Radio frequency identification (RFID) in pervasive healthcare

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Abstract: Active and passive RFID (Radio Frequency Identification) technology are available and licensed for the use in hospitals, and can be used to establish highly reliable pervasive environments within healthcare facilities. They should not be understood as competing technologies and complement each other when intelligently integrated in compact frameworks. This paper describes the state-of-the-art of RFID technology and the current use in the healthcare industry, and points out recent developments and future options.

Keywords: pervasive healthcare; RFID.

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1 Introduction

When the original work on ubiquitous, or pervasive, computing was conducted back in the late 1980s, at the Xerox Paolo Alto Research Centre in California, researchers had the idea of integrating computing processes seamlessly into real-world applications (Weiser et al., 1999). Mark Weiser, one of the pioneers of Ubiquitous Computing, later pointed out that he saw Ubiquitous Computing as a counterpart to the notion of Virtual Reality, where a great deal of equipment was required to interface with computers. He thus had a vision of using computers in everyday applications without them being visual, or affecting the original process (Weiser, 1991). His vision of the seamless support of everyday applications in real-world environments by powerful machines is now about to come true in many industries. In particular the healthcare industry could be on the brink of a critical threshold in the way that information is gathered, stored and distributed (Wang et al., 2006).

Radio Frequency Identification (RFID) technology dates back to the second world war where it was used as a tool for airforce pilots to distinguish enemy planes from friendly planes. It was then rediscovered by the US military to track equipment in huge containers full of different devices, without having to unpack them, and has since become widespread in the retail industry (Nemeth et al., 2006).

A significant impact has been predicted on the healthcare industry, such as in patient identification, object tracking, blood tracking, and so on. Unfortunately, for many reasons, the spread of the technology in healthcare has taken longer than expected (Al Nahas and Deogun, 2007; Leonidas, 2007; Varshney, 2007). The reasons for this include: health and safety issues; budget constraints; patient confidentiality; litigation issues; technical problems; and specific issues linked with the structure of the decision-making processes in the healthcare industry. These have thus delayed the spread of RFID technology, however, given the popularity of the technology in many industries, and the growing number of applications, it is likely that a breakthrough in the healthcare sector is immanent. One of the key drivers of this is the strong, and ever rising, world-wide demand for improvement in areas such as: patient identification; prevention of mixed identities; prevention of unintended drug applications; patient flow; bed management and capacity management; health economic controlling; procurement; infection control; and so on.

2 Radio Frequency Identification (RFID)

RFID cannot be seen as a homogeneous entity, but needs to be understood as an array of different technologies. Key classifications are between active and passive devices, and between their different frequency bands. Table 1 compares the features of passive and active RFID technology, and Table 2 gives an overview of frequency bands used.

Active RFID tags have an in-build power supply which boosts the range of the device to up to 100 metres, while passive tags use the energy coupled from an RF transmitter, and thus only have a maximum range up to one metre, depending on the energy levels applied to read them. The low range might, on the first glance, make passive tags look less suitable for healthcare environments, but there are many factors which make passive technology favourable, such as: cost effectiveness; small size; low weight; enhanced security; high reliability; and so on. Typically, also, due to lack of size and power capabilities, there is typically only limited amount of data which can be stored on passive tags. New

Table 1 Active and passive RFID

	Active RFID	*Passive RFID*
Power source	Internal Battery	RF Energy transferred from the reader
Availability of power	Continuous	Only within field of reader
Signal strength from reader to tag	Low	High
Signal strength from tag to reader	High	Low
Range	100 m or more (300 feet)	3 m or less (10 feet)
Price	\$15–\$50	\$0.10–\$4
Reader price	Typically low cost	Typically high cost
Disposable	No	Yes
Tag life	3–8 years	Up to 10 years
Typical storage capacity	128 KB Read/Write	128 Bytes Read/Write

Table 2 RFID frequencies

Frequency	*Low frequency (30–300kHz)*	*High frequency (3–30MHz)*	*Ultra high frequency (300 MHz–3GHz)*	*Microwave (2–30 GHz)*
Typical RFID frequency	125–134 kHz	13.56 MHz	433 MHz 865–956 MHz	2.45 GHz
Range	< 0.5 m	< 1.5 m	433 MHz (< 100m) 865–956 MHz (< 5 m)	< 10 m
Typical data transfer rate	< 1 kbps	25 kbps	30 kbps	Up to 100 kbps

technologies such as Memory Spot from HP are now appearing on the market, which have relatively large transfer speeds (10 Mbps) with fairly large amounts of memory. One application could be electronic paper, where an RFID tag is embedded into the fabric of paper sheets. Unfortunately the reader is not widely available for current applications.[1]

The weaknesses of lack of range and memory storage have been overcome with improved scanners and middleware technology, where passive tags can be read by handheld devices which are linked wireless to the internet. Specific information can then be matched with a unique chip or patient identification code (Thuemmler et al., 2007).

The most commonly-used devices in healthcare applications are either based on 13.56 MHz or on 2.4 GHz. A key factor is that existing RFID applications in healthcare have to be fully compliant with the American Health Insurance Portability and Accountability Act (HIPAA) standards, whereas the European Commission and several national governments are working on harmonised guidelines for the European Union. Although no adverse effects have been described so far when using RFID technology in hospitals, a recent publication by van der Togt et al. (2008) suggest the possibility of adverse reactions. This seems to be an isolated opinion referring to uncontrolled inappropriate operation of RFID equipment, as tests were performed with unauthorised frequencies, high output energy levels and without a control or reference group. However, the side effects caused by RFID devices operated on authorised frequencies obeying the relevant regulations have not been described yet, and the United States Food and Drug Administration has even approved an RFID device that is implanted under the skin of the upper arm of patients and complied with HIPAA legislation (Levine et al., 2007).

3 Passive RFID

Passive RFID technology is widely used in the retail industry. Tagging is typically cheap and handheld reader-writer devices help to manage relatively huge amounts of objects, easily. For the health industry, RFID tags usually carrying a 13.56 MHz receiver, but the storage on the passive RFID chip is often limited. At the moment the technology is mainly used for blood tracking solutions and patient identification projects where patient identities are verified, or in surgical departments where small pieces of information are added onto the chip to avoid medical errors during surgery (Fuhrer and Guinard, 2006).

Many researchers intuitively feel that the potential of passive RFID tagging is huge but obviously the limited range of the emitted signal from the tag, in connection with strict upper limits for energy levels sent to the chip are some obstacles in the way which need to be overcome. The small size, the low weight and the low costs are ideal prepositions for the use of passive RFID in disposable wrist bands to tag patients in pervasive environments. Several researchers have pointed out, though, the necessity for the development and improvement of appropriate middleware to close the gap between the passive tag and the user front end (Floerkemeier and Lampe, 2005; Seemann et al., 2007).

Furthermore a universal concept for linking the RFID setup with the existing hospital infrastructure needs to be developed and standards need to be agreed with researchers, service providers and the RFID industry, on an international level. Some proposals have already been made and there seems to be agreement about the minimum data set required to describe one operational event: chip ID; reader ID; and a time stamp (Bolotnyy, 2008; Thuemmler et al., 2007). One workable alternative is using mobile devices offering a RFID reader/writer feature, as well as WLAN function to link with an external database. The unique chip ID is then used to identify the patient and the patient data is stored externally on a database. This eliminates the risk of data being read from a stolen or lost RFID tag.

In practice, patient wristbands are scanned by staff with handheld readers which are tagged actively to provide the exact location of the tag at any given time. Using reader/writer devices enables staff to read or edit patient data on the external storage system using the unique patient wrist band chip ID to clearly allocate newly generated information. Furthermore antennas can be used to collect additional information, for example when patients have passing defined points (choke-points), as when they are leaving A&E, X-ray department, and so on. This allows for data mining of more higher-level applications such as real-time monitoring of patient flow, health economical controlling; and the capturing of data to evaluate internal process variation without crossing the critical line of total surveillance. Once standard interfaces are defined for linking pervasive RFID platforms with existing hospital infrastructures, patient information can be appropriately formatted and transferred into electronic patient files. Other, further reaching options might be the use of embedded systems linking with remote databases outside the healthcare facilities. In some studies have shown that passive tags to not always scan correctly, and can have a success rate of just 66% (Bolotnyy, 2008). To overcome this problem, some authors suggest multi-tagging.

Although the feasibility of pervasive environments based on passive RFID in healthcare is proven, the technology is still waiting to be implemented on a large-scale scale. Reasons for this might be:

- fears of need for additional investment to upgrade existing hospital/healthcare IT
- concerns about the staff training required
- concerns that returns from the investment might not take place within a financial year
- lack of communication between industrial partners
- complex structure of decision-making processes in large institutionalised healthcare providers, such as government agencies, health maintenance organisations (HMOs), and so on
- lack of standards for application of RFID in healthcare.

Passive RFID technology is expected to spread rapidly based on its cheapness, and its improved security and user privacy (Chien, 2007; Kim and Choi, 2007; Kim et al., 2006a,b; Luo et al., 2005). An additional issue is that sooner or later multi-domain systems will occur where RFID tags belonging to different domains, will coexist in the same environment (Kim et al., 2007). In order to keep pervasive RFID systems stable, and to guarantee reliability, especially in highly sensitive areas like healthcare, there needs to be guaranteed functionality under extreme conditions, such as high performance processing is a highly important field of research (Wu et al., 2006).

Application research is also taking place in order to integrate the existing RFID technologies into frameworks and produce universal interfaces for future applications like intelligent homes (Corchado et al., 2008; Ho et al., 2005); bio-sensoring and health monitoring (Morak et al., 2007; Yang et al., 2008); Body Sensor Networks (Shinagawa et al., 2004); hospital controlling (Meng et al., 2008; Sangwan et al., 2005; Thuemmler and Morris, 2005); infection control (Wong et al., 2005; Zhuge, 2005); and robotic pharmacy dispensary (Florentinus et al., 2006). There is also ongoing research into the establishment of tracking models based on super-distributed RFID tags which looks promising and might be suitable for application in hospitals but not in the immediate future (Bohn, 2008).

There are several 2.4 GHz passive tag prototypes discussed in the literature but there are few case study regarding of the use of 2.4 GHz passive RFID technology in healthcare has been reported so far (Kitayoshi and Sawaya, 2005). Passive 2.4 GHz technology will eventually offer a longer range and therefore will be superior when competing with passive 13.56 MHz technology.

An interesting development is Google's Google Health, an individual electronic patient record, exclusively available in the US at the moment. Google might extend their services in the future so that patient flow data generated by RFID tags within a pervasive environment (Steinbrook, 2008). A similar product is equally available from Microsoft which is in the process of being piloted by Kaiser Permanente the largest US health maintenance organisation.[2]

4 RFID in patient ID

Patient ID is likely to drive the spread of RFID in healthcare, as it seems a more promising technology than other competing areas such as barcodes. The major problem with barcodes is that they often require a direct line-of-sight in order to be detected, and are prone to errors when the barcode label is washed out, crumbled, or affected by chemicals or blood. Bluetooth typically requires carrier medias, such as mobile phones or other powered devices, which are often not allowed in hospitals. Although a considerable amount of work has been done to develop NFC (Near Field Communications) for the use in healthcare, at this point in time the technology cannot be regarded as ripe, and more work needs to be added in order to support specific applications (Benyó et al., 2007a,b; Karduri et al., 2006; Leong et al., 2006; Ortiz, 2006; Strömmer et al., 2006). As an alternative, RFID is the intelligent replacement, and is a good solution for overcoming patient identification problems (Murphy and Kay, 2004) in healthcare environment. Another application area is in surgery, where relatively simple setups have been used to write and read relatively small amount of information to/from passive RFID tags, in order to eradicate medical errors and to prevent litigation (Birmingham Heartlands, 2005; Macario et al., 2006).

There has been a growing interest in passive tagging recently (Malkary, 2006), and most passive tags typically do not actually store extensive patient information A further advantage of the passive tag is that a passive tag does not need to be cleaned and disinfected as it is disposable, and they will not be reused. Furthermore, they are not prone to wireless spoofing attacks and other manipulations with criminal intent (Halamka et al., 2006). There are, though, possibilities for unauthorised access for active wrist-bands due the lack of a mechanism for authentication. They could thus be accessed and scanned by a third party to either identify the individual, or provide valuable data to market researchers or competitors to an organisation (Sarma et al., 2002).

Clinical trials with almost 1,000 patients have been conducted in Germany and the US, but in neither trial, used passive tags which were directly linked to the central hospital patient database (Collins, 2005). The main focus, though, for many RFID systems, is on active tagging which allows patients or machinery to be identified and located anywhere within designated areas (Wang et al., 2006). The disadvantage of these tags is that they are relatively expensive, although it has been successfully introduced to high-risk areas, such as neo-natal wards where child abduction has become a serious issue in recent years (Al Nahas and Deogun, 2007).

5 Patient monitoring and patient-flow

Apart from smart tracking solutions, RFID is already being used in a wide range of intelligent healthcare applications such as in an elderly healthcare system which monitors patient's medication intake (Ho et al., 2005). This research project by Intel focused on monitoring elderly activities by sticking tags on household objects and collecting information when the object was touched. This might help in the future to generate more accurate analysis of Activities of Daily Living (ADL) (Consolvo et al., 2004) in order to support further research in accident prevention, thereby improving elderly healthcare. Other more experimental areas of application of RFID cover hospital workflow monitoring by tracking equipments and patient transfers, dental moulds/implants, and the magic medicine cabinet (Wan, 1999).

Apart from patient safety issues, the research focus has currently been on exploring the usefulness of technologies to dynamically support managerial decision making processes (Dugas et al., 2008; Focke and Stummer, 2003; Mahaffey, 2004). Novel technologies, including RFID, could thus radically modernise the increasingly important process of data mining in hospitals and, in particular, in Accident and Emergency Departments, and could solve the problem of providing accurate, timely information for real-time patient flow monitoring with automated real-time patient flow analysis (Hoot et al., 2008; Isken and Rajagopalan, 2002; Thuemmler and Morris, 2005). The availability of real-time patient flow information will allow managers to take the appropriate steps to deal with the effects of unpredictable changes in the number of attendees, severity of conditions, case mix, and so on. This is usually summarised under the term: external variation. It also enables them to monitor and analyse the internal variation, which is a term covering those factors which relate to the hospital, to the individual differences in performance of teams, and so on (Litvac et al., 2005). Patient flow monitoring and analysis are important tools to eliminate bottlenecks from the process and to improve effectiveness and efficiency (Litvac et al., 2005). There is also a clear international trend towards the benchmarking of hospital performances and pervasive environments are likely to play a key role in this process (Sutherland et al., 2005). Some validated software tools for retrospective data analysis are available but are limited without the ability to perform prospective data mining and monitor patient flow in real-time (Bottle and Aylin, 2008).

The combination of intelligent predictive probabilistic algorithms such as Bayesian logic, fuzzy logic and genetic programming, with tracking matrixes, might allow, in the future, the use of data collected within pervasive environments to predict workload, bed occupancy and resource requirements. Having this information at hand when needed will be vital for hospital managers in the future to meet quality standards under growing budget constraints.

6 Location tracking patient positioning and asset tracking

Active RFID technology has been established as the method of choice for asset tracking in healthcare facilities. Increasing numbers of hospitals use active RFID technology to tag their high-cost equipment, such as defibrillators, infusion pumps, and ventilators. This helps to protect it against theft and unauthorised use, along with locating equipment which has high demand and limited availability, such as wheel chairs, special lifting equipment, special beds, and so on. Once tagged with an active RFID tags, the objects can be tracked down easily to a close proximity (Coyle et al., 2006).

Active tags can either be tracked done by triangular positioning (Heo et al., 2007), or by signal strength detection (Krishnakumar and Krishnan, 2005; Z'aruba et al., 2007). Both techniques can gain additional functionality by linking them with GSM (Global System for Mobile Communications), SMS (Short Message Service), or WebGIS (Web Geographic Information System) (Al-Ali et al., 2006; Guillemette et al., 2008; Meng et al., 2008). Satellite tracking (GPS) does not typically work within buildings, but new applications are being developed for wandering demented patients (Vargas, 2006), and the tracking of staff using a hybrid RFID-RTLS-GPS system (Guillemette et al., 2008). In experimental settings, active RFID Indoor Positioning Systems (RFID IPS) has been shown to streamline patient flow, improve equipment management and staff efficiency although ethical and social issues require further discussion and investigation (Dempsey, 2005; Fisher and Monahan, 2008).

7 RFID in infection control

RFID is used extensively in many application domains, especially in B2B (Business-to-Business applications), but the health market has been slow to adopt it. There is, though, increasing pressure from Governments to adopt it, in order to improve patient safety. A Frost and Sullivan report in 2008 outlines the increasing needs for awareness of nosocomial infection (an infection which is gained within hospital care), and there is an increasing regulatory environment for this, where many Governments around the World are moving to overcome this problem. The drivers for this include increasing infection control awareness; increasing press coverage (especially for MRSA); and through educational objectives.

At present most companies in the area of infection control focus on disinfectant solutions, which is obviously important, but does not give the full auditable solution as RFID tagging does and can also result in strains resistant to disinfectants. Some companies have also used RFID technology to monitor employees and patients washing their hands, but again this does not give a complete picture of the whole of the healthcare infrastructure.

A key element to the deployment of RFID for infection tracking is to provide a strong business case to show the payback in terms of costs. The annual cost of Hospital Acquired Infection has been highlighted by many sources, such as in Massachusetts, to be more than $400 million, and $30 billion across the whole of the US. In the US, for example, there is now a move towards inspections of hospitals, where state inspectors are sent to hospitals to ensure that they conform to basic rules on infection spreading to patients. Along with this there is even a move towards posting infections rates for itemised infections within hospitals, such as knee and hip surgeries.

8 Issues facing passive RFID technology

At present the general use of active RFID technology in hospitals, in terms of patient monitoring, patient-flow and capacity management, is limited to very few locations. The main reasons for this limited scope are:

- *Cost effectiveness*. The price of active tags is still in the range of $40, which is far too high for routine use in patient tracking. This price would have to come down significantly to be acceptable to healthcare providers.
- *Hygiene*. There have been suggestions in the past to clean and disinfect used active tags, and reuse them in hospitals in order to produce a workable business case for active patient tracking. There can be no doubt that with professional equipment, and

with an appropriate level of care, active RFID devices can be cleaned and disinfected properly, and the likelihood of patients being infected by a reused device seems to be negligible. Nevertheless, many hospitals are extremely concerned about litigation issues and even the smallest possibility of being found guilty of having put patients at risk causes extreme scepticism. Given the preference for disposable articles over the last 30 years in the healthcare industry, and the growing concern over hospital acquired infections in hospitals, the concept of reusing disinfected active tags seems to be anachronistic and acceptance is low.

- *Security issues*. Unlike passive tags, active tags offer a relatively large storage in order to capture patient information. This makes patient data easily accessible in healthcare facilities and allows easy transfer of information between several sectors of health and social care. Unfortunately this leads to a major security problem in case of a patient tag being lost or stolen.
- *Ethical issues*. Active tagging allows virtually unlimited surveillance if it comes to matters of location and time. This might be perceived by some as too much of a good thing and some patients might fear breach of privacy. If used for human resources management purposes there are definitely questions which still need to be answered, such as rights of employer for tracking employees. Is it ethical to track down the employee and record their activities at any given moment when at work, and so on? Many employees fear an abuse of the data collected by their employer. On the other hand many employers are reluctant to risk conflicts with their employees, and the organisations representing the workforce like trade unions or professional societies are suspicious about these kinds of issues, as very little legislation and very few court rulings are available. So the introduction of active RFID tagging of individuals might give a reason for legal conflicts, bad publicity and as a worst case scenario industrial actions.

Internationally, there seems to be frustration regarding the speed of the spread of RFID technology on both sides of the negotiation table. The manufacturers of RFID devices are unhappy about the lack of solid business cases and the healthcare providers are waiting to be presented with a compact, out of the box RFID solution. In fact it seems that there is a lack of communication between the industries which needs to be overcome in order to achieve a breakthrough with a much needed technology. In the UK recently the UK Working Group on RFID in Health Care has been launched in an attempt to close information gaps and bring the different camps of manufacturers and potential users of RFID closer together.[3]

9 Conclusions

RFID technology is a mature technology which offers ample opportunity for healthcare providers to improve patient safety, quality of care and the utilisation of system resources. Passive and active RFID technology must not be understood as competing technologies, but complement each other when intelligently integrated in compact frameworks. A key factor to the future adoption will not only be in terms of the technology, but will be on patient and healthcare practitioner acceptance, along with overcoming the sometimes negative and often ignorant or simplistic viewpoints on RFID in healthcare. The applications of the technology will be key, as these will show the benefits in the environment. Typical useful examples include patient ID, patient flow analysis, and infection control auditing, which can be seen as obvious areas where patients would want to opt-in to an RFID tagging system. Without definite paybacks in terms of financial benefit, and a reduction of patient risk, the healthcare system will not actively adopt RFID. A key focus must thus be on making the technology as pervasive as possible, without affecting the operation of the healthcare professionals, or the patients, and also in making sure other issues such as security, device interference and contamination are overcome.

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Notes

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