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Review

Sensor Mania! The Internet of Things, Wearable Computing, Objective Metrics, and the Quantified Self 2.0

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Abstract: The number of devices on the Internet exceeded the number of people on the Internet in 2008, and is estimated to reach 50 billion in 2020. A wide-ranging Internet of Things (IOT) ecosystem is emerging to support the process of connecting real-world objects like buildings, roads, household appliances, and human bodies to the Internet via sensors and microprocessor chips that record and transmit data such as sound waves, temperature, movement, and other variables. The explosion in Internet-connected sensors means that new classes of technical capability and application are being created. More granular 24/7 quantified monitoring is leading to a deeper understanding of the internal and external worlds encountered by humans. New data literacy behaviors such as correlation assessment, anomaly detection, and high-frequency data processing are developing as humans adapt to the different kinds of data flows enabled by the IOT. The IOT ecosystem has four critical functional steps: data creation, information generation, meaning-making, and action-taking. This paper provides a comprehensive review of the current and rapidly emerging ecosystem of the Internet of Things (IOT).

Keywords: Internet of Things; sensors; objective metrics; quantified self; personal metrics; high-tech hardware; integrated sensor platforms; multi-sensor platforms; information visualization; health Internet of Things

1. Introduction: The Rapid Approach of the Internet of Things

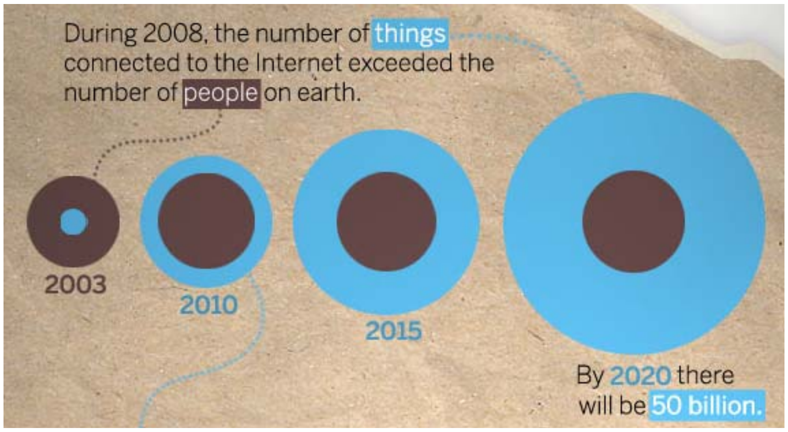
1.1. What is the Internet of Things?

There are several definitions of the Internet of Things (IOT). One that is salient for how the term is *general idea of things, especially everyday objects, that are readable, recognizable, locatable, addressable, and controllable via the Internet - whether via RFID, wireless LAN, wide-area network, or other means* [1].” A key point is that while the most familiar Internet-connected devices are computers such as laptops, servers, smartphones, and tablets (e.g., iPads, *etc.*), the IOT concept is much broader. In particular, everyday objects that have not previously seemed electronic at all are starting to be online with embedded sensors and microprocessors, communicating with each other and the Internet. This includes items such as food, clothing, household appliances, materials, parts, subassemblies, commodities, luxury items, landmarks, buildings, and roads. It is estimated that 5% of human-constructed objects currently have embedded microprocessors [2]. These tiny microprocessor chips and sensors record and transmit data such as sound waves, temperature, movement, and other variables. Other terms for the Internet of Things include Internet-connected devices, smart connected devices, wireless sensor networks, machines and devices communicating wirelessly, ubiquitous computing, ambient intelligence, and smart matter.

One way of characterizing the IOT is by market segment where there are three main categories: monitoring and controlling the performance of homes and buildings, automotive and transportation applications, and health self-tracking and personal environment monitoring. Some of the basic IOT applications underway in the connected home and building include temperature monitoring, security, building automation, remote HVAC activation, management of peak and off-peak electricity usage, and smart power meters. Worldwide smart power meter deployment is expected to grow from 130 million in 2011 to 1.5 billion in 2020 [3]. Some of the many automotive and transportation IOT uses include the Internet-connected car (syncing productivity, information, and entertainment applications), traffic management, direction to open parking spots, and electric vehicle charging. It is estimated that 90% of new vehicles sold in 2020 will have on-board connectivity platforms, as compared with 10% in 2012 [3]. In industrial transportation, train operators like Union Pacific use IOT infrared sensors, ultrasound, and microphones to monitor the temperature and quality of train wheels [4]. One of the biggest IOT growth areas is measuring individual health metrics through self-tracking gadgets, clinical remote monitoring, wearable sensor patches, Wi-Fi scales, and a myriad of other biosensing applications. Two high-profile prizes in this area are designed to spur innovation, the $10 million Qualcomm Tricorder X Prize for the development of a handheld device to non-invasively monitor and diagnose health conditions in real-time [5], and the $2.25 million Nokia X Challenge for sensor technology that can bring about new ways to monitor, access, and improve consumer health [6].

The rapid growth of the IOT is pictured in Figure 1, comparing the number of devices on the Internet to the number of people on the Internet. Connected devices surpassed connected people in 2008. Cisco estimates that by 2020 there will be 50 billion connected devices, 7 times the world’s population [7]. Similarly, the Connected Life initiative sponsored by the GSMA (GSM Association, an industry-association for worldwide mobile operators) found that in 2011, there were 9 billion total Internet-connected devices (compared to the total human population of less than 7 billion), two-thirds (6 billion) of which were mobile, and estimates that in 2020, there will be 24 billion total Internet-connected devices, 12 billion mobile [8]. Moreover, these 24 billion Internet-connected devices are estimated to have an economic impact of over $4.5 trillion in 2020 [8].

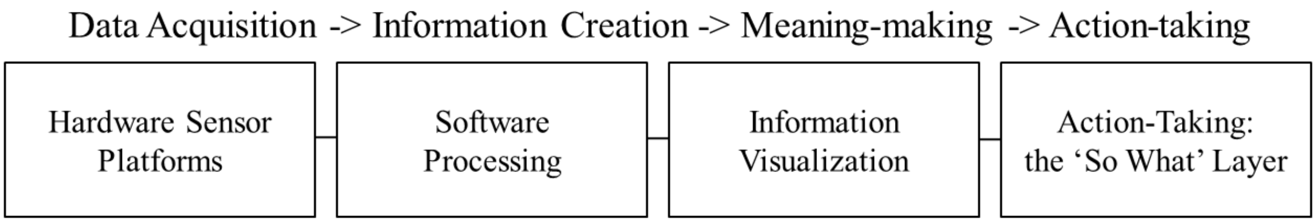
Figure 1. The accelerated growth of Internet-connected devices [7].



1.2. The Internet of Things Ecosystem

The IOT is connecting real-world objects to the Internet with tiny sensors. A number of functional layers are starting to be visible in the developing ecosystem as pictured in Figure 2, starting with data generation, and moving to information creation, and then meaning-making and action-taking. The broad brush categories are the Hardware Sensor Platform layer, the Software Processing layer, the human-readable Information Visualization layer, and the human-usable Action-Taking layer.

Figure 2. Processes and Layers in the Internet of Things Ecosystem.



2. Hardware Sensor Platforms

One of the biggest drivers of the IOT is the increasing number of low-cost sensors available for many different kinds of functionality. Some of the standard sensors include movement (via accelerometer), sound, light, electrical potential (via potentiometer), temperature, moisture, location (via GPS), heart rate and heart rate variability, and GSR (galvanic skin response or skin conductivity). Other sensors include ECG/EKG (electrocardiography to record the electrical activity of the heart), EMG (electromyography to measure the electrical activity of muscles), EEG (electroencephalography to read electrical activity along the scalp), and PPG (photoplethysmography to measure blood flow volume).

These sensors are included in a variety of devices and solutions. The trend is moving towards multi-sensor platforms that incorporate several sensing elements. For example, the standard for the next-generation of personalized self-tracking products appears to be some mix of an accelerometer, GSR sensor, temperature sensor, and possibly heart rate sensor (from which heart rate variability may be calculated). Some recognized first-generation quantified tracking devices and applications include the Fitbit, myZeo, BodyMedia, MapMyRun, RunKeeper, MoodPanda, Nike Fuelband, The Eatery, Luminosity's Brain Trainer, and the NeuroSky and Emotiv brain-computer interfaces (BCI). One website listing of quantified tracking devices is maintained by the Quantified Self community (http://quantifiedself.com/guide). As of October 2012, over 500 items were listed, with keywords from the text descriptions visualized in Figure 3, showing that the tracking tools having a number of quantitative and qualitative dimensions including social, technological, and technical capabilities.

Figure 3. Visualization of Keywords Used in Quantified Tracking Device Descriptions.

The next generation of IOT quantified tracking devices is visible in product announcements, many of which fall into the category of wearable electronics and/or multi-sensor platforms. These products include smartwatches, wristband sensors, wearable sensor patches, artificial reality-augmented glasses, brain computer interfaces, wearable body metric textiles (such as Hexoskin (http://www.hexoskin.com/). Other important categories include smartphone applications and their enhancements, and environmental monitoring and home automation sensors.

2.1. Smartwatches and Wristband Sensors

Wearable computing as a category is being defined by smartwatches and wristband sensors, augmented eyewear such as Google's Project Glass, and wearable textiles. A new product category, the smartwatch, effectively a wearable connected computer, is expected to have several product launches in the fall of 2012. This new generation of programmable watches includes the Pebble watch, the Basis watch, the Contour Watch from Wimm Labs, and the Sony SmartWatch as pictured in Figure 4. The Pebble watch (preorder: $150, http://getpebble.com/) has received a lot of attention as the developer was unable to raise funding via traditional means but then became the highest-funded Kickstarter project (a crowdfunding website) to date, raising $10 million from an initially-sought $100,000 (http://www.kickstarter.com/projects/597507018/pebble-e-paper-watch-for-iphone-and-android).

The Pebble watch provides Internet-connected applications like notification of incoming calls, email, and message alerts using Bluetooth to connect to smartphones. The Basis watch (preorder: $199, https://mybasis.com/) is a quantified self-tracking watch, a multi-sensor platform with a 3D accelerometer, heart rate monitor, temperature sensor, and GSR sensor. Like the Fitbit, it does not sync in real-time but only when connected to a computer. Wimm Labs intends to provide an open-platform Android operating system-based alternative to the Pebble watch. The Wimm Labs Contour Watch (~$200, http://www.wimm.com/) is envisioned to enable a wide range of mobile, sports, health, fashion, finance, consumer electronics, and other applications. The Sony SmartWatch, offering Twitter, email, music, and weather information is currently available ($175, http://www.sonymobile.com/gb/products/accessories/smartwatch/). In a potential extension of Google's Project Glass (augmented reality eyewear), Google has patented smartwatch technology for an augmented reality smartwatch with two flip-up screens, a touchpad, and wireless connectivity [9].

Figure 4. Smartwatches: A New Product Category of Programmable Watches: the Pebble Watch (from Pebble Technology Corporation), the Basis Watch, the Contour Watch from Wimm Labs, and the Sony SmartWatch.

Wristband sensors are a predecessor to smartwatches and remain a successful product category on their own. One of the first examples of wristband sensors was using accelerometers to measure steps taken with products like the Nike Sense. Current examples continue to feature accelerometry and include the Nike Fuelband ($149, monitoring steps taken), the Jawbone UP wristband and iPhone app ($99, tracking steps taken, distance, calories burned, pace, intensity level, active *versus* inactive time, and GPS), the Adidas MiCoach ($70, providing heart rate monitoring, real time digital coaching, interactive training, and post-workout analysis of pace, distance, and stride rate). Three next-generation products add new functionality to the standard metrics of total steps taken, distance, and calories. The Mio Active ($119, http://www.mioglobal.com/) adds heart rate, either with or without a chest strap. The LarkLife ($149, http://www.lark.com/) identifies type of activity, allows single-button press diet tracking, measures sleep, and uses the combined metrics to make personalized recommendations about changes a user can make to feel better [10]. The Amiigo ($119, http://www.amiigo.co/) wristband and shoe clip also measure the type of exercise, plus body temperature and blood oxygen levels through an infrared sensor [11]. Other sensor platforms also focus on fitness and athletic training, for example Somaxis (www.somaxis.com) with ECG and EMG muscle and heart sensors and GolfSense ($130, http://www.golfsense.me/) where users attach a wrist-based sensor unit to a golf glove. The unit has two accelerometers and other sensors that collect and transmit data wirelessly for real-time feedback. Multi-sensor wristband devices are also in development for clinical use, for example in epilepsy. One team created a wristband to detect convulsive seizures through electrodermal activity and accelerometry, a useful improvement over lab-based EEG methods as the device can be worn continuously [12].

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