# A Transdisciplinary Approach to Wearables, Big Data and Quality of Life

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***Abstract*— Today, the term "wearable" goes beyond the traditional definition of clothing; it refers to an accessory that enables personalized mobile information processing. We define the concept of wearables, present their attributes and discuss their role at the core of an ecosystem for harnessing big data. We discuss the concept of a meta-wearable and propose a transdisciplinary approach to transform the field and enhance the quality of life for everyone.**

## I. WOW – The World of Wearables

In today's digital word, the term "wearable" has a new meaning. It no longer conjures up images of clothing such as an elegant evening dress or the heated Sherpa jacket worn by a mountaineer at the base camp on Mount Everest. Rather, it brings up the images of accessories such as a smart watch on the business executive's wrist, a head-mounted display worn by an immersive gamer, a tiny sensor on a cyclist's helmet, or a smart garment that tracks and monitors a runner. In a few short years, the dimensions of fashion and protection typically associated with the traditional wearable of clothing have expanded to include "functionality" on the go; this functionality can essentially be characterized as mobile information processing – whether it is the executive checking e-mail, the gamer shooting at a target that is also being simultaneously chased by a fellow gamer on the other side of the world, the cyclist's trainer ensuring that the rider is maintaining proper posture on the curve or the runner tracking his workout for the day.


Figure 1. The World of Wearables Enabling Digital Lives

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Just as clothing can be personalized and customized for each person (depending on the physical dimensions, taste and style preferences) and/or occasion (business, evening, home, and hiking), the new wearable too can be configured to realize personalized mobile information processing for specific applications such as immersive gaming, fitness, public safety, entertainment, healthcare, etc. In short, as shown in Figure 1, the world of wearables (WOW) is wowing us by transforming our lives into digital lives today.

## II. The Emerging Concept of Big Data

Park and Jayaraman have discussed the role of wearables vis-à-vis "big data" [1]. Big data refers to large amounts and varieties of fast-moving data from individuals and groups that can be processed, analyzed and integrated over periods of time to create significant value by revealing insights into human behavior and activities. According to McKinsey, if the US healthcare system could use "big data creatively and effectively to drive efficiency and quality," the potential value from data in the sector could be more than $300 billion every year, two-thirds of which would be in the form of reducing national healthcare expenditures by about 8 percent [2].

Recently, the State of Washington demonstrated the benefits of harnessing "big data" pertaining to emergency department (ED) visits and implementing intervention mechanisms or best practices to prevent abuse of ED by patients. As a consequence, the rate of emergency department visits declined by 9.9%; the rate of visits by frequent clients (who visited five or more times annually) decreased by 10.7%; rate of visits resulting in a scheduled drug prescription decreased by 24.0%; and rate of visits with a low acuity diagnosis decreased by 14.2% [3].

Thus, there is great value in harnessing big data; moreover, with the increasing shift from volume-based to value-based reimbursement for services rendered – one of the key facets of the Patient Protection and Affordable Care Act of 2010 – healthcare providers are incentivized to provide holistic care to patients by closely monitoring them to ensure compliance with medication and promoting healthier lifestyles.

### *A. Attributes of Big Data*

The four important attributes or dimensions of big data are shown in Figure 2.

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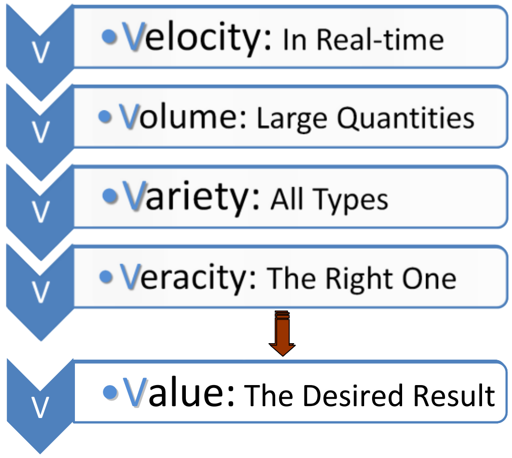


Figure 2. The Attributes or Dimensions of Big Data and Delivering Value

The data are coming in at high velocities from real-time transactions; the volume of data is very large and has been likened to drinking from a "fire hose" because it is being generated by a multitude of sources – individuals, transactions and sensors/devices, among others. The variety of data is heterogeneous and diverse; depending on the source, data are structured and unstructured. The former can be processed using traditional database management systems, while the latter such as text, image, video and social media postings (e.g., "Likes" on Facebook) are unstructured and highly valuable, but also more difficult to process and harness in real-time. Finally, it is important to ensure the veracity of the data so that the resulting decisions are made based on noise-free verifiable data. Thus, these four important dimensions of big data must be considered in harnessing the data to deliver value, the ultimate objective, also shown in Figure 2.

### B. *Harnessing Big Data: The Role of Wearables*

Figure 3 shows the major steps in harnessing big data. These are data Acquisition, Transmission, Storage, Analysis, Utilization, and Learning. Let's consider the example of an individual with an implanted pacemaker: During the course of the day, the individual must be continuously monitored during the various activities, such as walking, exercising, working, shopping, eating, etc. The parameters could include heart rate, respiration rate, electrocardiogram, distance walked, time exercised, foods consumed, and so on.

The ideal means for acquiring the data while meeting the four attributes (Figure 2) is a "wearable" or a suite of wearables, which must perform the following major functions: *sense*, *collect*, *process*, *store* and *transmit*. The sensor suite could include vital signs sensors for the individual, a camera for the pictures, a microphone for voice/audio to record foods consumed, creative ideas generated, and environmental sensors for the ambient conditions, (for instance, the pollen count in the air that might affect the person's respiratory health).

This suite of wearables not only helps to continuously monitor the individual during the course of the day, it can also potentially save the person's life in the event of a medical emergency, such as a stroke. If information about the individual's condition is transmitted immediately to the hospital even as the individual is being rushed there, the hospital doctors can prepare in advance to provide speedy and safe treatment and, hopefully, ensure the individual's survival by reducing the door-to-balloon time [4]. Thus, the individual is both the information node and the target node receiving the value from the collected data. What is needed in this scenario is personalized mobile information processing, or PMIP for short, which can transform the sensory data to information and then to knowledge that will be of value to the individual in suitably adapting the response to the situation.

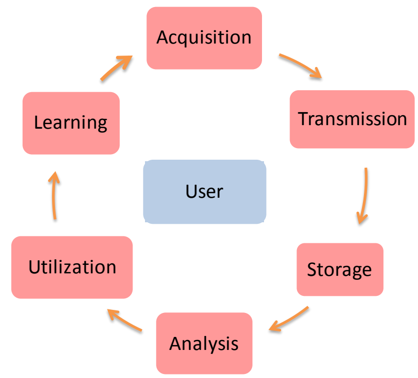


Figure 3. Harnessing Big Data: The Key Unit Operations

## III. THE ECOSYSTEM ENABLING DIGITAL LIVES

Wearables are key enablers of remote health monitoring of patients; the health data can be wirelessly sent to the physician's office by the wearable, thereby obviating the need for office visits. Consequently, the cost of care delivered will decrease. Moreover, the ability to continuously track the patient's health will help identify any potential problems through preventive interventions and thus enhance the quality of care while eliminating unnecessary procedures since the cost of prevention is significantly less than the cost of treatment. The result will be a higher quality of care at a lower cost while eliminating any abuses of the healthcare system, such as the unnecessary visits to the emergency department found in the State of Washington [3].

The advancements in, and convergence of, microelectronics, materials, optics and bio technologies, coupled with miniaturization, have led to the development of small, cost-effective intelligent sensors for a wide variety of applications. These sensors are now so intimately interwoven into the fabric of our lives that they are not only pervasive but are also operationally "invisible" to the end-user. The user interface is so simple that with the touch of a few buttons a different "programming" sequence can be launched by anyone – from a young kid to a senior citizen – for a wide variety of tasks, viz., from monitoring vital signs of individuals to controlling the ambience in the room. Thus, the transparency of the user interface coupled with the invisibility of the "embedded" technology in the various devices and systems have contributed to the proliferation of these sensors in various applications such as those represented in Figure 1. By effectively taking advantage of these technological advancements, it is possible to create an ecosystem that facilitates the harnessing of large amounts of situational awareness data.

### A. Attributes of Wearables

Park, Chung and Jayaraman have carried out an in-depth assessment of the attributes of wearables [5]. As shown in Figure 4, the wearable must be lightweight and the form factor should be variable to suit the wearer. For instance, if the form factor of the wearable to monitor the vital signs of an infant prone to sudden infant death syndrome prevents the infant from (physically) lying down properly, it could have significant negative implications. Ideally, it should become such an integral part of the wearer's clothing or accessories that it becomes a "natural" extension of the individual and "disappears" for all intents and purposes. It must have the flexibility to be shape-conformable to suit the desired end use; in short, it should behave like the human skin. The wearable must have multifunctional capability and it must be easily configurable for the desired end-use application. Thus, the design of wearables must be driven by these attributes.

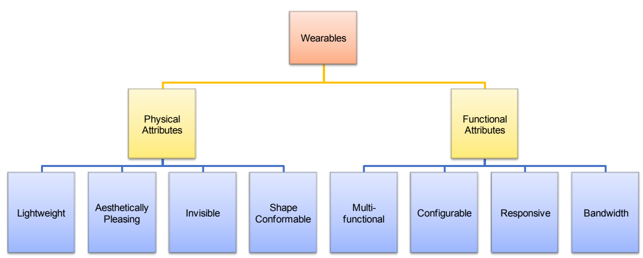

Figure 4. Key Attributes of Wearables

### B. The Latest Trend in Commercial Wearables

The new generation of wearables in the market is shown in Figure 5 [4].

Figure 5. The Emerging Set of Wearables

These typically have only some of the attributes of wearables shown in Figure 4. For instance, most of these perform a *single* monitoring function (e.g., measuring heart rate during workout) and so, their application domain is limited. The recent arrival of Google Glass® appears to be the tipping point in terms of accelerating the wearables movement into the mainstream since Google is an entity with sizable technical and financial resources. Yet another form factor that is emerging is that of a watch with the Smartwatches from Sony and Samsung; these have capabilities for checking e-mail and surfing the internet, which were done primarily on personal computers and/or laptops until now, thus making personalized mobile information processing a reality.

## IV. THE CONCEPT OF A META-WEARABLE

A critical need for the extensive deployment of wearables for personalized mobile information processing is that they should not impose any additional social, psychological or ergonomic burden on the individual. For instance, Google Glass significantly impacts the social dynamics since the ones without this wearable device are not sure of what the wearer is doing with the device while being part of the conversation. Moreover, glasses alter the "natural" facial view/profile of the wearer thus leading to yet another social facet of Google Glass. What is therefore needed is an infrastructure or platform that will be unobtrusive, natural, and pervasive, and not adversely impact social interaction.

Moreover, for many real-world applications, multiple parameters must be simultaneously acquired, processed and used to develop an effective response. The major requirements for creating and developing a useful wearable sensor network system have been discussed in Park and Jayaraman [6]. The key need is for a platform that has both a physical form factor and an integral information infrastructure. In addition to serving as a wearable sensor in its own right, the platform must be able to host or hold other "wearables" or sensors in place and provide data buses or pathways to carry the signals (and power) between sensors and the information processing components in the wearable network [7]. Simply attaching different types of sensors and processors to different parts of the body is not the ideal solution. What is required is a *meta-wearable* [1].

### A. Textiles and Clothing: The Meta-Wearable

That meta-wearable is textiles because it meets all the attributes of wearables in Figure 4. For instance, the textile yarns, which are an integral part of the fabric, can serve as data buses or communication pathways for the sensors and processors and can provide the necessary bandwidth required for interactivity. The topology, or structure of placement of these data buses, can be engineered to suit the desired sensor surface distribution profile, making it a versatile technology platform for wearables. Moreover, they can readily accommodate "redundancies" in the system by providing multiple communication pathways in the network and enable easy power distribution from one or more sources through the conducting textile yarns integrated into the fabric, thereby minimizing the need for on-board power for the sensors. Finally, they themselves can act as sensors and be used for applications such as monitoring vital signs [8]. Thus, from a technical performance perspective, a textile fabric (or clothing) is a true meta-wearable acting as a sensor by itself *and* serving as a platform for the incorporation of additional sensors and processors to harness situational awareness data while retaining its aesthetic and comfort attributes, among many other textile-unique properties.

### B. *Realization of the Meta-Wearable: The Wearable Motherboard*

The Wearable Motherboard or Smart Shirt is the first such meta-wearable that has been successfully developed [9-11]. It has since paved the way for today's wearables revolution. The comfort or base fabric provides the necessary physical infrastructure for the wearable motherboard. The base fabric is made from typical textile fibers (e.g., cotton, polyester) where the choice of fibers is dictated by the intended application. The conducting yarns integrated into the fabric serve as data buses and constitute the information infrastructure. Optionally, these conducting fibers can themselves act as "sensors" to capture the wearer's vital signs [8]. An interconnection technology has been developed and used to route the information (signals) through desired paths in the fabric thereby creating a motherboard that serves as a flexible and wearable framework into which sensors and devices can be plugged. Thus, the wearable motherboard is a platform that enables true convergence between electronics and textiles; and, its modular architecture enables the user to control the degree of convergence based on the application.

## V. RESEARCH ROADMAP: A TRANSDISCIPLINARY APPROACH

Wearables play a critical role in enabling the emerging paradigm of "Information Anywhere, Anytime, Anyone." A detailed analysis of the technical, business and public policy issues including the need for a "killer app" to influence the widespread adoption of wearables has been carried out [12]. What has emerged is the need for a transdisciplinary approach to exploring the future of wearables, which means that it should be pursued as a *new* field of endeavor that brings together knowledge (both foundational and technological advancements) from other established fields such as materials/textile science and engineering, electronics, manufacturing and systems engineering, computing and communications, industrial design, and social sciences [13].

Figure 6 attempts to capture this transdisciplinary approach to wearables research. The major building blocks of wearables, viz., sensors, actuators, processors, energy sources, and interconnections are shown in the figure; the standards governing the design and use of wearables, which must be developed, are also shown in the figure. The materials and manufacturing methods that are integral to the realization of wearables are shown in the left and right panels to signify their key roles in bringing the building blocks together and making the wearable a reality. A change to any of the building blocks will affect the others and, in turn, influence the wearable that is shown in the center of the figure. It is therefore important to view this as a unified ecosystem rather than as a collection of individual pieces. For this key reason, the transdisciplinary paradigm should be adopted to drive the advancements in the field of wearables. Such an approach will bring an innovative perspective leading to revolutionary advancements. This is because a transdisciplinary inquiry focuses on *the* issue, viz., the wearable, rather than what each of the disciplines can *individually* bring to the table and "contribute" to it (the interdisciplinary mode of inquiry and research).

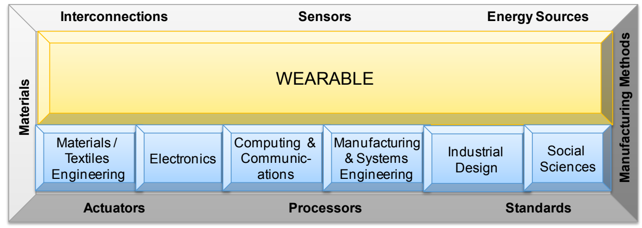


Figure 6. Research Roadmap: Need for a Transdisciplinary Approach

In closing, wearables are increasingly becoming an integral part of our digital lives and the potential application areas are only limited by our imagination. Indeed, it is hard to fathom life without a wearable. A transdisciplinary approach will move us rapidly forward on this exciting journey towards the Holy Grail of a meta-wearable and, in the process, enable us to "do well by doing good."

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