The Use of RFID in Healthcare: Benefits and Barriers

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***Abstract*—Radio Frequency Identification (RFID) technology not only offers tracking capability to locate equipment and people in real time, but also provides efficient and accurate access to medical data for doctors and other health professionals. However, the reality of RFID adoption is far behind earlier expectation. This study reviews the literature on RFID applications in healthcare based on a formal research framework. We aim to identify current opportunities, potential benefits and adoption barriers. Our study shows that most care providers indicated that RFID to be functional and useful in asset tracking and patient identification. Major barriers to RFID adoption in healthcare include prohibitive costs, technological limitations, and privacy concerns. Although RFID offers healthcare practitioners advantages to enhance clinical practice, better designed RFID systems are needed to increase acceptance and proper use of RFID in healthcare.**

I. Introduction

RADIO Frequency Identification (RFID) is a fast developing technology that uses radio waves for data collection and transfer; it can capture data efficiently and automatically without human intervention. RFID is believed to be the next generation innovation for automatic data collection and asset tracking. Although the technology is attractive in its obvious advantages over other identification technologies such as bar coding, its adoption and diffusion lags behind the optimistic expectation of the early years. For a variety of reasons, adoption of RFID by healthcare has been sluggish because the payback is less immediately visible than what most companies prefer. Although costs are decreasing, many companies are still reluctant to invest in a technology not yet widely adopted [1]. RFID shows great promise in helping healthcare improve patient safety and achieve operational efficiency, but it also presents implementation challenges such as interference with medical devices, privacy concerns, prohibitive costs, and lack of global standards.

Given the current implementation pace, this paper systematically and comprehensively reviewed the literature on the use of RFID in healthcare. We provide an introduction to the RFID technology, its use in healthcare, advantages, and barriers on the basis of published research work. This paper aims to identify the potential applications of RFID in healthcare from multiple perspectives. We examined the potential benefits of RFID as a driver that will promote its adoption and identified the barriers to their acceptance in healthcare. The organization of this paper is as follows. Section 2 discusses research methodology and motivation. We review critical problems faced by healthcare and common applications of RFID in healthcare in section 3. The adoption benefits and barriers are presented in section 4. Finally, section 5 provides implications and guidelines for RFID implementation and concludes the paper.

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II. Methodology and Framework

A. Review Methodology

We use a systematic method, which is divided into three phases: literature collection, categorization and analysis (see Fig. 1.), to guide our literature review,

Fig. 1. Review methodology

1) Literature Identification and Collection: The literature search was conducted with the help of library search engines available at the Penn State library. We used professional databases, including Medline, ABI/INFORM, ACM Digital library, Elsevier, IEEE Explore, and Springer. In addition, general search engines such as Google Scholar were used to supplement this process. Since the use of RFID in healthcare industry is quite recently, we did not limit our search to any publish date. The search was performed in early June and repeated at the end of December in 2009 to ensure that our literature review is most up-to-date and comprehensive.

For our searches, we employed the following keywords and their combinations: RFID, healthcare, hospital, health and medicine in the searching areas of title, keywords or abstract. Journal and conference papers addressing all healthcare providers and their uses of RFID were identified. Technical reports were excluded since we focus on research papers. More than 148 indexed articles were identified and 90 of them were reviewed based on their relevancy. Bibliography management tools such as Firefox plug-in

"Zotero" and EndNote were used to help manage the references and citations.

2) Literature Categorization and Research Framework: In the second stage, collected literature was classified into several categories based on the proposed research framework, which will be introduced in the next section. With the guide of this framework, we identify why RFID is attractive to healthcare, how it is applied in different areas, and what technologies are used in practice. Meanwhile, research papers that discuss the potential benefits as incentive factors in RFID adoption and barriers that impede RFID implementation are also categorized in this framework.

3) Literature Analysis, Evaluation and Implications: The last phase followed our proposed research framework and conducted detail analysis with regard to the literature. We proposed some useful suggestions and implications (e.g., the most popular application, the perceived benefits and critical barriers) for researchers in this area.

B. Research Framework

Figure 2 depicts the logical process of RFID adoption in healthcare. To better understand how RFID can help improve healthcare practices, we first identify the existing problems and challenges faced by this industry. Then we study how RFID is applied in different application areas to solve or partially solve these challenges. By analyzing the research prototypes, pilot studies, and case studies in our collected literature, we identify the benefits and barriers of RFID adoption in healthcare. These implications can be used to guide future research in this field.

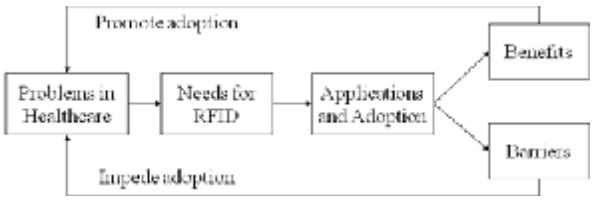

Fig. 2. Research framework

C. Related Work

Although RFID technology is starting to make inroads into healthcare, literature that systematically examines its potential in healthcare is still lacking as compared to those in the retail and the supply chain industry. On the one hand, compared to other technologies such as PDA, RFID is not widely adopted in healthcare. On the other hand, healthcare is a complicated application domain and presents its unique features. A few studies have contributed to literature review in this area. For example, [2] reviewed different ways how RFID systems are being used in hospitals. They focused on the applications and failed to discuss the benefits and barriers. Thus, their study is not very helpful for making adoption decision. In contrast, [3] analyzed the potential benefits, implementation challenges and strategies. However, their review is more industrial oriented and does not follow a formal research framework. Other studies [4]-[6] also gave an overview of the current research in applications of RFID in hospitals but they are not comprehensive. Existing pilot studies and research works were not included.

Clearly, there is an urgent need to conduct a systematic review of literature toward RFID applications, benefits and barriers in healthcare. Our review aims not only to provide a state-of-art assessment for other researchers but also to offer a useful guidance for implementing RFID-enabled systems for healthcare administrators.

III. RFID APPLICATIONS IN HEALTHCARE

A. The RFID Technology

The main components of an RFID system include the hardware (tags, readers and antennas) and the software systems. RFID tags can be passive or active, depending on powering techniques. Passive tags can only communicate with the reader when they are sitting in an electromagnetic field of the reader since they do not have battery power; while active RFID tags can power the integrated circuits and broadcast the response signal to the reader.

An RFID reader scans the tag and sends the tag information to the back-end database system that filters, analyzes, and stores the data and then passes on useful information to other enterprise application systems for further processing. The database system can have multiple readers located in different places sending data through wired or wireless networks. In addition, enterprise application systems, such as hospital information systems (HIS) and supply chain management systems, can connect to the middleware to retrieve tags information via security protocols. In healthcare, RFID systems are usually combined with other technologies such as Bluetooth, mobile devices, and sensors for different purposes. Passive RFID tags are primary used for patient identification and drug authentication while active RFID tags are mainly used for the tracking purpose.

B. The Needs of RFID in Healthcare

Hospitals are currently facing challenges of improving patient safety and reducing operational costs, which are often compromised by human and systemic errors. The Institute of Medicine (IOM) estimated that between 44,000 and 98,000 deaths per year were related to medical errors, showing the desperate need to improve the patient safety in U.S. hospitals [7]. Meanwhile, achieving high operational efficiency in healthcare is another essential goal for organizational performance evaluation [8]. Five problems are identified as the common phenomena that lead to healthcare operation failures including: medical mistakes [9], increased costs [3], theft loss [9] [10], drug counterfeiting [11], and inefficient workflow [12].

1) Medical mistakes: Medical errors have become a leading cause of death, killing more people each year than AIDS or airplane crashes. The IOM estimated that "tens of thousands of deaths and injuries are caused by medical mistakes each year" while the Food and Drug Administration (FDA) estimated that number to be nearly 500,000 [9]. However, the FDA also estimated that half of the drug errors

are preventable by adopting the appropriate information technologies. Medical malpractice can come from patient misidentification which is recognized as a serious risk to patient safety [13], adverse drug events, infant missing or mismatch, and accidents like sewn-up of surgical tools inside the patient body after the operation.

2) Increased cost: Hospitals are actively seeking solutions to reduce the rising healthcare expenses as well as not adversely affecting patient satisfaction. According to [3], a good health information system could save economy $140 billion a year. That is about 10% of our total health-care spending, and that's a conservative estimate.

3) Theft loss: It is estimated that the theft of equipment and supplies costs hospitals $4,000 per bed each year, which represents a potential loss of $3.9 billion annually with over 975,000 staffed beds in the U.S. [10]. Thus, tracking medical devices, especially expensive assets, is of upmost importance. Besides, some recyclable medical instruments are unnoticed and discarded by the cleaners without medical knowledge.

4) Drug counterfeiting: Tempered or altered products entering the healthcare supply chain is a growing concern [1]. The FDA estimated that up to 40 percent of the medicines shipped from countries such as Colombia and Mexico may be counterfeit, which caused a huge problem for people's health and the society [11]. The pharmaceutical industry reported that it loses $2 billion per year due to counterfeiting drugs. Both consumers and manufacturers are looking for ways to keep drugs safe [1]. Item level RFID tagging is believed to be the best solution against counterfeit drugs.

5) Inefficient workflow: Inefficient workflows exist in every hospital because of the difficulty in allocating resources in real time. For example, doctors and nurses wasted over 30 percent of their working time searching for or reading information about patients [14]. Most medical facilities practiced managing the large number of seriously injured patients expected during catastrophic events. During mass casualty events, as the demands on healthcare teams increase and the challenges faced by managers escalate, workflow bottlenecks begin to develop and system capacity decreases as well [15].

C. RFID Applications in Healthcare

RFID has been applied in a variety of healthcare practices. We investigated a total of 55 research papers to identify the cutting-edge hospital applications, which is organized in five categories in terms of system functionalities: tracking (16 papers), identification and verification (11 papers), sensing (6 papers), interventions (12 papers), and alerts and triggers (14 papers). Several papers described more than one application so they are analyzed in more than one category. Table I summarizes the diverse venues of the collected papers, including journals and conferences in information technology, medicine, surgery, and forensics.

TABLE I
DISTRIBUTION OF LITERATURES FROM DIFFERENT SOURCES

Journal/conference	Number	%
IEEE Engineering in Medicine and Biology Society	7	12.73
Studies in Health Technology and Informatics	4	7.27
AMIA Symposium	4	7.27
Journal of Medical Systems	3	5.45
Forensic Science International	2	3.64
Journal of Healthcare Information Management	2	3.64
Surgical Endoscopy	2	3.64
Others	31	56.36

1) Tracking: Tracking assets and equipment is the most widely used application in hospitals. Passive RFID tags are used to track telemetry transmitter in Hartford Hospital, Connecticut, USA [16]; active RFID tags along with barcode are used to track infusion pumps, beds, and wheelchairs in a 120 bed acute-care hospital [7]; Brigham and Women's Hospital in Boston, USA used RFID tags to track commonly lost medical items [17]; RFID-based robots were deployed by FirstHealth Moore Regional Hospital, North Carolina, USA to track valuable assets [18]; Reference [19] evaluated an infrared/RFID equipment tracking system in a tertiary care hospital and observed increased use of infusion pumps as a result of efficient tracking capability offered by the RFID technology.

RFID is moving beyond the perception of being solely an asset tracker and increasingly viewed as a technology that can improve care by tracking vulnerable patients, e.g., elderly dementia patients [20], children [21], and newborn [22]. Further, RFID is used to accurately determine the location of victims and staff at the emergency site [15] [23]. Hospital staff tracking is also presented as a prototype [24]. Compared to asset tracking, people tracking is more challenging since it involves patients, doctors, medical know-how and other organizational, privacy and social issues [25].

Tracking drugs from creation to receipt is applied in the pharmaceutical industry, to alleviate drug counterfeiting, theft, and misuse of medications [3]. Medicine bottles are being fitted with RFID tags to detect fake drugs moving through the supply chain [26]. Purdue Pharma announced to place RFID tags on bottles of pain reliever OxyContin to protect drug safety [27]. Besides, RFID is used to track other medical supplies that are sensitive to environment, e.g., blood bag [28].

2) Identification and Verification: Misidentification is one of the major sources of medical errors and it can be reduced by RFID. Positive patient identifications (PPI) applications include using a smart patient wristband that when scanned by a RFID reader reveals patient information such as name, date of birth, admitting orders, insurance information, and the surgical site [13]. A patient identification system has been implemented and evaluated in the University College Hospital in Galway, Ireland, to improve patient safety [13]. It can also support nursing shift exchange to save time and efforts [29]. PPI applications also include newborn identity reconfirmation [22] and disaster victim identification (DVI) [23]. The placement of the RFID chip inside victim bodies

was proved practical by the Austrian DVI team in Thailand in early 2005 [23]. Beth Israel Deaconess Medical Center found that a combination of bar codes, passive RFID and active RFID worked well for patient identification in their pilots study [30]. Besides, implantation of an RFID tag into human molars is used in security and access control [31].

ID-based system using RFID technology can also be used for automatic identification of medical articles in hospitals [32] [33]. Mount Sinai Hospital of New York conducted pilots on tagging contrast agent syringes with details on the volume, name, as well as the expiration date of the product [34]; a new specimen-labeling system that uses RFID was proved to be useful in reducing specimen labeling errors in the pathology laboratory [35]; RFID tag-labeled endotracheal tubes have been used for accurate bedside monitoring of endotracheal tube position [36] to reduce health risk to patients. In addition, these specimens can be uniquely and accurately linked to a patient's records so as to prevent human errors.

3) Sensing: An RFID tag can be applied to collecting sensor-derived data and doing computation by extending the chip's interface capability to a sensor. Sensing applications of RFID include integration with physical and chemical sensors for logistic data logging [37], and integration with gas sensors for food logistics [38]. Others include temperature sensing [39], humidity sensing [40], and chemical sensing [41]. In hospitals, temperature sensing makes it very convenient to track tainted blood to aid in protecting a hospital's blood supply; chemical sensing can support advanced medical monitoring. In the future, RFID tags will likely be used as environmental sensors on an unprecedented scale [42].

4) Interventions: RFID-enabled interventions can provide automated care, improve current procedure, guide pathway, enable automatic data capturing and collaboration, etc.

First, automated care is helpful for patients at home, e.g., a self pill-dispenser to help patients take their dose safely [43], and an assisted living system to support daily activities for visually sighted or brain injured people [44]. Second, RFID interventions can help alter current procedures and automate manual process in hospitals, e.g., automatically determining patient discharge time [45]. Furthermore, one-stop healthcare services enabled by RFID are possible to serve smoothly from registration to examination, treatment, prescription, and next reservation to improve workflow efficiency [46].

Third, finding pathways for patients in the indoor environment can be accomplished by RFID, such as an indoor navigational system for blind or visually impaired people [47] [48]. Reference [49] installed a map information system on a white cane to inform the patient using colored guideline and vibration. An RFID-based navigation systems was deployed in 18 elderly people's homes in Southern Spain and it has more than one year of validation [50].

Fourth, currently data collection in hospitals is done manually. This process is time consuming and error prone. Fortunately, this problem can be solved by RFID. The Capital Regional Medical Center in Tallahassee, USA has analyzed such data to identify the current hospital functioning status under the scenarios of low or moderate patient load [51]; researchers from the simulation community collected data through RFID on a consulting engagement at a hospital [52]. Collaborating with HIS, RFID can help build intelligent clinical diagnosis and treatment support system [53], which is applied in Alfred hospital, Melbourne, Australia. Lastly, with the data logged by RFID, hospitals can provide an audit trail of the equipment and staff involved, in the event of an incident with patients [54].

5) Alerts and triggers: Applications involving alerts and triggers are designed to protect patient from dangerous events or emergencies during the surgery, blood transfusion, drug administration, hand hygiene monitoring, etc.

In the surgical environment, 1,500 objects are estimated left inside patient bodies after surgery each year in the U.S., and two-thirds of them are sponges [55]. To solve this problem, a handheld wand scanning device was proposed to detect sponges inside the patient body [55]; a similar experiment was conducted with a detection accuracy of 100% [56]; use of gauze sponges with embedded passive RFID tags was tested with an animal and proved useful [57]. RFID applications are examined in surgery and believed to make patient care safer [58].

During blood transfusion, it is important for a patient to receive the safest blood possible, which is done by tracking the donated blood to guarantee the quality of the blood source [59]. Reference [60] estimated the error rate for blood usage to be one out of 14,000 in the U.S. and suggested adding an RFID layer to the blood safety loop. A prototype adopted a fingerprint sensor with RFID, so as to ensure the process of identifying blood donor more reliable and credible [59].

Drug administration can be improved by alerting care providers any critical situation. A dosage system presented by [61] used PDA to scan the barcodes on the drug package and the RFID wristband carried by a patient, to alert drug mismatch, over-dosage or drug errors; other prototypes for monitoring drug compliance include smart cabinet and smart refrigerator [62], home robot based on facial recognition [63], and an electronic health record synchronized system [64]. Such applications usually combine RFID with other technologies such as sensor networks [65], barcode [66], and text-to-speech technology [14]. Taichung Hospital in Taiwan deployed a drug administration system and showed effective reduction of medication errors [67]. Other uses can include tube and syringe monitoring, hand hygiene monitoring, etc.

IV. Benefits and Barriers

A. Benefits of RFID in Healthcare

RFID adoption in healthcare can not only reduce cost and improve efficiency by tracking asset and people, but also reduce medical errors to improve patient safety and save lives. Table II summarizes the potential benefits that can promote RFID adoption.

TABLE II
BENEFITS OF RFID APPLICATIONS IN HEALTHCARE

Benefits	Findings
Increased safety or reduced medical errors	Reduce misidentification of patients [13], medical articles [32] [33], patient chart and images [54]. Improve patient drug compliance by monitoring dosage taking process [61] [63]. Affection control during disease fashion [73].
Real-time data access	Provide real-time data access for health professionals via hand-held wireless PDA, e.g., contact history of patients [74], online laboratory data and radiology report [75].
Time saving	Identify empty beds >20 minutes earlier 67% of time [45]. Identify a time reduction of more than 50% in the daily activities of hospital staff [69].
Cost saving	A 500 bed hospital could save $1 million annually [12]. Reduce theft loss [16] [25] and unnecessary waste [72]. Bon Secours Richmond Health System finds RFID saves $2 million annually by real-time location system [76].
Improved medical process	Streamline patient admission to ICU [75]. Process can be improved so patients can have less waiting time and enhanced care experience [54] [73].
Other benefits	Improve drug supply [27] [71], improve resource utilization [19] [72], improve patient satisfaction [3].

1) Improved patient safety or reduced medical error: The primary goal of applying RFID technology in healthcare is to improve patient safety. First, RFID is a valuable tool for quickly retrieving patient information and monitoring patient location in hospitals so as to improve the accuracy of patient identification [13] and any medication a patient is taking [61] [63]. Second, alerting services can identify possible human errors and warn care providers in case of danger. For example, automatic sponge counting by RFID can avoid sponge left inside the patient body [55]. Third, finding the required equipment with minimal delay can save patient life [12]. Fourth, integrating RFID with existing HIS can improve decision making by accessing patient information in real time accurately. Further, RFID-based tracking system can improve personal safety and security by better access control.

2) Time and cost saving: Another critical challenge faced by healthcare is increased costs which can be reduced by several approaches. For example, RFID-based asset tracking and monitoring system can help prevent valuable assets and equipment from being stolen [16] [25]. Other benefits include improving staff productivity, decreasing equipment rental, and improving regulatory compliance [2] [68]. Doctors and nurses in their daily activities can save a lot of time searching for medical devices and can focus on their professional duties [69]. These improvements can in turn reduce medical costs, as much as $1 million annually for a small-scale hospital [12].

3) Improved medical process: Hospitals want to improve the patient workflow and the operational process so as to save costs and enhance patient satisfaction. With automatic data capturing and storage capability of RFID, manual processes which are typically employed to record data can be automated. RFID has the potential to significantly improve operations by actively monitoring asset and patient flow through the hospital [70]. Besides, the recorded data can be analyzed to improve hospital efficiency [51].

4) Others benefits: RFID technology brings other benefits such as protecting drug supply [27] [71], improving resource utilization [72], and enhancing patient satisfaction [3].

B. Barriers to RFID Adoption

Deploying RFID technology in the healthcare industry for promoting patient safety is a complex issue since it involves technological, economical, social, and managerial factors. Table III summarizes the major barriers and findings from collected literature.

1) Technical issues: Technological limitations of RFID can impede its adoption especially for healthcare. First, RFID may interfere with the hospital environment [6] [72], e.g., medical devices [77]. Second, RFID systems are not always reliable. RFID read accuracy depends on a variety of factors such as tagged object, tag placement, angle of rotation, and read distance [78] [79]. Last, lack of commonly accepted industrial standards prohibits RFID deployment in large scale, including standards of RFID data structure, air-interface, and local interface. Health Industry Business Communication Council (HIBCC) has been working on establishing common standards for healthcare systems.

2) Cost: RFID costs include initial hardware and software costs, training, as well as the continuously high costs of RFID infrastructure maintenance and upgrade. The infrastructure requires not only tags and readers, but also additional servers, databases, middleware and applications. Each passive RFID tag costs approximately 10 cents and active one costs several dollars, compared to 3 cents per barcode sticker [68]. The difference in total cost can be substantial if all equipment and patients are tagged. In addition, RFID integration with back-end systems and data synchronization networks is needed to make RFID viable. The total cost can be huge.

TABLE III
BARRIERS TO RFID ADOPTION IN HEALTHCARE

Barriers	Findings
Interference	Electronic medical devices may fail in the presence of high-power RFID reader [85]. In 123 Electromagnetic interference (EMI) test, RFID include 34 EMI incidents: 22 were classified as hazardous, 2 as significant, and 10 as light [77].
Ineffectiveness	Tag placement is one of the main factors involved in correct identification of people and medical equipment [78]. RFID tag readability is strongly dependent on the factors such as dosage form, angle of rotation, read distance [79]. Readability can be affected by insufficient read range, and existence of multiple tagged objects [70].
Standardization	The lack of standardization of the protocols for RFID at the hardware and software levels causes lack of interoperability across providers [82].
Cost	RFID infrastructure can run from $200k to $600k for a tracking system in a medium-sized hospital [86]. Integration costs can range from $3 to $16 million [32] . An RFID system can run from $20k to over $1 million [87]. A typical 800-bed hospital spends additional $1,050 per day in medication tagging alone [68].
Privacy and legal issues	Privacy concerns can include inappropriate collection, intentional misuse, or unauthorized disclosure of healthcare information resulting from use of RFID technology [80]. RFID systems introduce a key ethical concern regarding privacy because of its surveillance potential [82].
Other barriers	Lack of organizational support [82], trust issue [83], unclear return on investment [88], security

	concern [84],current RFID systems not designed for needs of hospitals [82].

3) Privacy concerns: The benefits of using RFID in medical settings are achievable only if patients are confident that the data being transmitted will not be misused [80]. When an RFID tag is associated with a patient, it can contain the unique identification number that associates with any type of personal information, such as patient name, gender, home address, and medical history. This information is highly mobile and sensitive. Thus, healthcare organizations should ensure neither personal nor confidential information is transmitted via RFID. Such data should be stored in a secure server in compliance with the Health Insurance Portability and Accountability Act (HIPAA). Besides, to relieve the anxiety of hospital staff and patient, it is important to tell them the purpose of this data collection [52]. However, a 2007 national public opinion survey of 1404 Americans revealed that interest in RFID personal medical technology was positively associated with high levels of trust in others and social supports [81]. Only a small minority were negatively disposed toward such applications [81]. As the technology is regulated by more legislative bodies, public concerns will be alleviated.

4) Other barriers: Other barriers to RFID adoption include the lack of organizational support [82], trust issues [83], security concerns [84], etc.

V. DISCUSSIONS

RFID applications have attracted attentions and interests from diverse research communities in medical informatics, computer science, industrial engineering, electric engineering, etc. Useful and novel applications have been designed and evaluated in laboratories and hospitals.

The most widely accepted and adopted application is asset and equipment tracking since it is badly needed by hospitals and does not involve privacy and social issues. Asset tracking applications can reduce theft, improve resource utilization and save costs. A number of pilot tests and small-scale projects in hospitals have proved that. In contrast, people related applications such as patient tracking are more complicated since there are major concerns about privacy issues. One popular research topic is the patient drug compliance since it can largely reduce medical errors associated with the medicine taking process. Although drug administration systems can help improve patient safety, most of them are still in prototype stage and not yet accepted in hospitals. Once social and privacy issues are solved by improved technology and consolidated legislations, hospitals will soon adopt patient related applications to reduce medical errors and improve patient safety.

RFID suggests a digital infrastructure that changes the way of care delivery and it has the possibility to revolutionize the healthcare industry. With automatic data collection, RFID enables ubiquitous collecting of hospital data, provides strategic services to patient-centered recording, and uses these medical data for cooperative care. The real value of RFID can be realized when it is integrated with existing HIS. It can provide valuable process-integrated decision support through current medical knowledge. In addition, it can comprehensively use patient data for research and healthcare reporting. Several studies envision the future of an RFID-enabled smart hospital that uses RFID and wireless technology to provide a variety of applications [89] [90]. This will benefit vulnerable people such as the elderly.

The top benefit is recognized as improved patient safety and reduced medical errors. Besides, care professionals in their daily activities can save a lot of time searching for medical devices. Also, they have real-time access to patient related data, so they can focus on their professional duties. Other benefits include cost saving, improved medical process, and enhanced patient satisfaction. As the healthcare industry is investing more money and efforts, RFID is expected to be able to help achieve the two goals of reducing costs and improving patient safety.

However, healthcare presents unique challenges for RFID adoption. Major barriers to RFID adoption are identified as prohibitive costs, technological limitations, and privacy concerns. We provide the following suggestions to healthcare stakeholders toward successful implementation of RFID systems.

First, the stakeholder should perform a sound and clear return on investment (ROI) analysis of an RFID project before implementing it. The main issue is to compare the total costs of implementing a RFID system and the total saving by using this system. The cost saving can come from many sources such as optimized workflow, reduced medical error, and improved service quality. Patient satisfaction and staff productivity should also be evaluated.

Second, RFID performance in hospitals should be tested to rule out technological deficiencies. Several studies have shown hazardous interference between RFID signals and medical equipment. Besides, RFID is not always reliable and 100% accurate. Countermeasures to these problems, such as using middleware to improve data quality or using multiple readers to increase data accuracy, should be carried out to improve the system performance.

Third, patients and medical staff should be educated about the RFID technology so they have a better understanding on the benefits and possible privacy issues. Once they realize that RFID can help improve their safety and reduce medical errors, they will be more convinced to wear RFID tags and worry less about their privacy.

Fourth, technology vendors should act positively to customize RFID systems for hospital needs and make it interoperable with existing HIS since hospitals can vary a lot depending on the location, age size, etc [82]. For example, to reduce costs, bar codes and existing wireless network can be combined with RFID technology; to add new features in the future, RFID systems should be designed with the capability of modifying and removing services.

To sum up, the RFID technology offers healthcare practitioners advantages to improve patient safety, save time, and reduce costs but also causes critical issues for successful implementation. To increase the acceptance and wide use of RFID in healthcare, more customized RFID systems, more institutional support, seamless integration with existing HIS,

satisfactory security/privacy measures, and mature regulations to protect privacy are needed.

REFERENCES

[1] J. Reiner and M. Sullivan, "RFID in healthcare: a panacea for the regulations and issues affecting the industry?," in *Healthcare Purchasing News*, 2005.

[2] Anonymous, "Radio-frequency identification: its potential in healthcare," *Health Devices,* vol. 34, pp. 149-60, 2005.

[3] A. M. Wicks, J. K. Visich, and S. Li, "Radio frequency identification applications in hospital environments," *Hospital Topics,* vol. 84, pp. 3-8, 2006.

[4] H. A. Nahas and J. S. Deogun, "Radio frequency identification applications in smart hospitals," in *Proceedings of the 20th IEEE International Symposium on Computer-Based Medical Systems*, 2007, pp. 337-342.

[5] A. Lahtela, "A short overview of the RFID technology in healthcare," in *4th International Conference on Systems and Networks Communications*, 2009, pp. 165-169.