the early days that researchers with a wearable vision had to prototype their own systems, often from scratch and with themselves as a primary user. Focus was on dealing with computers' limited working memories, processing power, and battery charge. As just one example, CMU's Navigator 1 wearable computer, shown in Figure 1, was developed in 1992–1993 for two applications: a campus tour guide and an aircraft wiring harness manufacturing tool. The Navigator 1 hardware included GPS to gather location data, sound processing to support continuous speech recognition, a head mounted display to provide feedback, and an analog cell phone for wireless communication.[4] Meeting the expected battery life of eight hours for the manufacturing application was difficult given the available hardware and software at the time. Today's commonplace, high-energy density lithium-ion batteries were not yet commercially available, so the final design used two lead-acid batteries, which accounted for nearly six pounds of the system's eight pound weight (and that heavy weight required a custom fabric harness from a local backpack maker to be wearable). Low power hardware intended for mobile systems was difficult if not impossible to find off-the-shelf. For example, the

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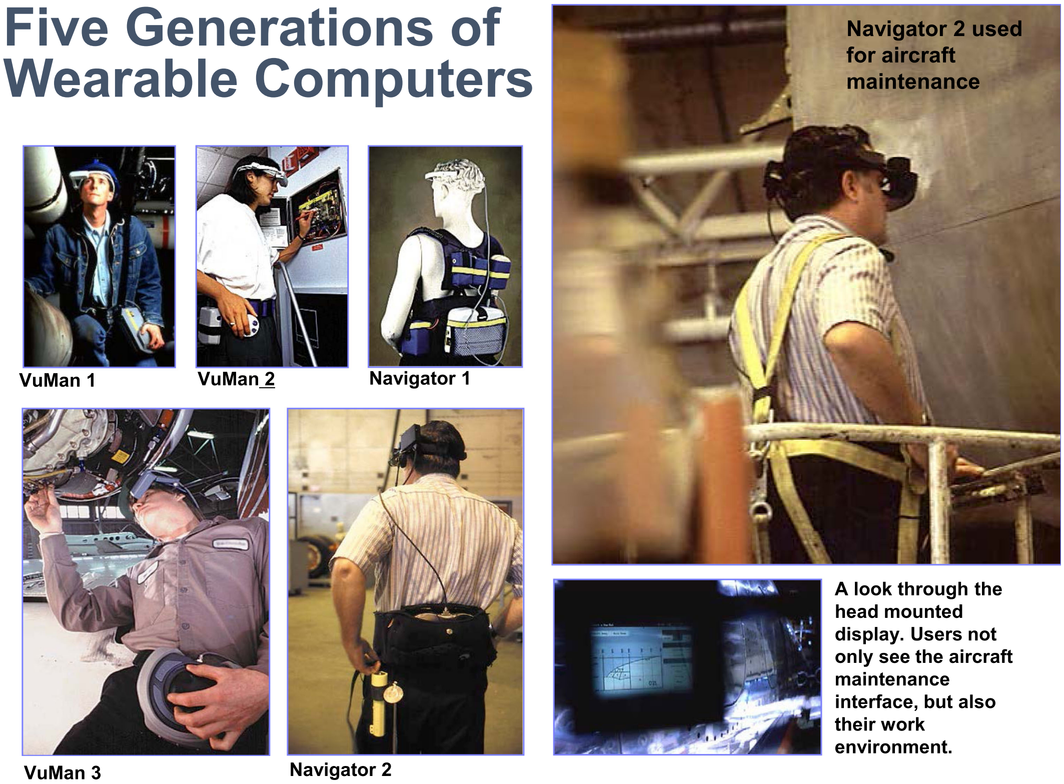

FIGURE 1. The VuMan and Navigator wearable computers, circa 1991–1995.

Navigator 1's sound processing board was intended to be used in a desktop personal computer; unnecessary hardware was desoldered from the board to save power. More dramatic power savings were available by modifying the Unix-based operating system to halt the CPU during the OS's idle loop and to put the spinning hard drive in standby mode when the drive was not being used. The combination of hardware and software changes to lower the power consumption nearly tripled the battery life. Within a few years, power management features such as these would become commonplace in off-the-shelf hardware and software, but at the time, they had to be designed and implemented from scratch.

Starting in the 2000s, steadily increasing attention from industry in wearable and portable devices has spawned smaller, lower power, and interchangeable components. Furthermore, many of these components were also higher performance than earlier versions, thus more complex and compelling wearable computing applications could be developed in a smaller form factor with less weight and a longer battery life. One concrete example of this trend is that the speech recognition software for the Navigator 1 took about ten times talk-time to process speech, e.g., one second of speech took about ten seconds to process. Within about five years, that speech recognition software was ported to the Itsy handheld computer, where the software ran in less than talk-time—and the Itsy fit in the palm of the user's hand and was powered by two AAA alkaline batteries.[2] Much of these essential hardware components of the early wearable systems have now been integrated in smartphones and smartwatches, allowing research to increasingly build new wearable functionalities through software and Apps.

CONCEPTS THAT STOOD THE TEST OF TIME

By wearing their own hardware, researchers could "live in the future" and explore both the promise and the challenges of mobile technologies before they became commonplace. Which research strands have grown into products and research communities? In the following, we list the ones that stand out to us.

Augmented Reality

One of the intended applications of the Navigator 1 was a manufacturing application for aircraft wiring harnesses for Boeing, which assisted workers by overlaying

VISIONARY WEARABLES RESEARCH

Augmented Reality: Early example of smartphone AR and use of QR-style codes.

[SB1] D. Wagner and D. Schmalstieg, "First Steps Towards Handheld Augmented Reality," in Proc. *7th IEEE Int. Symp. Wearable Comput.*, 2003, pp. 127–135, doi: 10.1109/ISWC.2003.1241402

Task Guidance: Inspection, maintenance, and repair were identified early as tasks where wearables might help guide the user.

[SB2] L. J. Najjar, J. C. Thompson, and J. J. Ockerman, "A wearable computer for quality assurance inspectors in a food processing plant," in Proc. *1st Int. Symp. Wearable Comput.*, 1997, pp. 163–164, doi: 10.1109/ISWC.1997.629935.

Remote Collaboration: Enabling a remote expert to help a local worker.

[SB3] M. Bauer, T. Heiber, G. Kortuem, and Z. Segall, "A collaborative wearable system with remote sensing," in Proc. *2nd Int. Symp. Wearable Comput.*, 1998, pp. 10–17, doi: 10.1109/ISWC.1998.729524.

Context Awareness: Forerunners to Google Lens and annotating of phones' photos with location or notes.

[SB4] T. Starner, B. Schiele and A. Pentland, "Visual contextual awareness in wearable computing," in Proc. *2nd Int. Symp. Wearable Comput.*, 1998, pp. 50–57, doi: 10.1109/ISWC.1998.729529.

[SB5] J. Pascoe, "Adding generic contextual capabilities to wearable computers," in Proc. *2nd Int. Symp. Wearable Comput.*, 1998, pp. 92–99, doi: 10.1109/ISWC.1998.729534.

Fitness and Healthcare: Wearable health monitoring and early smart watches.

[SB6] P. Lukowicz, U. Anliker, J. Ward, G. Troster, E. Hirt and C. Neufelt, "AMON: a wearable medical computer for high risk patients," in Proc. *6th Int. Symp. Wearable Comput.*, 2002, pp. 133–134, doi: 10.1109/ISWC.2002.1167230.

[SB7] C. Narayanaswami and M. T. Raghunath, "Application design for a smart watch with a high resolution display," in Proc. *4th Int. Symp. Wearable Comput*, 2000, pp. 7–14, doi: 10.1109/ISWC.2000.888452.

Wireless Personal Area Networks: ISWC involvement in today's common standards.

[SB8] R. F. Heile, "Solutions for the last 10 meters: an overview of IEEE 802.15 working group on wpans," in Proc. 3rd *Int. Symp. Wearable Comput*, 1999, Art. no. 10, doi: 10.1109/ISWC.1999.806636.

E-Textiles: A clothing liner with integrated sensors

[SB9] E. J. Lind *et al.*, "A sensate liner for personnel monitoring applications," in Proc. *1st Int. Symp. Wearable Comput*, 1997, pp. 98–105, doi: 10.1109/ISWC.1997.629925.

Everyday-use, eyeglass-based displays: Lightweight eye display prototype by Minolta

[SB10] I. Kasai, Y. Tanijiri, T. Endo, and H. Ueda, "A forgettable near eye display," in Proc. *4th Int. Symp. Wearable Comput*, 2000, pp. 115–118, doi: 10.1109/ISWC.2000.888472.

Intelligent Agents: Foreshadowed agents like Alexa or Siri accessed via mobile devices.

[SB11] B. J. Rhodes, "The wearable remembrance agent: A system for augmented memory," in Proc. *1st Int. Symp. Wearable Comput.*, 1997, pp. 123–128, doi: 10.1109/ISWC.1997.629928.

Gesture: Gesture recognition in a wristwatch form factor.

[SB12] J. Rekimoto, "GestureWrist and GesturePad: Unobtrusive wearable interaction devices," in Proc. *5th Int. Symp. Wearable Comput*, 2001, pp. 21–27, doi: 10.1109/ISWC.2001.962092.

schematics on a wiring board to show where wires should be attached and connected.[1] While Tom Caudell and David Mizell were pioneering this work with Boeing, Thad Starner wrote a 1990 proposal to the US Air Force advocating "augmented realities" that used computer vision to observe the user's motion to control objects in virtual reality. Steve Feiner's use of "augmented reality" in the titles of his influential papers in 1993 cemented the use of the term, and AR became one of the unifying themes for the wearables community by the first ISWC in 1997.

Early AR work by the ISWC community foreshadowed recent products. For example, Niantic uses location-based services and device-tracking AR on smartphones for their games, such as Pokémon GO, resulting in over a billion downloads. Similar frameworks and functionality can be found in the ARQuake game from ISWC 2000[3] and the Touring Machine from ISWC 1997, which used GPS to overlay information about Columbia University's campus using a head-tracked, see-through, head-worn 3-D display. Industry, meanwhile, has come full circle, with Boeing developing a task guidance application for wiring harnesses using Google Glass.[5]

Task Guidance

Today, companies like Ox and TeamViewer use head worn displays to guide warehouse pickers to retrieve inventory from the correct storage location to fulfil customer orders. Similarly, industry is using wearables to assist workers in data collection, inspection, maintenance, and repair tasks. Wearable computers can even offer automated on-the-job training for these tasks. Some of the first ISWC papers from CMU, Georgia Tech [SB2], and wearable computer manufacturer Symbol (now Honeywell) explored many of the interactions now commonly available from these vendors.

Remote Collaboration

Another early industrially focused theme at ISWC was using wearable computers to allow remote experts to help local workers complete tasks. Remote personnel could converse with local workers, see their environment and even point at objects in that environment [SB3]. Other work explored creating spatially oriented conference spaces.[9] Today, TeamViewer provides similar functionality on commodity wearables, and Augmedix uses Google Glass to allow remote scribes to help doctors take notes and retrieve records in real time while interviewing patients.

Context Awareness

Modern smartphones routinely use context, such as location, to help improve web searches (for example, finding a nearby restaurant for lunch). Such context-based services were the subject of early ISWC papers. Google cites Ashbrook's work[12] when discussing how their services automatically detect meaningful locations such as "home" and "work" to suggest targets for navigation, and Google Maps AR resembles an interface demonstrated by Thomas in ISWC98.[13] Modern context services leverage local transmitters and computer vision [SB4] to better locate the user, and activity recognition by on-body sensors remains an active area of research in both industry and academia. Much of Pascoe's [SB5] use of context to aid an ecologist's observations of giraffes in a Kenyan game reserve is now commonplace in which most smartphones can tag images with GPS location, date, and user notes, saved directly in the image's formatting.

Fitness and Healthcare Sensors

Before Fitbit and fitness smartphone applications, ISW2000 exhibitor FitSense showed their FS-1,[a] which used a shoe pod and heart strap connected wirelessly to a wristwatch to help users track pace, distance, calories burned, and heart rate. That same year, Martin *et al.* described their ECG wearable, which provided real-time feedback to the patient, either as a warning of impending medical emergency or as a monitoring aid during exercise. At ISWC2002, ETH-Zurich described their AMON wrist-based medical monitor [SB6]. Similar functionality can now be found in the Apple Watch.

Wireless Personal Area Networks

Today most technologically savvy users have heard of Bluetooth, but most are not familiar with the IEEE 802.15 standard that covers such personal area networks. Fewer still know that this standard started as the "Ad Hoc Committee for Wearables Standards" in 1997. ISWC researchers were active in the earliest days of the standard [SB8] and presented creative alternatives such as using clothing or the human body as a carrier.[11]

A SURPRISING DEVELOPMENT: THE SMARTPHONE

Not all devices and ideas that were started in the International Symposium of Wearable Computers have proven to be successful commercially (yet!). For some trends, though, the research community was even taken by surprise by the speed of commercial adoption. One development that few in the community saw coming was the widespread adoption of smartphones, which have rapidly become a generic platform for small wearable hardware. Features of many of the early applications of wearable computing are readily apparent in currently available smartphone applications such as when one compares the Touring Machine created by Steve Feiner's team to Google navigation. However, few members of the research community, if any, anticipated that consumers would be likely to spend so much time on applications that heavily relied on touch interaction. While ARQuake from ISWC 2000[3] foreshadowed many of the elements of Pokémon GO, the research community did not anticipate that when an outdoor AR game did become popular, it would be on a smartphone with the screen held at arm's length.

[a]FitSense (exhibitor): http://wcc.gatech.edu/exhibition

COMING ATTRACTIONS

While the smartphone has sped the development and adoption of many of the ideas articulated in ISWC over the years, there are many research directions that are still formative, due to limitations in current hardware or how wearables can interact with the user currently.

Electronic Textiles

ISWC researchers have long held a fascination with electronic textiles (e-textiles), whether it be the technical contributions of weaving fiber optics or electrically conductive fibers [SB9] into fabrics or the stylings of the ISWC Design Competition. Industry has shown interest, as evidenced by several conferences on smart textiles, Google's Jacquard products, and Volt's smart yarns. Yet, no iconic products have yet emerged. If the main utility comes in the form of military or medical use cases, the general public may never become acquainted with e-textiles, and, indeed, several barriers to a consumer product seem apparent. Since users change clothes daily, any e-textile integration must be inexpensive, and fashion may be a barrier as users often like to change the style of clothes they wear. Outerwear, such as jackets that change less frequently and are less often washed, may provide an opportunity, and, indeed, the Levi's Jacquard Truck Jacket and Ralph Lauren Heated Jacket are two such current products.

Everyday-use, Eyeglass-Based Displays

Optics design principles articulated by Spitzer in ISWC 1997 for eyeglass-based AR displays[14] can be seen in Epson's Moverio and Google's Glass line of products, and in ISWC2000 Minolta [SB10] demonstrated how holographic optical elements might be used to create a display that weighs 25 g. However, we have not yet seen a display in an eyeglass form factor sell more than 1 million units. One reason is fashion: that most displays are obvious when worn and most users want display glasses that look like normal eyeglasses even when they are being used. Other difficulties include discomfort due to overall weight (should be $<$75 g), weight on the nose (should be $<$40% of overall weight), and battery life (preferably enough for all day use).

Intelligent Agents

Another concept introduced at ISWC [SB11] is the idea of an intelligent agent that helps the user throughout the day with remembering key thoughts and proactively providing information based on the user's context. While Amazon's Alexa and Google's Assistant provide some such functionality, their use is episodic and limited as they often do not have access to on-body context continuously. Currently, such on-body sensing requires significant power, and interacting seamlessly with the user through eyeglasses or earbuds requires advances in HCI such as using context to know when, and in which modality, to interact with the user so as to avoid interruption.

Gestures

High profile news stories on gesture-based companies, such as Facebook's acquisition of CTRL-Labs, are regular fixtures of tech blogs, and ISWC has seen many papers on gesture over 25 years [SB12]. Yet, except in gaming, use of gesture is relatively rare in consumer electronics. One reason is that it is hard for users to discover and remember specific interface gestures. Sensor mounting locations for detecting gestures are limited to what users will tolerate, which usually means using wristwatches, mobile phones, or eyeglasses. Such wearables should provide feedback to the user while performing the gesture so that the user knows if they are doing it correctly. Such visual or auditory feedback while performing a gesture also limits the form factor of the device and the type of gesture that can be performed. However, recent investigation into movement correlation interfaces[10] may point to an intuitive solution where the eyes, hands, head, or any body part might be used for interaction.

Haptics

Smartwatches and mobile phones often include a vibrating motor for alerts; however, ISWC authors have shown that haptic interactions can be much more expressive.[6] Challenges to more widespread deployment of more expressive haptics are that actuators are often bulky and require wired connections to relatively large batteries due to the amount of power they consume.

Affect

ISWC was one of the first conferences to receive papers describing affective computing.[8] Wearable physiological sensors are now commonplace, embedded in watches and fitness sensors, but use of inferred affect remains more restricted in its use. One challenge is recognizing affect from low level sensing. However, the popularization of emoticons and emojis for mobile messaging shows a clear desire to convey affect to conversational partners.

Energy Scavenging

In some sense, power harvesting in the form of self-winding watches is one of the oldest forms of wearable technology. Yet most consumer wearables require more power than can be generated by casual movement of the wrist. Even so, ISWC authors have shown the viability of energy scavenging from footfalls[7] and other human activities, and recent advances in wireless backscatter technologies suggest that on-body sensors may soon commonly take advantage of energy scavenging.

CONCLUSION

The early wearable vision of a central processor in the pocket, wireless body network, and sensors and interfaces distributed across the body has come to pass in the form of smartphones, smartwatches, smart earbuds, and a myriad of other products vying for commercial viability connected over a low power (finally!), low latency, high-throughput version of Bluetooth. Augmented reality is a commonly used public term, and every year brings a new attempt at commercial AR display hardware. Yet there is much more potential for on-body devices that can be unlocked by the ISWC community. Wearable computers are unlikely to compete with laptops or desktops in terms of computing power, network speed, or storage space. However, wearables enable faster and more convenient interactions, on-body physiological sensing, and perception from the point of view of the user. While the pace of innovation on desktop interaction has slowed over the past 50 years, the relative recency of viable on-body hardware and its potential for a more intimate relationship with the user ensures that innovation will continue to accelerate in the wearables field for years to come.

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