LEVERAGING RFID IN HOSPITALS: PATIENT LIFE CYCLE AND MOBILITY PERSPECTIVES

Andrea Cangialosi and Joseph E. Monaly, Jr., California Institute of Technology
Samuel C. Yang, California State University

ABSTRACT

The application of Radio Frequency Identification (RFID) to patient care in hospitals and healthcare facilities has only just begun to be accepted. This article develops a set of frameworks based on patient life cycle and time-and-motion perspectives for how RFID can be leveraged atop existing information systems to offer many benefits for patient care and hospital operations.

It examines how patients are processed from admission to discharge, and considers where RFID can be applied. From a time-and-motion perspective, it shows how hospitals can apply RFID in three ways: fixed RFID readers interrogate mobile objects; mobile, handheld readers interrogate fixed objects; and mobile, handheld readers interrogate mobile objects.

Implemented properly, RFID can significantly aid the medical staff in performing their duties. It can greatly reduce the need for manual entry of records, increase security for both patient and hospital, and reduce errors in administering medication. Hospitals are likely to encounter challenges, however, when integrating the technology into their day-to-day operations. What we present here can help hospital administrators determine where RFID can be deployed to add the most value.

INTRODUCTION

The application of Radio Frequency Identification (RFID) to patient care in hospitals and healthcare facilities is just beginning to be accepted. The technology offers great potential benefits and is the next big step in identifying and tracking patients, objects, and assets, and speeds up or eliminates many manual operations in checking and processing patients. It can, for example, automate the admitting, screening and treating processes, enhance communications between caregivers and support teams, and reduce medical errors [1]. To reduce such errors, some hospitals have started utilizing wristbands embedded with RFID chips for identifying patients electronically and matching those patients to necessary surgical procedures [2].

Despite the many potential benefits, less than 10 percent of U.S. hospitals have adopted RFID [3]. This article considers where the technology can be applied to improve patient care and hospital operations. We do so by examining the current process used to manage patients from admission to discharge, and present a framework for a patient's life cycle in the hospital. We also discuss from a time-and-motion perspective how hospitals can implement an RFID system, and we examine the challenges to be faced.

THE ID TECHNOLOGY

RFID relies on radio energy to enable a remote device (the tag) to communicate with a base station (the reader, or interrogator) some distance away. The system relies on storing and retrieving data on these RFID tags. A tag contains writable memory, which stores data for transfer to the RFID readers. The data is then processed according to the needs of a particular application.

An RFID system consists of several components: tags, tag readers, and application software. The tag contains a transponder with a digital memory storing a unique electronic identifier, as well as information about the object it's attached to. The reader consists of a transceiver, decoder, and antenna. The reader reads from and, if necessary, writes to the tag, relying on a signal it emits that activates the tag so it turns into a transmitter. Such automatic tag reading allows great amounts of data to be transmitted at once, speeding up operations while improving accuracy and productivity. The readings do not require direct contact or line of sight between tag and reader.

Active RFID tags contain their own power source, usually an on-board battery. *Passive* tags obtain power from the signal of an external reader. *Semi-passive* tags are a variant of passive tags where a battery is included with the tag, but the tag must be excited by a reader to transmit data [4] (Table 1).

Active tags operate at higher frequencies-commonly 455 MHz, 2.45 GHz, or 5.8 GHz-depending on an application's read range and memory requirements. Readers can communicate with active RFID tags up to 500 meters away. Passive tags typically operate at frequencies of 128 kHz, 13.6 MHz, 915 MHz, or 2.45 GHz, and have read ranges of a few centimeters to 10 meters [5, 6].

THE PATIENT LIFE CYCLE FRAMEWORK

How RFID can be applied to improve operations can be understood from the perspective of a patient's life cycle in the

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Characteristics	Active	Passive
Power Source	Battery	From reader
Read Range	< 100 m	< 10 m
Frequency	433 MHz, 2.4 GHz	125 kHz, 13,56 MHz, 860–960 MHz

Table 1. *Comparison of different RFID systems [4].*

hospital. Many hospitals track their patients using manual systems. Typically these are paper-driven, utilizing everything from whiteboards, cards, and charts to self-adhesive notes. The patient life cycle has six stages (Fig. 1):

Admission

The first step in admission to a hospital usually involves paperwork filled out by both patient and hospital staff. Recorded information includes the insurer/ability to pay, patient name/contact data, and the reason for admission. Next, the patient is assigned an ID number that is written on a chart and on a wristband attached to the patient.

Examination

Once formally admitted, the patient is taken to the department handling diagnostics and treatment. At each treatment step, the wristband and charts (including medical orders) are visually inspected to confirm that the right patient is being treated. Such checks utilizing RFID to assure the correct patient is being treated can be applied to all other procedures, as well as to patient transportation within the hospital and, ultimately, to discharge from the hospital. Errors are a major problem with today's medical care. But RFID can be applied to address a number of potential errors, including:

- Contraindicated medications-by using the RFID database to track a patient's medications and to *wave a red flag* when they present problems.
- Matching medications to the right patient-by matching the name on the medical orders to the name on the patient's wristband.
- Matching specimen collection to the right patient-by coding the patient's name in the tag on the specimen bottle.

When first treated, the patient is questioned about his or her problem, and examined visually. If this does not provide the cause of the illness, tests are performed to determine possible causes. Still more tests may be necessary, and once enough information is obtained treatment either begins or the patient is discharged.

Patient Care

If further care is needed, the patient is assigned a bed and transported to a room by an orderly. At regular intervals, the following procedures could be carried out:

- Blood is drawn (by a phlebotomist) and analyzed.
- Blood pressure, heart rate, temperature, and O2 saturation are recorded.
- Intravenous (IV) fluid levels are recorded and replaced as needed.
- Other evaluations of the patient are recorded (for example, pupil condition, motor skills, awareness, pain sensations).
- Other specimens are obtained and sent to the laboratories.

During the course of care, the patient may be transported to other departments for treatments, tests and examinations.

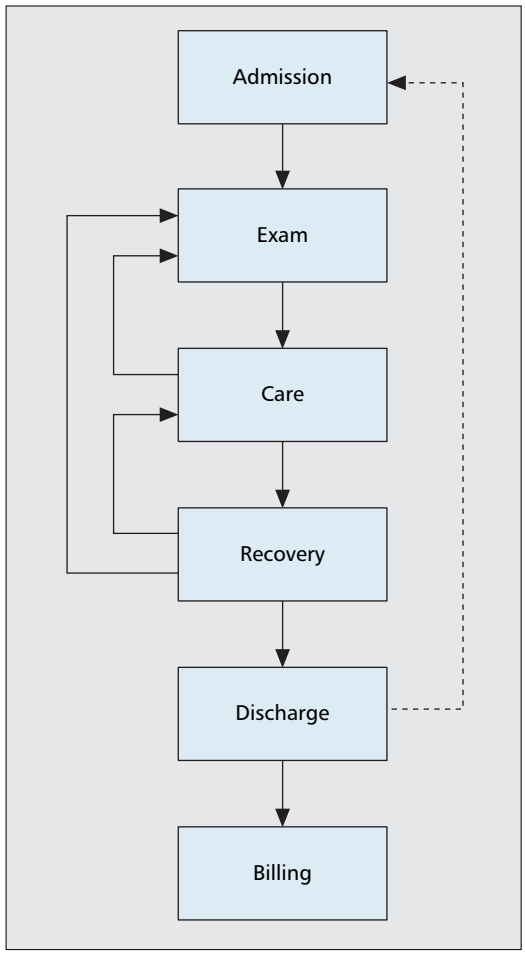

Figure 1. *Diagram of a patient life cycle shows the steps involved in a stay in a hospital, each of which can be carried out more efficiently using RFID, including re-admission after discharge.*

To document what's done, the caregivers record each and every action and their results on the patient's chart.

Recovery

As the patient improves, he or she is encouraged to walk for exercise. These movements are recorded (that is, when the patient left and returned). Meals, medical supplies, and medications consumed by the patient are also recorded.

Discharge

When the physician determines that hospital care is complete, the patient is issued post-hospital care instructions, and processed for discharge. Leaving the hospital, the patient is typically moved in a wheelchair to the curbside or taken home using a non-emergency medical transport service.

Billing

Billing information is processed and statements sent to various parties (for example, to the insurer) for payment [6].

The RFID Framework

In addition to applying RFID from the perspective of the patient life cycle, hospitals may also examine its application from a time-and-motion perspective. This framework is applied by classifying the ways RFID tasks can be performed. Figure 2 depicts such a framework, based on three ways to apply the RFID readers:

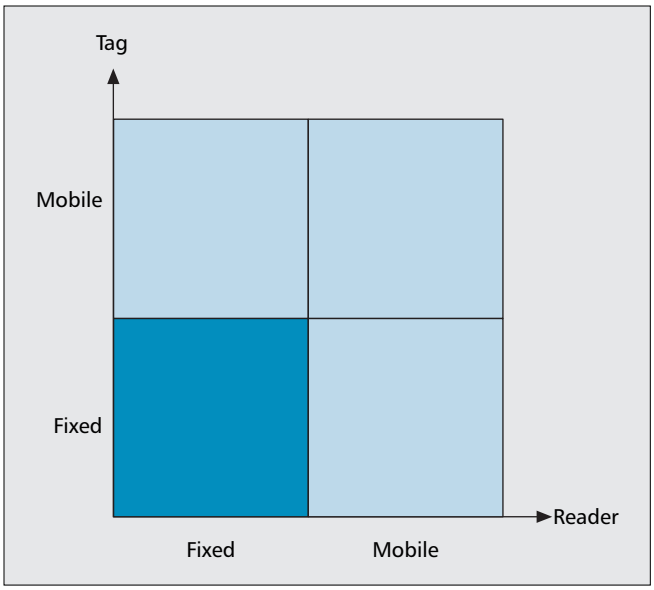

Figure 2. *Possible combinations of RFID readers and tagged devices.*

- A stationary RFID reader scans tags on moving, or mobile, objects
- A mobile RFID reader scans stationary objects
- A mobile RFID reader scans mobile objects

Not considered is when a stationary reader is used to scan stationary objects because of its limited utility.

Fixed Reader-Mobile Objects

Stationary readers deployed around the hospital can be used to monitor mobile objects. They can track the movement and location of a patient with an RFID-enabled device, such as a wristband, tag, chip, or ID card (Fig. 3) [7, 8].

The tracking here is much more robust than the tracking done by retail stores to combat theft or for inventory control. With a network of readers, which must be laid out with privacy and security concerns in mind, patients and staff can be tracked throughout a facility. Knowing their whereabouts will lead to quicker responses to patients in distress, and make it possible to stop patients who have wandered into a restricted area, as well as monitor patients walking around as part of their recuperative care. It's also possible to locate a specific piece of equipment once it's been tagged.

By placing RFID readers at the entry and exit of an operating room, it's possible to detect if any tagged items were left inside a patient during surgery, as well as record the patient's presence in the operating room. Corrective action, to remove such left items, can to be taken immediately instead of days later.

Stationary RFID readers deployed in a network or via a mesh are not the only way to improve efficiency. Places where numerous items, such as lab samples, laundry, medical waste, and hazardous materials, are processed may take advantage of simultaneous identification.

Since each tag has a unique identifier, it's possible to identify multiple objects simultaneously. A reader can scan multiple items in a single container so inventory of what's in the container can be available almost immediately. This approach can reduce the time and labor required to inventory multiple items and reduce recording errors. In instances where tagged items are previously recorded, this scanning process can identify if items are co-mingled improperly or if items are missing.

Tracking Fixed Objects

Fixed, or stationary, objects can be tracked with portable RFID scanners (Fig. 4) [7, 9, 10], MRI machines, X-ray equipment, and other large and expensive assets are typically fastened in place, and never meant to be moved. Smaller assets, such as a wall-mounted automated external defibrillator, are placed under lock and key. These are considered stationary assets in much the same way a fire extinguisher remains in the same location, except when used.

These expensive items are leased, rented, or purchased. As part of a hospital's asset management process, they must be inspected periodically to confirm their existence, location, and condition. Owners of leased or rented equipment may request updates before they bill. For assets it owns, the hospital can depreciate their cost over time. But to do so, the hospital must perform an inventory, as well as inspect the equipment. Portable RFID readers can readily be used to take an inventory.

Mobile Readers and Mobile Assets

The same methods for scanning fixed assets can be applied to items that move around, such as patients, bottles of medication, lab specimens, and portable medical equipment. They can all be given tags readable by handheld RFID scanners, equipped with displays suited for the application. The reader's output can be sent over the wireless RFID network in real-time to update a myriad hospital records (Fig. 5) [7].

With an RFID system integrated in a hospital's information system, staff members need only *point and shoot* a reader at tagged items, which would take little time from their medical duties. The automated data entry and recording could also lead to a system of checks and balances that would sharply reduce medical and documentation errors. Manual data-entry — errors would be a thing of the past; clerical errors in patient records would be minimized.

RFID technology can be applied with little significant change to existing hospital workflows. For example, currently, a phlebotomist applies a hand-written patient label to blood vials, collects samples, places the vials in either his or her lab coat pocket or on a small cart, and then brings the vials to the lab for processing. If the phlebotomist used a networked handheld reader, information about the blood sample could be immediately input into the hospital information system. Using this technology, the potential for error could be substantially reduced.

Hospital workflow could be streamlined by:

1 Scanning information from a patient wristband directly into the hospital information system. Wristbands could contain information in human readable and other electronic forms (barcode) to work with other information systems in use.
2 Scanning and transmitting information about patient blood vials to the central data repository. Machine-printed labels, which are both human readable and RFID-enabled, could be placed on the vials specifying the requested lab tests before samples are collected.
3 Working in reverse, the RFID scanner could obtain information from the central repository and display it using a more complex reader that comes with a graphical display. The display can provide information to verify the identity of a patient (such as the name of the patient and a photo) and the patient's previous lab work, as well as confirm that the requested lab tests have been performed
4 Identifying patients and reporting the vials drawn, together with their time and location as the phlebotomist makes rounds.
5 Identifying discrepancies between the vials drawn and the vials actually sent to the lab for processing. The expected

Figure 3. *RFID embedded patient wristbands in roll form, from InfoLogix7, prior to being printed are used to tag mobile objects; A flat panel fixed reader, from European Antennas8, installed above doorway to track patient and asset movements.*

Figure 4. *A fixed object tagged with an InfoLogix HealthTrax RFID asset tag [top left, white box] and RFID tags prior to installation9 [top right] can be read by the mobile HeliScan M handheld reader from Orion International10 [bottom].*

result for vials scanned at the end of rounds would be vials recorded in the central repository and scanned at the lab for processing. Examples outside of this condition include, vials taken and recorded during patient rounds and placed, and forgotten, in lab coat pockets are flagged as missing; vials found in the cart that are unrecorded are flagged as new and added to the batch; vials listed as processed and found in the cart are flagged as possibly involving fraud or a system error because an already processed vial with a unique ID cannot be collected and processed twice. Because every vial is uniquely identified, for each possibility the phlebotomist has the opportunity to correct any error.

This approach provides for a double-check of all samples entering the lab. Certainly, it could reduce the number of errors due to illegible handwriting, changes in workflow, the occasional misplacement of a vial, and fraud. An automatic audit process would identify problems before costly lab work is performed, such as duplicate requests for the medical order. And staff members would be freed from administrative tasks to perform their care-related duties.

RFID Benefits

Given that less than 10 percent of U.S hospitals have adopted RFID and most rely on paperwork, many opportunities exist for applying RFID to improve operational processes. Often, records and charts are recorded on paper with only some information entered at a computer terminal to be printed out and placed on the chart. Procedures, inventory control of assets and consumables, and billing information are all still recorded manually and later entered into a computer.

With RFID integrated into a hospital information system, much of the critical information regarding care can be input fairly automatically. Patients can be tracked from the time they enter the hospital to the time they leave, with the process starting when a patient is issued an RFID wristband (during *admission*). Once tagged, the patient can be monitored as he or she enters or leaves any room. This is where the fixed reader-mobile objects modality is used. As care is provided, information about the procedures performed and the patient's condition can be entered through handheld scanners and terminals with wireless capabilities

For example, emergency room staff could scan the patient's wristband and scan tags on all medicines and materials used in the patient's care (during *examination*). Whatever is given would be associated with the patient and recorded. Any harmful drug interactions could be identified and physicians notified. Also, staff on the next shift could review what was administered.

Integrated into an existing medical information system, RFID can be used for routine record keeping and to check for errors. A caregiver can update a patient's chart in real-time with the most current information (during *care*). Vital signs, test results, and procedures can be viewed and checked instantly by the medical staff or by automated routines. The real-time tracking can show what medication was dispensed and when it was administered. At any time during this physical process, software can check for errors and notify hospital staff if the wrong medicine was dispensed [1].

Recording all information centrally, allows closer monitoring of the patient by the medical staff (during *care*). Physicians and nurses at workstations could record and look up patient information in real-time, or look up patient records using handheld devices, wireless notebook computers, or even cell phones. If a patient's condition changes, event triggers written into patient-tracking software could notify physicians automatically. No longer would the physician need to see the patient or the printed chart at the bedside to offer assistance. The physician could quickly retrieve a patient's comprehensive medical records, review the recovery status, and check past medical logs, recorded by nurses at local terminals. As a patient recovers, he or she is frequently encouraged to exercise and walk around the hospital (during *recovery*). Fixed RFID readers scattered through the facility can track and log such movements to give the physician an idea of the patient's physical activity.

Throughout the patient's stay, equipment and consumables can be tracked and recorded for inventory and billing (for *billing*) as they are issued or used. This can help the hospital in its cost-recovery efforts, and automate billing generation for patients and insurance companies. By more closely tracking consumables, hospitals can avoid excess inventory, reduce out-of-stock periods, and improve the efficiency of the medical service supply chain. With a complete care history, it will also be easier to identify billing fraud [6].

When the patient is well enough to leave the hospital, the discharge process can be streamlined (during *discharge*) because most information related to care has already been

Figure 5. *InfoLogix H-2842-Z and S4M printers [left] print barcodes and human readable text on RFID embedded wristbands for mobile objects. A mobile reader scans mobile objects tagged with the InfoLogix Zebra wristband [top right] and a self-adhesive surgical label [bottom right].*

captured using RFID. Moreover, the record of the entire care process is useful if the patient ever returns for additional care. The medical history could be readily retrieved to view past diagnosis and treatment. Or the patient could even be given the record upon discharge in an RFID-tagged hospital card or subcutaneous implant.

Challenges to Implementation

As with any wireless technology, there is the possibility of RF interference. Solutions include both suppressing interference sources and placing the RFID tags and scanners closer together. In any case, there may be places-such as the room containing an MRI machine-where it is impractical to scan the tags. The electromagnetic (EM) fields in the bore of the machine's magnet are significant and could block most RF communications. Also for safety concerns, one would not want the presence of a scanner containing materials affected by strong magnetic fields near an MRI machine. Scanning patients just before they enter the room solves the problem.

Starting Slowly

Because RFID cannot be ubiquitously deployed in a hospital overnight, many hospitals are considering partial implementations. This requires a careful analysis of the hospital workflow to determine which activities are compartmentalized and separate from the rest of the hospital. Implementation could best begin here. In such a situation, a dual-use or tri-use wristband-that is, one with a bar code, an RFID tag and printed text-are useful. Such tags would allow departments to perform their work regardless of whether they have RFID scanners.

Security and Privacy

RFID is fundamentally secure because tags are extremely difficult to counterfeit and impossible to read without a reader. In fact, some consider the tags physically tamper-proof [11]. However, a common security concern lies with the radio transmission of the tag information. Tags emit omnidirectionally, and their radio transmissions can carry a relatively long distance. It could be possible for someone sitting in the parking lot with a high-gain antenna to pick up RFID tag transmissions from inside the hospital [12].

One solution is to reduce the transmit power of the tag so it transmits only a few centimeters. But if an operator holding a scanner must be so close to the tag to read it, the process becomes no different than bar coding, and many advantages offered by RFID are negated.

The long-term solution is to encrypt the data on the tags, thus making any data intercepted by a third party difficult to use. It would still be possible to read what is stored on the tag, but using the information requires additional knowledge.

There is also the issue of the tag remaining active after the hospital no longer needs it. If a patient were to walk out of the hospital wearing the wristband, the tag would still transmit data if interrogated by a reader. The solution is simply to deactivate the tag [13].

Operational Issues

The development of RFID as a viable alternative to bar codes is a challenge. Several problems that have emerged-such as insufficient range and accuracy-are being overcome. Passive RFID readers must be within a meter or two to read the tag accurately or write to it. Active tags, which allow for longer ranges, can be used when greater distances between the tag and reader are required.

In addition, reading the tags is difficult if multiple tagged objects are too close together. The materials on which the tag is affixed can affect readability. However, the new-generation Gen2 tags provide greater performance, even when placed on metal containers holding liquids, and allow more simultaneous reads [6, 14].

Conclusion

Implemented properly, RFID can significantly aid the medical staff in performing their duties. Hospitals should be aware of two frameworks with which they may explore opportunities for adopting RFID. The first, based on the patient life cycle in the hospital, considers where RFID can be applied to improve patient care and hospital operations. The second is the time-and-motion framework based on the mobility of objects and readers. If the challenges associated with deploying RFID technology in a hospital environment (can be overcome, RFID can be the major component of an automatic audit system [6]. Many other benefits are also possible, including increased security for both patient and hospital and reduced labor devoted to tracking materials and equipment.

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BIOGRAPHIES

ANDREA CANGIALOSI (Andrea.Cangialosi@caltech.edu) received a Bachelor of Science in Management and Human Resources with an emphasis in Human Resources and Computer Information Systems from California State Polytechnic University, Pomona in 1995. She has been an employee of the California Institute of Technology since 1995 where she began working in the Human Resources Department. In 1997 she joined the Administrative Process Engineering team to support the Y2K administrative applications upgrade. She continued in the field of Information Technology supporting Oracle and third party applications as a Systems Analyst and Applications Developer for eight years. She is currently working in the Audit Services and Institute Compliance Department as a Senior IT Auditor assessing IT controls for Caltech and the Jet Propulsion Laboratory. She is currently attending Claremont Graduate University pursuing a Master of Science in Information Systems (MSIS).

JOSEPH E. MONALY, JR. (jemonaly@caltech.edu) received a B.S. in Business Administration with an emphasis in Computer Information Systems from California State Polytechnic University, Pomona in 1995. During his undergraduate coursework, he became interested in telecommunications and voice networks. Immediately after receiving his undergraduate degree, Joe started working at the California Institute of Technology in Pasadena, California as a system administrator. In 1997, he transferred to the Voice and Data Network Services group where he designs, installs, operates and maintains the communications infrastructure. He is currently a M.Sc. student at Claremont Graduate University while working full time at Caltech. His work with communications technologies and their practical application to business challenges fueled his interest in RFID technologies and applications.

SAMUEL C. YANG (syang@fullerton.edu) holds an undergraduate degree from Cornell University and two graduate degrees from Stanford University, all in electrical engineering. He also has a Ph.D. in management of information systems from Claremont Graduate University. He is currently Associate Professor of Information Systems and Decision Sciences at California State University, Fullerton, where he was named the 2006 Outstanding Faculty at the College of Business and Economics for his research, teaching, and service. Prior to entering academia, he had 14 years of managerial and professional experience in the telecommunications industry. He has published articles in refereed journals and conference proceedings and is the author of two books in wireless communications. His current interests are in telecommunications management, business data communications, and enterprise wireless networks.