A Prototype on RFID and Sensor Networks for Elder Healthcare

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ABSTRACT
RFID (Radio Frequency Identification) and sensor networks are both wireless technologies that provide limitless future potentials. While the industry has witnessed rapid growth in developing and applying RFID technology, and the network research community has devoted tremendous efforts in sensor networks, the two communities would benefit greatly by learning from each other these two closely related technologies. In pursuing this effect, we have developed a project integrating both technologies. A prototype that utilizes both technologies is described. The goal is to build an in-home elder healthcare system. It would help addressing the need of a worldwide aging population.

1. Introduction
Radio Frequency Identification (RFID) technology has recently become a viable replacement for Universal Product Code (UPC) technology in many industries. Its fast growth and huge potential benefits have motivated a major move independently taken by Wal-Mart (the world’s largest retailer) and the US DoD (Department of Defense), that required their suppliers to install RFID tags by 2005 [5]. In response, several major computer companies, including Intel, HP, IBM, and Sun, have announced their efforts and future plans to support RFID. RFID technology, however, has attracted relatively little attention in the network research community.

Meanwhile, sensors and sensor networks have in recent years been adopted as a major research focus by federal funding agencies. This has resulted in a fast growing amount of research proposals and publications. In an effort to bridge the gap between industry and academic focuses, we have been working on a prototype that utilizes both technologies, investigating the feasibility, technical challenges, and resulting capabilities of their integration.

An RFID system consists of two primary components: A tag and a reader. An RFID tag, like a UPC, is usually attached to a tracking object; a reader is then used to track tagged objects. While sensor networks are used to sense and monitor physical, chemical, and biological environments through sensing of sound, temperature, light, and etc., RFID tags allow any objects to be track-able or “sensible” - as long as a RFID tag can be attached. Even though RFID systems have limitations, such as low tolerance to fluid or metal environments, they (the tags) essentially extend a sensor network by providing sensing/sensible property to otherwise un-sensible objects and (with reader) the “last feet” connection to a sensor network.

RFID have been used in a number of biomedical and healthcare applications, such as artificial inter-ocular pressure measurement [7], dental implants and molds [9], and hospital workflow including intra-hospital patient and equipment tracking [6].

From a recent study, the population of age 65 and older in the US will grow from 10.6 million in 1975 to 18.2 in 2025, almost doubled, while the overall population increase is about 60%. The trend is global; the worldwide population over age 65 will be more than double from 357 million in 1990 to 761 million in 2025 [8]. Longevity has caused expensive age-related disabilities, diseases, and therefore healthcare. To address this aging population needs, we target our prototype on an in-home elder healthcare system.

The rest of this section presents major features of the RFID technology. Related studies on integration of RFID and sensor networks are described in Section 2. This is followed by a discussion of the two phases of the prototype. Finally Section 5 concludes this paper.

1.1 RFID
Since sensor networks have been a very familiar topic in academic, we skip its introduction and focus only on RFID. An RFID system, more specifically, includes three components: A tag (transponder) located on the object to be identified, an interrogator which may be a read or write/read device, and an antenna that emits radio signals to activate the tag and read (and sometimes write) data to it. At its simplest a tag is a beacon announcing its presence to a reader. These types of tags are often seen in retail store used to prevent theft by announcing their presence when taken past a reader. RFID tag capabilities extend well beyond a simple beacon. Tags may hold a unique ID to be
used for inventory management, such as a UPC. More than just an ID, a tag may carry information in a re-writeable memory accessible via the reader.

RFID Tags may be classified in many ways. Three classification of tags distinguished by their energy source are passive, semi-active (also called semi-passive), and active. A passive tag has no battery of its own and makes use of the incoming radio waves broadcast by a reader to power its response. An active tag uses its own battery power to perform all operations. A semi-active tag uses its own battery power for some functions, but like the passive tag uses the radio waves of the reader as an energy source for its own transmission.

RFID readers employ tag-reading algorithms that are capable of identifying hundreds of tags per second. Once identified a reader may read data from or write to (depending on the permissions granted by the tag) a tag’s memory. RFID readers generally fall into two categories – high frequency (HF) and ultra-high frequency (UHF). Currently HF RFID systems adhere to the ISO standard while UHF RFID systems have yet to become standardized globally. Table 1 shows a comparison between HF and UHF RFID technology.

<table>
<thead>
<tr>
<th>Field</th>
<th>HF RFID</th>
<th>UHF RFID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>13.56 MHz</td>
<td>902 – 928 MHz N. America</td>
</tr>
<tr>
<td></td>
<td>860 – 868 MHz Europe</td>
<td>950 – 956 MHz Japan</td>
</tr>
<tr>
<td>Read Range</td>
<td>10 – 20 cm</td>
<td>3 – 6 meters</td>
</tr>
<tr>
<td>Read Rate</td>
<td>50 tags / sec</td>
<td>400 tags / sec</td>
</tr>
<tr>
<td>Memory Size</td>
<td>64 – 256 bits read/write</td>
<td>64 – 2048 bits read/write</td>
</tr>
<tr>
<td>Power Source</td>
<td>Inductive / Magnetic Field</td>
<td>Capacitive / Electric Field</td>
</tr>
<tr>
<td>Advantage</td>
<td>Low Cost Standard Frequency</td>
<td>High Speed Longer read range</td>
</tr>
</tbody>
</table>

2. Related Studies

When an RFID tag is given sensing capabilities, the line between RFID and Sensor Networking becomes blurred. Many active and semi-active tags have incorporated sensors into their design allowing them to take sensor readings and transmit them to a reader at a later time. They are not quite sensor network nodes because they lack the capacity to communicate with one another through a cooperatively formed ad-hoc network, but they are beyond simple RFID storage tags. In this way, RFID is converging with sensor networking technology. From the other direction some sensor nodes are now using RFID readers as part of their sensing capabilities. The SkyeRead Mini M1 made by SkyeTek is an example of an RFID reader designed to mate directly with the Crossbow Mica2Dot sensor mote [15].

In the following, we describe several projects and prototypes taken places in industrial and federal research laboratories, as well as some products adopted by companies.

NASA: Sensor Webs – The project has the objective of using readily available technologies to create a wireless network with embedded intelligence [2]. In this way, instead of reporting to an external control system, sensed data may be shared throughout the network and be used by the embedded intelligence to act directly on any detected changes. RFID is added so that RFID tagged objects, such as a firefighter or an astronaut, may be sensed and be guided by the intelligent sensor web; or that product components and production flow may be sensed and be guided to slow down or speed up.

Intel Labs: Proactive Healthcare – In addition to leading a major force on sensor network research, Intel Research Labs also initiated an effort to explore ways technology could help with the care of a growing elderly population [4]. One project jointly worked by Intel Research Seattle and Univ. of Washington, Caregiver’s Assistant and CareNet Display, aims to provide elder care by monitoring elders’ activities [11]. RFID tags are stuck on household objects; combining with a sensor network the system would collect information on which objects are touched and when. These data are used by an artificial-intelligent based Caregiver’s Assistant to fill out a standard Activities of Daily Living (ADL) form.

HP Labs: Smart Rack and Smart Locus – HP opened its US RFID Demo Center in HP Labs on Oct 2004. Two major research prototypes are Smart Rack and smartLOCUS [12]. Both prototypes geared toward integrating RFID and other types of sensors, such as video cameras or thermal sensors, into “multimodal sensor networks” that use more than one type, or mode, of sensors. Smart rack uses thermal sensors and HF RFID readers to identify and monitor the temperature of servers sitting in large metal server cabinets. These sensors and readers are networked and the collected data are used to show, in real time, an inventory of the cabinets and temperature profile of each cabinet. It may become a commercial product and offered within HP’s OpenView network management system.

Others: DOD and BP Oil – A few other DOD and private sectors are also using RFID integrating with sensor networks. The US Navy, working with Georgia Tech, has developed an RFID sensor network that monitors the temperature, humidity, and air pressure in containers where
aircraft parts are stored [13]. The US Military’s Combat Feeding Program pilot used active RFID tag-based sensor network to provide real-time visibility of rations as they move from the manufacturer to units in the field [13]. The BP oil company uses RFID and sensor network to monitor assets and react quickly to changes in environmental conditions.

3. Learning Phase: - Integrating Off-the-Shelf Sensors with Simulated RFID Reader

The first phase of the project is to investigate the capability of sensors and RFID and how they may be integrated. As there are many choices of commercial products, and each may cost from hundreds (sensor network and HF RFID) to thousands of dollars (UHF RFID), we first develop a prototype consisting of both hardware and simulating software.

There are a number of embedded platforms available. Adapting the sensor network platform is the most logical choice. The initial commercially available sensor network platform is the Berkeley mote. The Berkeley mote has been replaced by Mica, Mica2, Mica2Dot, and MCS Cricket manufactured by CrossBow Technology [3]. The Mica2 mote is selected for this phase to determine its capability, feasibility, and integration effect with RFID. Due to hardware cost, a RFID simulator reader is developed and used instead of an actual RFID reader.

In this test bed, there are four system components – two Mica2 motes, one simulated RFID reader, and a base station personal computer (PC), as illustrated in Figure 1. The two Mica2 motes – named RFID mote and base station mote - are used for RF communication. The simulated RFID reader is used to simulate (the lack of) an actual RFID reader via a serial port. The base station PC is used to perform statistic gathering as well as other required processing. It is connected to the base station mote via serial port. The message flow of the entire system is also illustrated in Figure 1. Each component is described in the following subsections.

3.1 RFID & Base Station Motes

The RFID Mote software is developed using TinyOS and the nesC language [17]. This software interacts with the simulated RFID reader via the mote’s serial port. The software module consists of RFID mote (control), RFID reader, battery, and communication modules as illustrated in Figure 2. The control module provides control to all sub-modules and handles inter-module interaction. The RFID reader module handles interaction with the RFID reader. All RFID specific details are hidden in this module. The battery module handles battery voltage measurement. The communication module is divided into three sub-modules – packet management, serial communication, and RF communication – with an interface module. With limited memory resource, the packet management sub-module manages a fixed memory size associated with each communication packet. The serial communication sub-module is TinyOS communication module over serial port. There are a few RF communication modules that have been developed by various members of the open source community. TinyOS has an RF communication module [17]. CrossBow Technology has a mesh RF communication module [3]. An S-MAC module is also available for this platform [19]. The RF communication sub-module is designed to allow for easy replacement. All three RF communication sub-modules are wrapped around a common interface and are selected at compile time.

![Figure 2 – RFID Mote Software Component with SMAC](image)

Figure 2 – RFID Mote Software Component with SMAC

The RFID mote software queries the RFID simulator every second for tag messages. In response, the RFID reader simulator sends a set of tag messages to the RFID mote. Tag messages are queued by the RFID mote software and transmitted over RF to the base station mote. To allow efficient transmission, up to 12 tag messages are encoded into a single RF message. If there are fewer than 12 tag messages, the RFID mote waits for 300 ms before starting transmission. With a baud rate of 115,200 bps, 300 ms delay is sufficient. To receive 12 tag messages from the RFID reader, the base station mote requires 153.6 milliseconds with a rate of 12.8 bytes per millisecond.
The base station mote software is the same as the RFID mote with run-time behavior changes based on the mote id. The base station mote software gathers the received packets and forwards them via the mote serial port to the base station PC.

3.2 PC RFID Reader Simulator
The PC RFID Reader Simulator is developed to simulate an HF RFID reader. The simulator emulates Texas Instrument HF Tag-it protocol [16]. It is written in Java using part of the existing TinyOS serial communication module. When the simulator receives a “Read Transponder Details Command,” it sends a series of simulated tag messages to the RFID reader mote via serial port. The number of tags is specified via its command line. The simulated tag ID is fixed.

3.3 Base Station PC
The base station PC is programmed to process data received from the base station mote. It is written in Java making use of existing modules from TinyOS. The architecture of this module is designed with component re-use for the next phase of the project. The base station PC software consists of eight modules - RFID Station, RFID Database, RFID Station Packet, RFID Station Statistic, RFID Station GUI, TinyOS Comm, and MySQL Server.

The RFID Station module is the main module and handles all interaction between various sub-modules. The RFID Database module handles all database related interaction. Its main task is to store received tag messages to persistent storage. Persistent storage is accomplished using MySQL server and interface via Open Database Connection (ODBC). The RFID Station Packet module handles message decoding. The RFID Station Statistic module gathers statistic information based on messages received or statistic message from each mote. Using the RF message header, it can determine RF message receive rate as well as lost packet. The RFID Station Packet module handles message decoding. The RFID Station Statistic module gathers statistic information based on messages received or statistic message from each mote. Using the RF message header, it can determine RF message receive rate as well as lost packet. The RFID Station Packet module handles message decoding.

3.4 Performance Result
The TinyOS RF communication module has a packet size limited to 29 bytes. This allows only one tag message with overhead to be transmitted in a single RF packet. The CrossBow RF mesh communication module is too slow with too much overhead. It is rated at 1 packet per second. The SMAC RF communication module has a packet size limit of 256 bytes; it is used for bandwidth test described below.

The test setup consists of two motes, a simulator, and a base station PC. The simulator and base station software run on the same PC. The two motes are about 2 feet apart with battery power and communicate via USB serial port to the simulator reader or base station PC.

The initial test achieved about 10 tag messages of 19 bytes in length. To achieve a better transfer rate, as mentioned above, the communication module is modified to queue up to 12 tag messages. This achieves about 25 tag messages or 500 application bytes per second with 100 % reliable RF communication. This rate is sufficient in most embedded applications. Most commercial RFID readers can handle between 50 to 100 tags per second. On a pure ID based application, it usually requires 12 bytes for tag ID. Thus, this system can handle about 41 tags per second.

4. On-going Development Phase – Sensor Network with HF/UHF RFID for Elder Care
In this phase we decided to utilize the strengths of both HF RFID (lower cost) and UHF RFID (long distance) along with sensor motes for a medicine monitor system. The system monitors the amount of medicine elderly required and assists them in taking the accurate amount of medicine; it is an extension to a prototype built in Intel Labs [10]. Figure 4 shows a hardware prototype of the system.

The system consists of seven components – three motes, a HF RFID reader, a UHF RFID reader, a weight scale, and a base station. In the following, we first describe their roles in medicine monitor system. The HF RFID reader is used in conjunction with HF tags placed on each medicine bottle. The reader is used to track all medicine bottles within range of the reader. By performing reads of all tags at a regular interval, the system is able to determine when a bottle is removed or replaced by the patient. The short range of the
HF reader is actually desirable for this aspect of the application. The weight scale monitors the amount of medicine on the scale. Combining change in weight and HF tag event, the medicine bottle and amount of medicine can be determined when the patient takes a pill. An UHF RFID reader and tags are used to track the elder patient associated with the medicine bottles. The UHF RFID reader is able to detect a patient, wearing an UHF tag, when enters an area within 3-6 meters of the reader. By performing regular tag reads the system is able to determine the patient is in the vicinity and alerts the patient to take medicines via a beep sound or a blinking light.

Next, we describe the major interactions among the seven system components. Some components are further described in the subsequent subsections. The RFID mote communicates with the HF RFID reader and weight scale to monitor HF tags and medicine weight. Each HF RFID tag identifies a medicine bottle. The UHF RFID mote communicates with the UHF RFID reader to monitor patient arrives at the door of a room or other area where the system is installed. The base station mote provides message relay to the base station PC. The HF and UHF RFID readers are HF SkyeRead M1 Mini [14] and AWID UHF RFID readers [1], respectively. The base station is a PC running a Linux operation system. The base station software is extended from the first phase to accommodate this application.

4.1 Extension to Mote Software
The software for all three motes is identical with run-time functionality check using mote id. To support the HF RFID reader, the internal of the RFID reader module developed in the first phase is replaced with the actual protocol interface. The weight scale module is added to handle the scale measurement. The RFID tag and weight data are fused into a single source of information for transmission. A set of data fusion messages is created to indicate the following: weight change, tag no longer detected, tag detected again, and patient detected. This requires a number of error checking and handling to avoid un-reliable serial port communication as well as scale weight instability. The UHF RFID reader module is added to communicate with the AWID UHF RFID reader. Depending on the capability of the UHF RFID reader and its technology limitation, multiple tags may be needed to properly detect the patient as water concentration in human body can interfere with UHF RFID tag.

4.2 Extension to Base Station Software
The base station software developed in the previous phase is expanded for the application. A data fusion module is added to perform data aggregation processing. All data fusion messages are recorded in the persistent database. In supporting the application, a number of new database tables and schemes are created for recording additional information such as patient, tags, medicines, and history event information.

An embedded display may be purchased, or alternatively replaced by an emulated display within the base station software (adopted in this prototype). The display emulator provides a GUI to further assist patient’s medicine intake.

4.3 Simulators for HF/UHF RFID Readers and Weight Scale
Due to limited funding and hardware availability on hand, to allow students to work on the project individually, a simulator is also developed for each hardware component. The HF simulator simulates a HF RFID reader and tags. The HF RFID simulator, developed in the first phase, is modified to accommodate the actual HF RFID reader and its corresponding tag protocol. The UHF RFID simulator reader simulates the AWID UHF RFID reader protocol. The Scale simulator simulates the scale protocol. Each simulator has a GUI and interfaces with the mote via a serial port. All simulators and its GUI are written in Java and run under Linux on a PC. Figure 5 and Figure 6 show a sample GUI for RFID reader and scale simulators.
5. Conclusion
We have described an on-going project that integrates both sensor networks and RFID technologies. It includes an initial learning phase and a development phase. The learning phase investigates technology compatibility and capabilities through a sensor network interacting with a simulated RFID system. The development phase builds a system that consists of sensors and both HF and UHF RFID components. It is targeted for in-home medication monitoring. Simulating software modules are also described; they are needed when hardware purchases are limited. We are currently working on actual system testing. The next phase would be to extend the prototype from medication monitoring to a broader eldercare system, from one room to the entire house, featuring more sensors and RFID components distributed at various strategic places and on various household items. We would study the challenges and performance when different sensors and RFID inter-work, to provide an effective and user-friendly healthcare system.

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7. References