A Prototype on RFID and Sensor Networks for Elder Healthcare: Progress Report

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ABSTRACT
Radio Frequency Identification (RFID) 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, these two communities would benefit greatly by learning from each other. In pursuing this effect, a project utilizing and integrating both technologies is described. The goal is to build an in-home elder healthcare system that monitors patients' medication in take. This would help addressing the challenge of a growing aging population.

Categories and Subject Descriptors
C2.1 [**Network Architecture and Design**]: Network communications, wireless communication.

General Terms: Experimentation

Keywords: Healthcare, RFID, sensor networks.

1. INTRODUCTION
RFID technology has recently become a viable replacement for the 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 Department of Defense (DoD), that requires their suppliers to install RFID tags by 2005 [7]. 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 fast growing amount of research proposals and publications.

In an effort to bridge the gap between industry and academia focuses, we have been working on a prototype that utilizes both technologies and investigates its feasibility, technical challenges, and resulting capabilities of their integration.

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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 network is 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 technology has limitations, such as low tolerance to fluid or metal environments, tags can extend a sensor network by providing sensing/sensible property to otherwise un-sensible objects, thus provide the last-hop connection of a sensor network.

RFID have been used in a number of biomedical and healthcare applications, such as artificial inter-ocular pressure measurement [9], dental implants and molds [11], and hospital workflow including intra-hospital patient and equipment tracking [8].

From a recent study, the population of age 65 and older in the United State will grow from 10.6 million in 1975 to 18.2 in 2025, an increase of 72%, 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 [10]. Longevity has caused expensive age-related disabilities, diseases, and therefore healthcare. To help in addressing this aging population medication needs, we target our prototype on an in-home elder healthcare system. This is a continuation of our work on applying wireless technologies for biomedical applications [5][14].

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 system. Finally, Section 5 concludes this paper.

1.1 RFID
Since sensor network has been a familiar topic in academia, we skip its introduction and focus only on RFID. An RFID system, more specifically, includes three components: (1) a tag or transponder located on the object to be identified, (2) an interrogator (reader) which may be a read or write/read device, and (3) an antenna that emits radio signals to activate the tag and read/write data to it.

At its simplest form, a tag is a beacon announcing its presence to a reader. These types of tags are often seen in retail stores used to prevent theft by announcing their presence when taken past a reader. RFID tag capabilities, however, extend well beyond a simple beacon. Tag can hold a unique identity (UID) of 8 bytes in length and can be used for inventory management at global scale, such as a

UPC. More than just an UID, a tag can carry re-writeable persistent storage and accessible via a reader.

RFID tags are classified by its energy source as passive, semi-active (or 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 tag memory, depending on the permissions granted by the tag. 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 1. Comparison of HF and UHF RFID Technology [22]

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

2. RELATED STUDIES

When an RFID tag is given sensing capabilities, the line between RFID and sensor network 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 motes [4] .

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 can be shared throughout the network and be used by the embedded intelligence to act directly on any detected changes. RFID tagged objects, such as firefighters or astronauts, may be sensed and be guided by the intelligent sensor web; or product components and production flow may be sensed and be guided to slow down or to 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 technology that can help in caring for the growing elderly population [6]. A joint project called "*Caregiver's Assistant* and *CareNet Display,"* developed by Intel Research Seattle and Univ. of Washington, aims to provide elder care by monitoring elders' activities [13]. RFID tags are stuck on household objects. Combined with a sensor network, the system would collect information on which objects are touched and when. These data are used by an artificial-intelligent program, *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 [15]. Both prototypes gear 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 with integrated 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 [17]. The US Military's Combat Feeding Program pilot uses active RFID tag-based sensor networks to provide real-time visibility of rations as they move from the manufacturer to units in the filed [16]. The BP oil company uses RFID and sensor network to monitor assets and react quickly to changes in environmental conditions [18].

3. LEARNING PHASE - Integrating Off-the-Shelf Sensor Network 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 (for sensor network or HF RFID) to thousands of dollars (for UHF RFID), we first develop a prototype consisting of both hardware and software simulator.

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 prototype, 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 reader mote and base station mote - are used for RF communication. The RFID reader simulator is used to simulatean actual RFID reader, communicating via a serial port. The base station PC is also used to perform statistic gathering as well as other required processing. It is connected to the base station mote via a serial port. The message flow of the entire system is also illustrated in Figure 1. Each component is described in the following subsections.

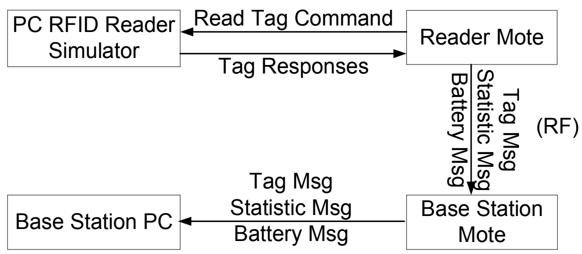


Figure 1 – System Component Overview

3.1 Software for RFID Reader Mote and Base Station Mote

This section describes the software developed for RFID reader mote and base station mote. The one for RFID reader mote is first described in detailed.

The RFID reader mote software is developed using TinyOS and the nesC language [21]. 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 interactions. The RFID reader module handles interactions with the RFID reader. All RFID-specific details are hidden in the 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 the TinyOS communication module over serial port. There are a few RF communication modules developed by various members of the open source community. TinyOS has an RF communication module [21]. CrossBow Technology has a mesh RF communication module [3]. An S-MAC module is also available for this platform [23]. 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.

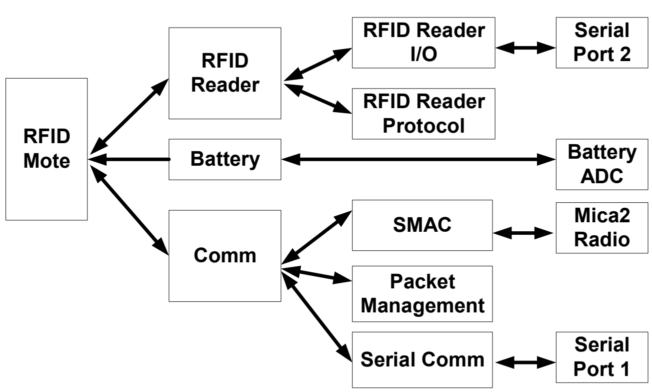


Figure 2 – RFID Reader Mote Software Components (with SMAC RF Communication Sub-Module)

The RFID reader mote software queries the RFID reader simulator every second for tag messages. In response, the RFID reader simulator sends a set of tag messages to the reader 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 see this, each tag consists of 19 bytes, but each byte of 8 bits needs 1 stop-bit; thus, transmitting would need to transmit 171 bits. A message of 12 tags needs transmission of 2,052 bits. Given the above baud rate, it needs theoretically 17.8 ms.)

The base station mote software is similar to the RFID mote with run-time behavior changes based on the mote ID (identity). The base station mote software gathers the received packets and forwards them via the mote serial port to the base station PC.

3.2 RFID Reader Simulator

The RFID reader simulator is developed to simulate an HF RFID reader. The simulator emulates Texas Instrument HF Tag-it protocol [20]. 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's are fixed.

3.3 Software for Base Station PC

The base station PC is programmed to process data received from the base station mote. It is written in Java, and 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 (Graphical User Interface), 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 GUI module (obviously) handles GUI; a GUI screen includes node statistics, list of node details, list of tag details, and command input, as shown in Figure 3. Finally, the TinyOS Comm module is the TinyOS reliable communication module. This module handles all serial communications as well as network communication over a serial port.

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 RFID reader simulator, and a base station PC. The simulator and base station software both run on the same PC. The two motes are about 2 feet apart, both with battery power. The RFID reader mote (base station mote) communicates with the simulator reader (base station PC) by a USB serial port; the two motes communicate with each other via wireless communication.

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, this usually requires 12 bytes for a tag ID. Thus, this system can handle about 41 (i.e., 500/12) tags per second. If only 8 bytes are required for a tag ID, the support rate goes up to 62 (i.e., 500/8) tags per second.

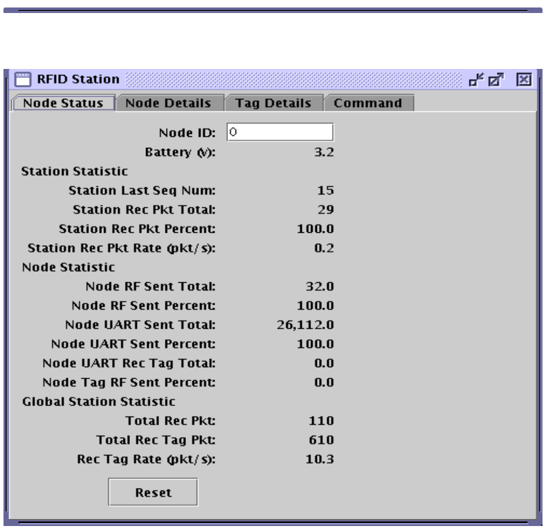


Figure 3 – Base Station GUI

4. DEVELOPING PHASE – Sensor Network with HF/UHF RFID for Elder HealthCare

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 [12]. In the Intel system, a HF RFID reader and some tags are used along with two motes to monitor a patient's in-take of medicines. We extend the system to include the use of a UHF RFID system for patient alert. Our prototype does not repeat any particular hardware or software used in the Intel prototype since newer hardware continues to be available, and their software information is not available to the public. Figure 4 shows a hardware prototype of our proposed system, and Figure 5 shows the corresponding system component configuration.

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 the medicine monitor system. HF RFID tags are placed on each medicine bottle to identify each bottle. The HF RFID reader is used in conjunction 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* and *which* 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 medicine on the scale. Combining changes in weight and HF tag event, *which* medicine bottle and the *amount* of medicine taken can be determined when the patient takes their pills.

An UHF RFID system, including a reader and one or more tags are used to track the elder patient who needs the medicines. This patient wears a UHF tag that may be detected by the associated RFID reader within 3-6 meters. Thus, the system is able to determine that the patient is in the vicinity, and alerts the patient to take the required medicines via a beep sound or a blinking light.

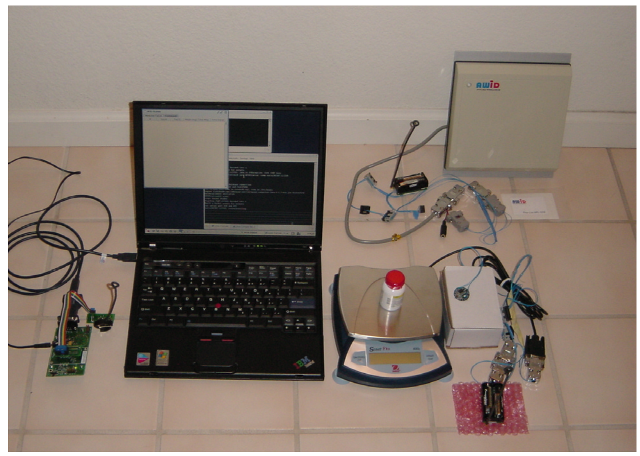
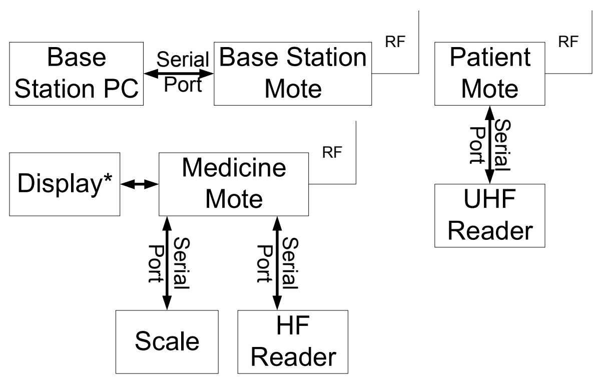


Figure 4 – Medicine Monitor System Prototype



* The embedded display is simulated on the PC base station using appropriate messages

Figure 5 – System Component Configuration

Next, we describe major interactions among the seven system components. Some components are further described in the subsequent subsections. As before, motes are mainly used for communicating readers from RFID readers to the control system. The Medicine Mote communicates with the HF RFID Reader and weight Scale to monitor HF tags and medicines weight. (Recall that each HF RFID tag identifies a medicine bottle). The Patient Mote communicates with the UHF RFID reader to monitor patient arrives to room or an area where the system is installed. The Base Station Mote provides message relay to the Base Station PC (the control system).

For HF and UHF RFID readers, HF SkyeRead M1 Mini [19] and AWID UHF RFID readers [1] are chosen, respectively, because of their features, functions, and availabilities. The Base Station PC is a PC running Linux, and Base Station Software is extended from the first phase to accommodate this new application.

4.1 Extension to Mote Software

The software for all three motes is identical with compile-time hardware assignment. Figure 6 shows an updated mote system software component. 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's and handlings to deal with unreliable serial port communications 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 a patient, since water concentration in human body can interfere with UHF RFID tag signals.

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 process data aggregations. 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 information, tags, medicines, and history event information.

An embedded display may be purchased, alternatively, it may be replaced by an emulated display within the base station software, adopted in this prototype. The display emulator, as shown in , provides a GUI to further assist the patient. Note the use of large font size for various medication/vitamins and of different colors for pill quantity; this is to make it easier for old patients. Alternatively, pictures of various medicine brands/bottles may be used to replace medicine names.

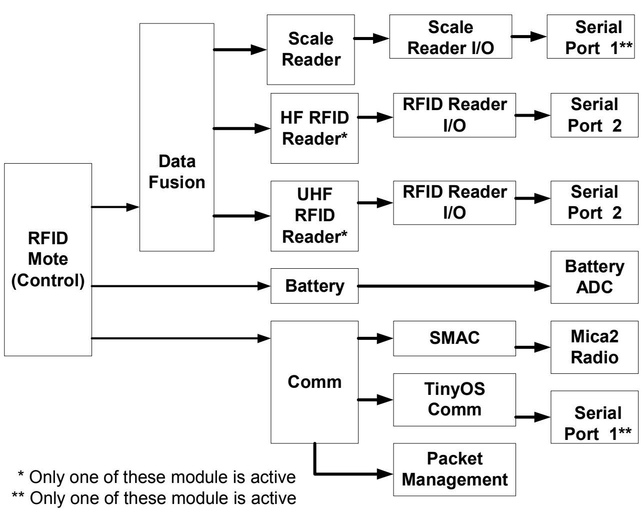


Figure 6 – Mote System Software Components

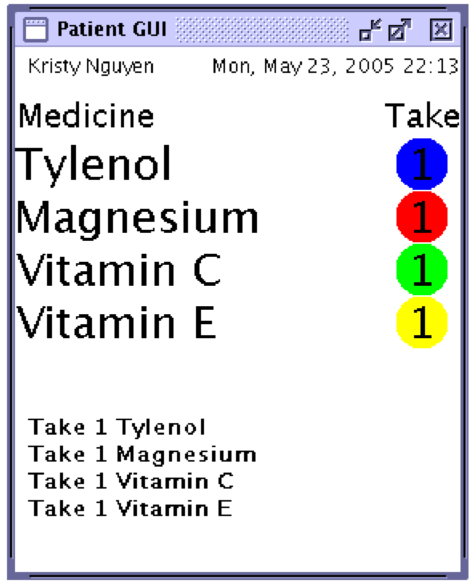


Figure 7 – Patient GUI

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. This is done by modifying the HF RFID simulator developed in the first phase to fit the actual HF RFID reader and its corresponding tag protocol. Similarly, the UHF RFID reader simulator simulates the AWID UHF RFID reader protocol, and the Scale simulator simulates the scale protocol. Each simulator has a GUI and interfaces with an individual mote via a serial port. All simulators and their GUI are written in Java and run under Linux on a PC.

5. CONCLUSION

We have described an on-going project that integrates both sensor network 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 an 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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