Pervasive Computing: Global Positioning System and Radio Frequency Identification Fusing with Mobile Phones and Related Privacy Issues

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Abstract

Pervasive Computing is all-encompassing technology enabling computers to be used everywhere in our everyday life. Radio Frequency Identification (RFID) and the Global Positioning System (GPS) are two enabling technologies of Pervasive Computing. A literature review of the technology is conducted and an introduction to RFID and GPS is presented with the fusing of this technology to cell phones enabling Pervasive Computing. Serious privacy issues exit with these technologies, yet according to published research the public remains in the dark about these issues. Barreras and Mathur (2007) posit two privacy concerns: who owns this information and what are they doing with this information? Recent published information concerning privacy issues along with solutions to address the privacy issues concludes this review.

Introduction

The notion of Pervasive Computing, originally termed Ubiquitous Computing by Dr. Mark Weiser while at Xerox's Palo Alto Research Center (PARC), is the concept of the all-encompassing technology enabling computers to be used everywhere in our everyday life (Weiser & Gold, 1999). Weiser and Gold discuss the early developments of Ubiquitous Computing breaking from "the then-current 'one person—one desktop computer' paradigm and opened up to researchers at PARC the idea of spreading computers ubiquitously, but invisibly, throughout the environment" (p. 693). The theory is that Pervasive Computing technology is everywhere and can interact with every person and every organization. Early developments of Ubiquitous Computing include LiveBoard, ParcPad, ParcTab, and the Active Badge system (Weiser & Gold, 1999). The products themselves were not the Ubiquitous Computing paradigm Weiser and Gold espoused, but they represented the beginning of that paradigm as Weiser and Gold state "…together with a flexible, computational infrastructure that recognized not just device name, but the location, situation, usage, connectivity, and ownership of each device, staked out a new conception of what computers could be and feel like" (p. 694). This is the beginning of Pervasive Computing. The technology and means to interface people with information anywhere and the related effect this will have on the way people can use the technology is investigated through this literature review. Two technologies which are at the forefront of Pervasive Computing are Radio Frequency Identification (RFID) and the Geographic Positioning System (GPS).

This literature review investigates the current state of research concerning Pervasive Computing. Examples of Pervasive Computing use and the current applications of Pervasive Computing are derived from published articles. Concerns of the directions that Pervasive Computing is heading, with respect to the public and their privacy, are also presented. The research extends to currently published resources which were discovered through the Internet and through online databases of scholarly journals such as EBSCO and ProQuest to name a few. The literature review is an inquiring process to understand the current state of published research. This corresponds well to the overall purpose of this article which is to gain an understanding of the current state of Pervasive Computing. The literature review method is preferred over other alternatives as assessing the current state of Pervasive Computing literature will also reflect on the adoption of this technology and its current trends.

Pervasive Computing removes physical boundaries and increases connectivity to data while being contextually aware. Pervasive Computing is everywhere and invisible. Three relative interactions can occur in Pervasive Computing which present different opportunities for the application of technology: 1) objects which are aware of their location can be mobile and interact with a stationary device; 2) objects can be stationary and interact with a mobile device which is aware of its location; 3) or both devices are mobile while aware of their location and interact with each other. As an example: a stationary device which is aware of its location and monitors mobile devices utilizes an identifying indicator which is positioned on the mobile entity to announce its presence. The underlying technology which announces its presence uses any variety of methods such as infrared, wireless transponders, or Radio Frequency Identification tags (RFID). Specific technologies, such as RFID and GPS, are presented as an enabler of Pervasive Computing.

Discussion

RFID

RFID is an enabling technology of Pervasive Computing. This technology, which has become very popular recently, allows a reader to identify an item electronically when in close proximity to an RFID aware system. Weiser and Gold (1999), commenting on a world with Ubiquitous Computing, state "…a physical world richly and invisibly interwoven with sensors, actuators, displays, and computational elements, embedded seamlessly in the everyday objects of our lives and connected through a continuous network" (p. 694). RFID enables this Pervasive Computing physical world which Weiser and Gold discuss.

Introduction of RFID.

One system developed at PARC, which was presented earlier, is the Active Badge system. This system, as described by Want, Hopper, Falcão, and Gibbons (1992) requires that a user is tagged with a badge which emits an infrared beacon which sensors pick up. Want et al. continue the description of the Active Badge system discussing connections to backend systems, like a phone system, which can route information such as telephone calls relative to the user's location, or this system could be used to simply locate people. The ability for the Active Badge system to track where the user is located, and send that information to a phone system, which will route phones calls to where the user can answer them is an example Pervasive Computing.

The Active Badge in today's world manifests itself through RFID technology. The application of RFID is not applied to route phone calls as the Active Badge system which Want et al. discussed, but the concept to utilize this vision of Pervasive Computing to locate and identify objects is enormously popular. Additionally, RFID has been used to identify objects in cities, museums, and most notably to track objects through the supply side of the retailing industry. A brief history and an introduction of RFID is given followed by the published research of using RFID in cities, museums, and tracking objects through the supply side of the retailing industry.

History of RFID.

RFID technology received U.S. Patent No. 3,713,148 (Cardullo, 1973), and physically requires two parts which are a tag and a reader. The tag consists of a micro-chip and an antenna. RFID has been related to its predecessor the Active Badge system which was produced at PARC (Weiser & Gold, 1999). The Active Badge system used an infrared (IR) beacon to communicate with the sensor because at the time they are small and cheap (Want et al., 1992). The beacon aspect of the Active Badge system relates with active RFID, except the active RFID uses radio frequency to communicate, whereas the Active Badge system used IR. The range of the Active Badge system is approximately 6 meters, and according to Want et al. the IR was "…reflected by partitions and therefore are not directional when used inside a small room" (p. 93). Conversely, the range of active RFID can be hundreds of feet (Hsi and Fait, 2005). An important difference with the Active Badge system is that the signals will not travel through walls (Want et al.), unlike active RFID which is transmitted via radio frequency and can penetrate walls in addition to traveling hundreds of feet.

The paradigm shift for RFID occurred roughly when Wal-Mart and the Department of Defense (DOD) mandated RFID tags. The *Economist* published an article in 2004 which signals the beginning of widespread RFID as it states "Wal-Mart, the world's biggest retailer, said it would require its 100 top suppliers to put tags on pallets and cases of products for shipment to a cluster of its supercentres in northern Texas" (The future, 2004, para. 5). Other organizations such as Tesco, Metro, Target and Albertsons were not willing to miss the opportunity to reap the financial benefits of RFID also enacted tag mandates on products from their suppliers (The future). The DOD mandated RFID tags as Erickson and Kelly (2007) state "…they instructed suppliers to convert to RFID systems by January 2005" (p. 107). This is a reflection of the usefulness that organizations see in the technology and of the maturity of the technology. The ability to track packages at a relatively close range with wireless technology enables organizations to become more efficient. Today there are a variety of RFID implementations which are generally classified into two groups: passive RFID, or active RFID.

Passive RFID.

There are two types of RFID which are active and passive. With passive RFID, the tag (see Figure 2) is activated and energized by the reader and reflects the information stored on the microchip through radio waves which the reader receives. The amount of data, or actual information, which a passive RFID tag holds is small, and for the purposes of this definition, is called an identifier because it uniquely identifies the tag to the RFID reader. The RFID reader is connected to a backend system which links the unique identifier to data which is useful to the user of such information. This identifier details information about the item where the tag is attached. RFID operates through radio waves and according to Bean (2006) "…systems can run on frequencies that vary from 125 KHz to about 915 MHz and that one company's tags may not be read by readers from other companies or readers of different frequencies" (p. 4). RFID technology has a variety of ranges associated with it from a few inches to hundreds of feet (Hsi and Fait, 2005). The other type of RFID is active RFID.

Active RFID.

Different from the relatively short range passive RFID tag which receives its power from the reader, the active RFID tag has a much longer range. Active tags are relatively larger because they are battery powered which also means that they have a limited life. One use for an active tag, as shown in Figure 1, is used for monitoring the proximity of people relative to the receiver.

Figure 1. An active RFID tag (coins for scale).

Figure 2. A passive RFID tag.

This device, as shown in Figure 1, has a memory capacity of 256 kilobits, which is equivalent to 32,000 text characters, and can receive transmissions from 100 feet away and transmit 280 feet

(Anonymous, 2007). This device has battery life of one to three years depending on use (Anonymous). Passive tags, as shown in Figure 2, require energy from the receiver to transmit their data, but are smaller and have an unlimited life (Roberts, 2006). Active RFID tags can contain around one megabyte of memory Kumar (2006). Kumar also brings up an analogy which is appropriate for RFID tags in that they are "…programmed with a unique set of data and most often operate as a license plate into a database…" (p. 16). These are the two different types of RFID. Both contain data and are usually linked to a backend data source, but passive RFID almost certainly require backend data connectivity to obtain any useful information other than the unique number which the RFID tag presents.

Technically, the concept of RFID started with a paper published in 1948 by Harry Stockman (Stockman, 1948). However, the technology required thirty years to mature before the technology was able for a practical match of the theory espoused by Stockman (Roberts, 2006) to a commercial application. According to Roberts, RFID becomes commercial between 1980 and 1990 and from 1990 to 2000 RFID becomes a part of everyday life.

RFID indeed has become a part of everyday life. According to Fitzpatrick, (2007) Ken Sakamura is applying this technology in Tokyo which "…is well on his way to building the world's first truly public ubiquitous computer network" (para. 8). Sakamura has initiated a project where objects in Tokyo have a RFID tag which will aid those who have a RFID reader to get information about the object or directions from place to place in the city (Fitzpatrick, 2007). People carry a RFID reader with them and scan the tags to retrieve information relative to the object. In this case mobile objects scan stationary objects which are aware of their location through a backend system. The backend system presents information to the user who scanned the

RFID tagged object. This is one example where RFID is used to enable a Pervasive Computing environment.

Fusing RFID with cell phones.

Fusing RFID with cell phones enable a Pervasive Computing environment through an organization called the Ubiquitous Networking Laboratory as they have developed the Ubiquitous Communicator. This device is an RFID reader and is styled after a PDA. The device is cleverly called the UC-Phone as it also has cell phone capabilities (anonymous, n.d.). The UC-Phone can scan a RFID tag on an object retrieving the unique identifier stored in the tag, interact with the backend systems to retrieve and display information about the scanned object.

The unique identifier obtained from scanning the tag affixed to an object is queried against a backend database which allows the information about the object and surrounding objects information to be presented to the user who scanned the RFID tag. One note, which will be discussed later in this article, is that whilst the user is traveling through the RFID enabled city, and scanning objects, a trail of virtual breadcrumbs is also being created on the backend system. This trail of breadcrumbs is interesting to those concerned with privacy.

The user is interested in locale relevant information and this information is presented back to the user. This information is not limited to data about the object, but rather the information is presented as though the object is the center of relevance as that is where the user's perspective is derived. Presenting this spatially relevant information to the user offers the power of Pervasive Computing to the user. Scanning a statue might give a short history of its meaning or related information such as other tourist attractions and directions to enable the user to get to their destinations. Additionally, commercial implications exist as backend systems might have heuristics which are time aware, and due to the approaching lunch hour notify the user of nearby buffet locations. Tourists may find this information very important in an unknown city where language is not familiar. Directions to these offerings are also provided upon request. Merging RFID technology to real world objects is an important development which enables a Pervasive Computing. RFID has been shown to enable Pervasive Computing environments outside; it also enables Pervasive Computing on a smaller scale indoors.

Another example of RFID technology enabling Pervasive Computing is detailed through the Exploratorium museum in San Francisco. In this system, which is called the eXspot, a RFID tag is carried by the user and the reader is mounted on museum exhibits. According to Hsi and Fait (2005) RFID technology allows visitors at the museum to interact with exhibits and it also will "…allow visitors to use their RFID cards to trigger cameras to take digital images of themselves…" (p. 62). After the trip to the museum, visitors can logon to the museum's web site and obtain picture souvenirs of their trip to the museum; in addition the users can gain more information about the exhibits that they visited at the museum. The museum gathers information about the user visit through the backend systems which the RFID readers interact. Some information which these backend systems gather includes the amount of time spent at each exhibit, path through the museum, and through demographic information the type of exhibits which appeal to what demographic groups. The user gets mementos such as pictures of themselves at the museum and the ability to learn more about the exhibit at a later date through the museum's web site. Hsi and Fait also suggest that the data collected offers longitudinal value concerning visitor's trends through a museum display through successive visits or through traveling displays.

RFID has shown the ability to accurately identify objects. These tags have a large commercial aspect on the supply side of an organization's inventory. Commercial applications of RFID attach a RFID tag to a moving object and the movement of this object is tracked through the supply side of the distribution network. The museum example used a mobile RFID tag which followed the museum attendee around and tracked their movements. The tagging of objects on the streets of Tokyo applied a RFID tag to a stationary object and allowed a mobile person to retrieve information about their surroundings relative to their position.

Other pervasive computing uses of RFID.

Specific uses for RFID technology which an individual may use is tourism. The user is guided through the streets of Tokyo, or their visit to a museum is enhanced. In either of the two scenarios listed above, or in other locations where RFID links the user to data about an object or its contextualized surroundings will enhance their connectivity in the Pervasive Computing environment. Specific organizations like Wal-Mart or the DOD are using RFID to conceptualize the physical movement of goods in a virtual environment to track the goods via data systems. RFID has enabled greater efficiency through the control of inventory. Similar to RFID another technology which transmits via radio frequency is the Global Positioning System.

GPS

The Global Positioning System (GPS) allows a receiver to accurately determine the relative location of an object with a high degree of accuracy. GPS is another enabling technology of Pervasive Computing. This technology enables a user to define with extreme precision their location. This technology gives more than simple directions; the technology actively reflects the location of the device. GPS when coupled with a backend data source, similar to RFID, details relevant information about ones surroundings, which is an enormous step towards Pervasive Computing.

Introduction to GPS.

The United States of America has installed and maintains a GPS system called NAVSTAR. Although other GPS systems exist the NAVSTAR system is the focus of this literature review and introduction to GPS. According to NAVSTAR (2004) "The global positioning system (GPS) is based on a constellation of twenty-four satellites at 12,625 miles (20,200 km) above the earth in six orbits" (para. 1). The number and distribution of satellites ensures that the minimum numbers of satellites are available to determine the location of the receiver. The reason for installing the GPS system is published by the United States Army Corps of Engineers which is:

> …to provide passive, real-time, 3-D positioning, navigation and velocity data for land, air, and sea-based strategic and tactical forces operating anywhere in the world. A secondary--and most predominant--application is a wide range of civil positioning and time transfer (US Army, 2003, p. 2-1).

According to Dana (2000) "Four satellites are required to compute the four dimensions of X, Y, Z (position) and Time" (para. 4). The foundation of GPS is based the concept of time, which makes the GPS receiver a good provider and source of very accurate time (Dommety & Jain, 1998). The US Army Corps of Engineers boasts that "Positional accuracies can range from 100m down to the sub-centimeter level" (p. 2-10). GPS uses atomic clocks and requires precise synchronization between the satellites which allows the GPS to function. These satellites communicate are periodically adjusted with ephemeris and clock data from the MCS located at Schriever Air Force Base (formerly Falcon AFB), Colorado (Dana, 2000). The communication between the satellites and the GPS receiver includes the following information:

> …satellite clock bias data, satellite ephemeris data, orbital information, ionospheric signal propagation correction data, health and status of satellites, satellite almanac data for the entire constellation, and other general information (US Army, p. 2-5).

Through mathematical manipulations, and the GPS receiver's internal clock, computations are performed on the received wireless information which computes the GPS receiver's location.

GPS can be used anywhere accurate positional location is important ranging from fitness users to recreational users (Garmin, 2008). The GPS system works well outside or wherever a receiver can receive signals from the NAVSTAR satellite system. Interestingly, most locations which receive cell phone signals also receive GPS signals, and most modern cell phones have GPS capability.

History of GPS.

There really is not predecessor technology of GPS. The everyday user used a compass and a map to figure out where they were. There was no device which automatically determined the location of a person. The military had a few previous technologies which were the precursors to GPS. A satellite called TRANSIT IB was launched in 1960 to aid the U.S. Navy to locate submarines and ships (Anonymous, 2005). This was followed in 1967 with Project 57, which Anonymous (2005) states that "According to Dr. Ivan Getting, it was 'in this study that the concept for GPS was born'" (para. 4). Similar to a cell phone, where a person can be called almost wherever they are, a GPS is a system which can locate a person wherever they are. The Pervasive Computing arena gets very interesting when most modern cell phones already contain a GPS receiver.

Fusing GPS with cell phones.

The paradigm shift for GPS, which moved this technology into the Pervasive Computing realm, is the requirement by the Federal Communications Commission (FCC) that cellular networks must be able to physically locate a cell phone if an emergency 911 call is made (Dragoi, 2005). This effectively required all cell phones sold to be GPS enabled, which as a result, GPS enabled cell phones are becoming an enabler technology of Pervasive Computing.

Other pervasive computing uses of GPS.

GPS is found in a variety of devices. Specific uses of GPS for an individual is through the use of a handheld GPS device which can be used by outdoor enthusiasts to locate a favorite fishing location or find their way through a scenic trail. Currently a user of a GPS enabled cell phone can subscribe to a service which enables them to check and keep track of the location of their cell phone, and correspondingly the owner (Adomatis, 2007). This is useful for parents to understand where their children are or where their children have been. Organizations may also want to keep track of mobile employees. For instance Schneider Transportation, headquartered in Wisconsin, has implemented a system from Qualcomm which tracks their signature orange trucks across the country through the use of GPS technology (Wireless, 2004). Another use of GPS is when an emergency 911 call is made. GPS enabled phones aid people who make emergency calls and emergency workers when trying to locate an emergency. Mobile GPS tracking systems, like the one used by Schneider Transportation, also help transportation companies track where there freight is located (Wireless, 2004). This information and the tracking of this information have become more prevalent with enabling technologies such as RFID, GPS, and the fusion of these two technologies with mobile phones. The privacy issues associated with these technologies is discussed next.

Privacy issues fusing RFID and GPS with cell phone technology

Both RFID and GPS, when coupled with mobile phone technology, are enabling technologies for Pervasive Computing. These technologies are useful and have commercial uses. However, these technologies also have issues with respect to privacy concerns. Weiser and Gold (1999) state:

> The problem, while often couched in terms of privacy, is really one of control. If the computational system is invisible as well as extensive, it becomes hard to know what is controlling what, what is connected to what, where information is flowing, how it is being used, what is broken (vs what is working correctly, but not helpfully), and what are the consequences of any given action (including simply walking into a room) (pp. 694-695).

RFID and GPS technologies are invisible systems where it is hard to know, if not impossible in some cases, where the information is flowing. Currently RFID and GPS technology are coupled with wireless mobile devices or cell phones. All new cell phones released in the United States of America contain a GPS receiver. Currently cell phones enabled with the GPS receiver transmit the location of the phone if the user either subscribes to a service or makes an emergency 911 call (Adomatis, 2007). Does a cell phone also transmit the data when a user does not make a 911 call or subscribe to a service?

Published information exists where law enforcement agencies have received court authorization to track criminals through the use of their cell phones, and can get real time information about where a criminal's phone, and hopefully the criminal is located (Barreras & Mathur, 2007). Barreras and Mathur also discuss that tracking a cell phone does not require a call being made. GPS enabled phones constantly send their location to cell phone carriers and according to Barreras and Mathur "Wireless service providers disclose that phone call histories are stored in databases; however, many are very reluctant to admit that they store location histories" (p. 178). Barreras and Mathur continue by stating that "…however, all wireless companies store such data" (p. 178). Barreras and Mathur bring up many issues relating to this issue but principally the two main concerns relate to who owns this information, and what are cell phone companies doing with this information?

Research conducted by Barreras and Mathur (2007) found that "88% of the Sprint-Nextel & Verizon Wireless customers were unaware that their phones were GPS equipped and nearly everyone (93%) responded that they did not think or did not know that their location histories were stored" (p. 184). Additionally, Barreras and Mathur found that 67% of the respondents, once informed of this information believed that their privacy was invaded.

RFID, by nature of the system design, requires that a system retrieve the information on a tag and link the unique information about that item presenting information back to the user. This means that the user who scans an RFID tag creates a virtual path of where they have traveled. Similar to the question which Barreras and Mathur (2007) posed with respect to storing the tracking information of cell phone locations, who owns the data, and what are they doing with the information? The ability to store information concerning scan activities raises RFID privacy issues.

Similar to phone companies storing location information, concern also exists with unintended uses of RFID. An example is provided through the adding an RFID tag to a passport. While this will help security with respect to identifying people, Burgess and Fox (2007) state that "…experts in RFID field say they can be accessed from 30 to 65 feet away" (p. 56). In addition to information gathered by the backend systems about the history and frequency of RFID scans concerning passports, which is out of the owner's control, the tag is accessible to *others* who have the scanning hardware and can get within the range Burgess and Fox disclose. Whichever governmental or non-governmental agency desires the RFID tag information is freely available to any who are within range. The user has no way of knowing that the information on the RFID tag was accessed or what the intended use of the information is.

At the macro scale, GPS enables the ability for consumers to take advantage of the information which links their position to a service which is nearby and has the potential for enormous productivity. At the micro scale, utilizing a RFID equipped phone such as the UC-Phone (anonymous, n.d.) promises the ability to gain local information about objects which is too granular for GPS to differentiate. The issue with these enabling technologies is public acceptance of these systems and the controls on the availability of the information which these technologies create. Unanswered questions such as who owns the data and what can they do with the data need definition with publically available methods and procedures surrounding the handling of the data. This has yet to occur in the United States primarily because the public does not know this is an issue, because they do not know that the data is being collected and stored.

A call for further research with respect to the concerns forwarded by Barreras and Mathur (2007) which are: who owns the data and what are these companies doing with the data? The only way this issue will receive attention is by an informed public which understands that the information is being gathered and stored and what that means for privacy concerns. This is not a RFID, GPS, or cell phone issue, but rather an information handling and privacy issue.

Conclusion

Pervasive computing technologies like RFID and GPS enable a rich and useful opportunity for people to interact with technology fostering increased productivity and efficiency. The increased flow of information occurred rapidly as the two paradigms of RFID and GPS presented in this literature review accelerated the use of Pervasive Computing. Wal-Mart and the DOD mandating RFID signaled the beginning of widespread RFID use. The FCC mandating that cell phones have GPS also signals the beginning of widespread cell phone location services, most of which have not commercially been presented, while others are currently serving a niche market. All of these technologies increase the information flow and have related and unaddressed privacy concerns with the information. A review on privacy issues with respect to GPS, RFID, and mobile phone fusion is presented. The concept of Pervasive Computing is becoming clearer as people become accepting of the technology, but the issues surrounding the control of the information is concerning and not understood primarily because the general population does not know who owns the data, and what are these companies doing with it (Barreras and Mathur, 2007). Weiser and Gold (1999) state “The problem, while often couched in terms of privacy, is really one of control” (p. 694). The ability for users of the technology to turn off the information flow, or access the backend information when they want to is essential for the widespread acceptance of Pervasive Computing. The unanswered questions of Barreras and Mathur still exist concerning who owns the data, and what the companies are doing with it will need a clear understanding before any controls are put on this information. Until adequate controls exist on the data a humble call for publication and research about these repositories is made.

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