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RFID Integration with Wireless Sensor Networks

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Abstract

Radio Frequency Identification (RFID) and Wireless Sensor Network (WSN) are two important wireless technologies that have wide variety of applications and provide limitless future potentials. However, RFID and sensor networks almost are under development in parallel way. Integration of RFID and wireless sensor networks attracts little attention from research community. This paper first presents a brief introduction on RFID, and then investigates recent research works, new products/patents and applications that integrate RFID with sensor networks. Four types of integration are discussed. They are integrating tags with sensors, integrating tags with wireless sensor nodes, integrating readers with wireless sensor nodes and wireless devices, and mix of RFID and sensors. New challenges and future works are discussed in the end.

Keywords: *RFID, Sensor networks, Integration, Survey*

I. INTRODUCTION

While there has been a rapid growth on developing and applying RFID technologies in industries, research communities have paid less attention to the integration of RFID and WSNs. Few introductions on RFID and WSNs have been presented, such as [10] and [24]. These works either are outdated or miss comprehensive study. The paper surveys recent research works, new products/patents and applications that integrate RFID with wireless sensor networks. It classifies current works into four categories according to different

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manners of integration. The investigation starts with a brief introduction on RFID. Since sensor network has been a familiar topic in academic, we skip its introduction and focus on only RFID in rest of the section.

1.1 Radio Frequency Identification

RFID is a means of storing and retrieving data through electromagnetic transmission to an RF compatible integrated circuit [4]. It is usually used to label and track items in supermarkets and manufactories. For example, Wal-Mart, Procter and Gamble, and the U.S. Department of Defense have deployed RFID systems with their supply chains [13]. However, potential of RFID is much more than that. Today, RFID has been widely applied in supply chain tracking, retail stock management, tracking library books, parking access control, marathon races, airline luggage tracking, electronic security keys, toll collection, theft prevention, and healthcare [22]. Current trends and forecasts indicate that the market will grow fast in the next 10 years. In 2006 alone, 1.02 billion RFID tags were sold [8]. Total value of the market, including hardware, systems and services, is expected to grow from €500 million to €7 billion by 2016 [6].

Briefly, RFID systems consist of two main components: tags and readers. A tag has an identification (ID) number and a memory that stores additional data such as manufacturer, product type, and environmental factors such as temperature, humidity, etc.. The reader is able to read and/or write data to tags via wireless transmissions. In a typical RFID application, tags are attached or embedded into objects that are in need of identification or tracking. By reading tag IDs in the neighborhood and then consulting a background database that provides a mapping between IDs and objects, the reader is able to monitor the existence of the corresponding objects [20].

1.2 Tags and Frequency Ranges

RFID tags can be classified into three major categories by their power source: active tags, passive tags, and semi-passive (semi-active) tags. An active tag contains both a radio transceiver and a battery that is used to power the transceiver. A passive tag operates without any battery. It reflects the RF signal transmitted to it from a reader or a transceiver and adds information by modulating the reflected signal. The passive tag does not use any battery to boost the energy of the reflected

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signal [4]. Similar to passive tags, semi-passive tags use the radio waves of senders as an energy source for their transmissions. However, a semi-passive tag may be equipped with batteries to maintain memory in the tags or power some additional functions. Active tags are more powerful than passive tags/semi-passive tags, such as larger range and memory, more functions. Meanwhile, the active tags are more expensive than passive/semi-passive tags.

RFID tags operate in three frequency ranges: low frequency (LF, 30~500kHz), high frequency (HF, 10~15MHz), and ultra high frequency (UHF, 850~950MHz, 2.4~2.5GHz, 5.8GHz) [13]. LF tags are less affected by the presence of fluids or metals compared to the higher frequency tags. They are fast enough for most applications, and are also cheaper than any of the higher frequency tags. However, low frequency tags have shorter reading ranges. The most common frequencies used for LF tags are 125~134.2kHz and 140~148.5kHz.

HF tags have higher transmission rates and ranges but are also more expensive than LF tags. RFID smart cards, working at 13.56MHz, are the most common member of this group. UHF tags have the highest transmission rate and range among all tags. They range from 3~6 meters for passive tags and more than 30 meters for active tags. High transmission rate of UHF allows reading a single tag in a very short time. This feature is important in the application where tagged objects move very fast and remain within a reader's range only for a short time. UHF tags are more expensive than any other tag and are severely affected by fluids and metals. These properties make the UHF tags most appropriate in automated toll collection systems. Typical frequencies of UHF tags are 868MHz (Europe), 915MHz (USA), 950MHz (Japan), and 2.45GHz. Frequencies of LF and HF tags are license exempt and can be used worldwide while frequencies of UHF tags require a permit and are different from country to country.

II. INTEGRATION OF RFID AND SENSOR NETWORKS

RFID and sensor networks are both important components of pervasive computing. Sensor network is usually used to sense and monitor physical, chemical, and biological environments through sensing of sound, temperature, light, etc.. Any object that is embedded with an RFID tag can be track-able or "sensible" in typi cal application of an RFID system.

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Although RFID technology has limitations such as low tolerance to fluid or metal environments, it can extend the ability of a sensor network by providing sensible property to otherwise un-sensible objects.

On the other hand, wireless sensor networks offer a number of advantages over traditional RFID implementations. First, sensors are able to provide much more information, such as the measurement of temperature, humidity, pressure, vibration intensity, sound intensity, power-line voltage, chemical concentrations, pollutant levels, etc., than simple RFID Second, incorporation with sensors enables RFID to push logic into nodes to enable RFID readers/tags to have intelligence. This allows for new applications, such as real-time warning of proximity to hazardous substances or enforcement of safety rules in the operation of heavy machinery. For example, the RFID sensor developed by Detection & Food Safety Center of Auburn University is able to measure contamination due to bacterial growth. It can operate in an alarm mode with signaling once a problem has been detected. Moreover, sensor networks provide limitless potentials for RFID. Note that in an RFID system, all communications are single hop, and there is no communication among RFID tags. Integration of RFID and sensor networks can provide RFID the ability to work in multi-hop way that potentially extends applications of RFID to operate in a wider area.

In this section, we discuss four types of integrations: integrating tags with sensors, integrating tags with wireless sensor nodes, integrating readers with wireless sensor nodes and wireless devices, and mix of RFID and sensors.

2.1 Integrating Tags with Sensors

RFID tags with added sensing capabilities use the same RFID protocols and mechanisms for reading tag's ID as well as for collecting sensed data. For example, Class 1 Generation 2 UHF protocol from EPCGlobal [9] allows to specify which part of tag's memory is used for reading. Thus, sensed data can be selected and read by EPC Generation 2 compliant reader by using properly configured command. Since RFID is used for communicating sensor information, current RFID protocols rely on single-hop communication.

Based on the level of integration, we can distinguish between RFID tags that have

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integrated sensors and RFID tags that allow for adding additional sensors. Second type of tags requires extending the chip's interface capabilities to a sensor. Semi-passive tag developed by Alien Technology (www.alientechnology.com/) is a combination of both types. It is easily extendable so that many different types of sensors can be connected to it through a serial I2C bus. It works in 2450MHz frequency range, and there is an onboard temperature sensor. The tags can be attached to temperature-sensitive products at production or shipment, and the temperature history of the product can be downloaded wirelessly at the final destination or at any point along the way [1]. Reading ranges are up to 30m. Another interesting solution that allows for integration with external sensors is Enterprise Dot from Axcess Inc (http://www.axcessinc.com/). It has three radios on the same chip and 3 antennas: UHF 315/433MHz range in which it acts as an active tag, UHF 900MHz range for EPC based applications in which it acts as a passive tag and LF 100-150kHz range. The chip also has an external connection through I2C bus.

There are several commercial RFID tags with integrated sensing capabilities. Current RFID sensing applications include monitoring physical parameters, automatic product tamper detection, harmful agent detection, and non-invasive monitoring [21]. A large portion of RFID sensors are used to monitor temperature of tagged objects and environments. Those tags are usually semi-passive tags or active tags. Two representative products are introduced in the following.

KSW – TempSens developed by KSW Microtec AG (www.ksw-microtec.de/) is able to periodically measure temperature with a configurable measurement interval. It is a semi-passive tag and can be attached in any product that could be spoiled during transport due to temperature fluctuations. For example, it can be attached to frozen chickens that have a risk of salmonella contamination if temperature of environment becomes too high for a long time. Main features of KSW – TempSens are shown in Table 1 [15].

Log-ic Temperature Tracker developed by American Thermal Instruments (www.americanthermal.com/) is an active tag. It acts as a watchdog in temperature-regulated or temperature-sensitive environment. The tag is capable of receiving programmable temperature thresholds via 2-way RFID

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communication. The LED indicator on the tag can blink with warning signals if temperature exceeds the thresholds. The main features of Log-ic Temperature Tracker are shown in Table 2 [3].

Table 1: Main Features of KSW – TempSens

Operating model	semi-passive
Operating frequency	13.56 MHz (HF)
Operating temperature	-15^{o}C to +50^{o}C
Operating voltage	3V
Security	6 Byte Code
Memory	2 Kbit SRAM, 4 Blocks of
	256 Byte each, configurable
Storable values	64 time and temperature
	values storable
Memory access	read / write
Sampling interval	10 seconds to 16 hours
	(configurable)

Table 2. Main features of Log-ic Temperature Tracker

Operating model	active
Operating frequency	13.56 MHz (HF)
Operating temperature	-40^{o}C to +65^{o}C
Accuracy	+/– 1.0 ^{o}C
Memory	Up to 64,000 readings

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2.2 Integrating Tags with Wireless Sensor Nodes

RFID tags integrated with sensors have limited communication capabilities. In high-end applications, it is possible to add RFID tag's capabilities to wireless sensor nodes. These new nodes may be compliant with existing RFID standards or they can have proprietary protocols.

CoBIs RFID tags [5] are designed to monitor the ambient conditions around them and provide alerts when detected conditions break predetermined business rules. Each CoBIs tag carries an accelerometer (movement) sensor, a wireless transceiver, up to 10 kilobytes of memory, and other computing components for storing and processing business rules. The tags are able to communicate with each other via a proprietary peer-to-peer protocol. Each node transmits not only its unique ID number but also details of its sensed data to all other nodes within a 3-meter range. These communications enable CoBIs tags to be tagged to chemicals containers to monitor ambient parameters and total volume of stored chemicals. It will show alarm messages and take corresponding actions if the detected ambient parameters or total volume of chemicals exceed some predetermined thresholds. The application requires communications not only between tags and readers, but also among tags for cooperative control on the total volume of chemicals.

It is possible to integrate or to add tag's features to sensor motes, such as Mica motes, such that tag sensors can cooperate with each other to form an ad hoc network. The tag sensors are able to decide by themselves where and when data should be transmitted / received as long as they are equipped with microcontrollers. However, cost of Mica motes is too high for commercial applications. It is possible to substitute Mica motes for RFID tags when the Mica motes become much cheaper in the future. As the cost of devices is low and data flow in the network is little, ZigBee / IEEE 802.15.4 standard [23] is applicable to the sensor tag networks to achieve end-to-end system security.

2.3 Integrating Readers with Wireless Sensor Nodes and Wireless Devices

Another type of integration of RFID and sensors is to combine RFID readers with RF transceiver. There are some industry solutions for RFID readers that are equipped with WLAN. One example is

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ALR-9770 series multi-protocol RFID reader that was developed by Alien Technology. The reader is equipped with up to 4 antenna sets for reliable tag reading and is able to communicate via 802.11 b/g standard [2].

Integration of the RFID readers with wireless sensor nodes and wireless devices enables new functionalities and opens the door to a number of new applications. Wireless devices will be able to sense environmental conditions, read identification numbers from tagged objects and effectively transmit this information to the host. Several academic and industrial solutions are presented next. See Figure 1.

The integration of RFID technologies into an ad hoc network such that information can be easily collected from multiple RFID tags spread over a large area has been studied in [10]. The basic idea of integration is to connect the RFID reader to an RF transceiver which has routing function and can forward information to and from other readers. Users are able to read tags from distance that is well beyond that of the normal range of readers through hop by hop communication of the readers. The integrated node consists of an RFID reader, an RF transceiver and a micro-controller that coordinates different components in the node. The micro-controller is also used to control the RFID reader and other components to go into sleep mode when they are not busy. Structure of the node is shown in Figure 1.

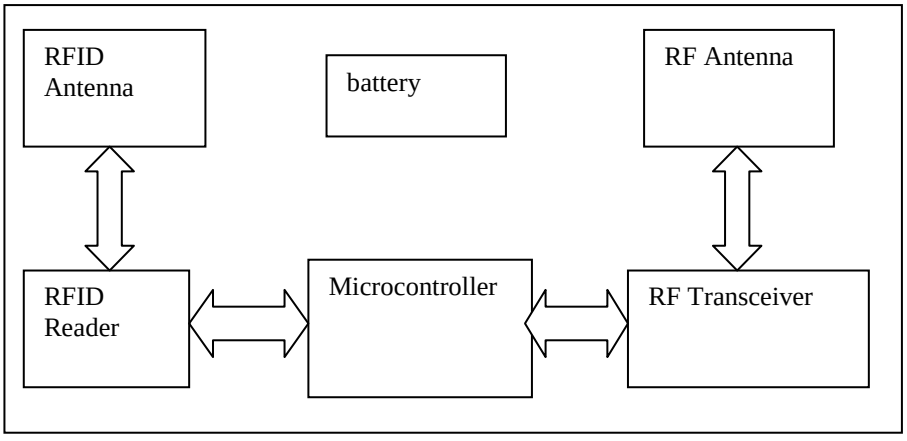


Figure 1: Structure of the node that combines RFID reader and RF transceiver.

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Lifetime of the battery is up to 1.04 years based on several assumptions made in [10].

Philips ICODE standard was adopted for the RFID system in [10]. ICODE standard is the industry standard for HF RFID solutions. It has the ability of reading from and writing to the tag, and can read up to 200 tags per second [17]. There are a number of embedded platforms available for RF transceiver, such as Berkeley mote, Mica, Mica2, Mica2Dot, and MCS Cricket manufactured by CrossBow Technology [7]. Mica 2 platform and event driven operating system TinyOS were adopted to construct the network in [10].

A prototype on RFID and sensor networks for elder healthcare was studied in [12]. Their system consists of seven components: three motes, a HF RFID reader, a UHF RFID reader, a weight scale, and a base station. System component configuration is shown in Figure 2. HF RFID tags are attached to each medicine bottle for identification. The HF RFID reader is used to track all medicine bottles within the range of the reader. The system is able to determine when and which bottle is removed or replaced by patients by reading all tags at a predetermined interval. The weight scale is used to monitor the amount of medicine in the bottle. By combining information from weight scale and HF tags, the system is able to determine how much medicine is taken from which medicine bottle when the patients take their pills.

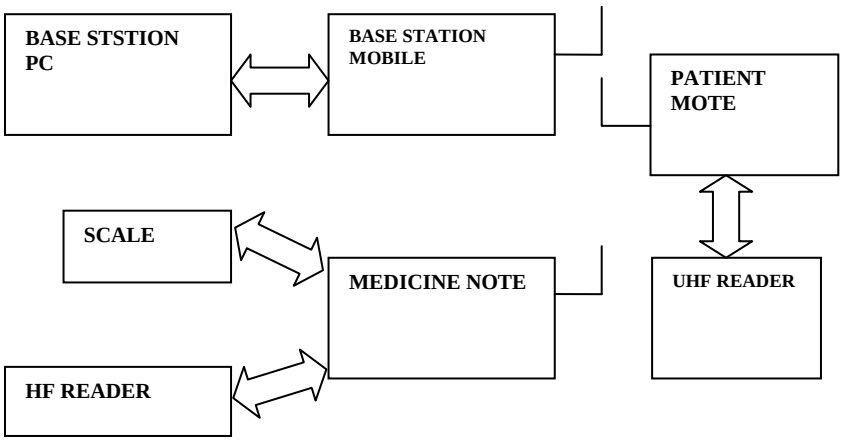


Figure 2: Component of the integrated RFID and WSN system [12]

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An UHF RFID system includes a reader and several tags that are used to track the elder patient who needs the medicines. A UHF tag attached with a patient can be detected by the associated RFID reader within 3~6 meters. The system is able to determine if the patient is in the neighborhood, and reminds the patient to take the required medicines via a beep sound or a blinking light. All motes are used to communicate with the control system (Base Station PC). The Medicine Mote communicates with the HF RFID Reader and weight Scale to monitor HF tags and medicine weight. The Patient Mote communicates with the UHF RFID reader to monitor patients when they are close to the room. All data from the Medicine Mote and the Patient Mote is relayed by the Base Station Mote to the Base Station PC. The energy consumption model of the system was further studied in [24]. It shows that the lifetime of battery can be 1.7 year if amount of data between the reader and the microcontroller is 60 bytes per read instruction and the microcontroller works with a duty-cycle of 1%.

A similar prototype in [16] combines wireless sensor nodes and RFID readers to provide a distributed application for automated asset tracking and inventory management. The prototype contains one wireless sensor node connected to the host device, called the host node and one wireless sensor node connected to a RFID reader, called the reader node. The host device can be an ordinary PC that has an inventory of tagged items in a database. A user on the PC is able to use the computer to execute a query on the database. The command from the user is transmitted to the host node and is relayed to the reader node via the wireless sensor network. The reader node passes the command to the RFID reader to get desired data. The communication is bi-directional. Using the same interface, data can be transmitted from the reader to reach the host device.

The RFID Based Sensor Networks patent [11] from Gentag (www.gentag.com/) provides a way to add sensor networks to RFID readers in wireless devices such as cell phones, PDAs and laptops. It describes the system and a method for the real-time concurrent detection of 13.56 MHz RFID and 8.2 MHz EAS (Electronic Article Surveillance) identification tags using a single stimulus signal.

The patent comprises an RFID reader and an EAS step-listen receiver that may be placed in a single housing. Both the RFID reader and the EAS step-listen receiver

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have respective antennae. In operation, the RFID reader emits the stimulus on frequency 13.56 MHz. A nearby RFID tag that is tuned to that RFID frequency emits a response that is detectable by the RFID reader. If an EAS tag is also present in the neighborhood and which is tuned to an EAS frequency, e.g., 8.2 MHz, the tag emits a response "ring down" signal which is detectable by the EAS step-listen receiver. Notice that the stimulus and the "ring-down" signal are nearly concurrent in time wh ereas the RFID response occurs later in time [18].

The basic idea of the patent is that by combining RFID cell phones and RFID sensors in cellular networks or the Internet, the consumers will be able to read any RFID sensor tag in almost any application. Information of RFID tags can be also downloaded to a cell phone from a remote database for some applications. For example, consumers can pay the bill using their cell phones once credit card information is embedded in the cell phone.

Nokia has already developed the cell phone that is embedded with HF RFID reader. Koreans are going to release the UHF cell phone. However, the ability of reading information with the cell phone also brings up security or privacy concerns.

2.4 Mix of RFID and Sensors

So far, there is little work discussing mix of RFID and wireless sensor nodes. System architecture of mix of RFID tags and sensor nodes was studied in [24]. The system consists of three classes of devices. The wireless devices in the first class are called smart stations which have no serious power constraints. A smart station consists of an RFID reader, a microprocessor for data processing, and a network interface. It can be treated as the wired device but uses wireless connections to the backbone network. The purpose of using wireless connection here is for more convenient deployment. The devices in the second and the third class are normal tags and sensor nodes, respectively. Smart stations gather information from tags and sensor nodes then transmit that to local host PC or remote LAN. The information coming from RFID and WSN can be further integrated into the base station for some specific application. For example, detection of sensed data value that exceeds some threshold may trigger RFID readers to read data from tags in some area.

The traditional Internet protocol architecture can be employed in the smart stations since there is no limitation on resources and power. It means that there is

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a multi-layer networking stack implemented in each smart station. Such implementation allows not only data processing, but also data routing and even reliable transport protocols such as TCP. The 802.11b / Wi-Fi platform can be adopted for such heterogeneous network. 802.11b / Wi-Fi uses the unlicensed 2.4 GHz band and DSSS technique in physical layer, and uses Carrier Sense Multiple Access with Collision Avoidance (CSMA / CA) scheme in MAC layer. The maximum data rate can reach 11 Mbps. [24].

Another type of architecture is 3-tier hierarchical architecture [14]. The lowest two tiers are normal RFID system, which is composed of reader tier and tag tier. RFID readers in reader tier read data from tags in tag tier, and delivery the data to upper sensor tier that is connected to base station and Internet. Communication between the tag tier and reader tier and communication between the sensor tier and base station can adopt associated standard protocols in RFID and WSNs. The communication of sensor tier and reader tier can be achieved either by embedding readers into sensors, or by 802.11b standard as long as readers are equipped with RF transceivers.

Currently, some software platforms for integration of RFID and sensors are available. For example, RFID middleware software -- RFID Anywhere, developed by Sybase iAnywhere (www.ianywhere.com), is a flexible software platform that integrates business logic and processes with a variety of automatic data collection and sensor technologies, including RFID, barcodes, mobile devices, locating racking systems, environmental sensors, and feedback mechanisms [19].

III. CONCLUSION AND FUTURE CHALLENGES

Although RFID has received more and more attention from industries and academic, more effort is needed in the study of integration of RFID and WSNs in future.

We envision that integration of RFID and WSN will open a large number of applications in which it is important to sense environmental conditions and to obtain additional information about the surrounding objects. One possible application is in robotics (for example rescue mission based on robots) where robots are equipped with RFID readers and WSN. These robots will be able to acquire environmental conditions from

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sensors and to understand better the environment after reading IDs from the tagged objects that are around. The information about the environment is very important and can be used for navigation of the robots or for making time-critical decisions. For example, stationary objects can be tagged in the known environment which can be used for navigation of robots.

Actually, any application where there is a need for collecting information about the environment can be a candidate for the mix of RFID and WSN. Since, RFID readers have relatively low range and are quite expensive, we envision that the first applications will not have RFID readers deployed ubiquitously. The applications which allow mobile readers to be attached to person's hands, cars or robots will be good candidates.

The use of semi-passive or active RFID technology in combination with WSN also has a promising future since reading range becomes larger. In addition, the appearance of new RFID chipsets from several companies (e.g. Intel) will reduce the price of RFID readers in UHF range in future. Using active technology and cheaper reader will allow stationary deployment of the readers in a similar way WSNs can be deployed. Similar multi-hop communication from sensor networks can be used to extract information from the readers.

Integration of RFID and WSNs raises new challenges also from the interference stand-point. There have been a lot of work on how to reduce the interference in large RFID networks and WSNs. Here the situation is even worse since the number of devices is larger and there is larger potential for interference. In the dense-reader mode in EPC Class 1 Generation 2 protocols, reader can communicate with tags at different frequencies. However tags are not frequently selective, so the time multiplexing is needed as well. A good collision free schedule for both WSNs and RFID networks has to be defined.

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