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RFID-based Real-time Smart Waste Management System

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Abstract - **In an environmental context, the use of RFID (Radio Frequency Identification) and load cell sensor technology can be employed for not only bringing down waste management costs, but also to facilitate automating and streamlining waste (e.g., garbage, recycling, and green) identification and weight measurement processes for designing smart waste management systems. In this paper, we outline a RFID and sensor model for designing a system in real-time waste management. An application of the architecture is described in the area of RFID and sensor based Automatic Waste Identity, Weight, and Stolen Bins Identification System (WIWSBIS).**

I. INTRODUCTION

Waste management is a basic requirement of ecologically sustainable development for over 200 municipalities in Australia [1], which are among the highest waste producers in the world (OECD 2002) [3]. Australia is amongst the top 10 generators of household waste in the OECD (Organisation for Economic Co-operation and Development) countries [4]. Australia generates waste at a rate of 2.25 kilograms per person per day. The majority of waste ends up in landfill [13]. During 2002-03 over 17 million tonnes of waste was disposed of at landfills in Australia. Over 30% of this was municipalities waste. In March 2003, Australian households produced almost 95% recycled waste and around 83% re-used wastes.

Australians also produce more than 1.3 million tonnes of plastic every year - more than 71 kg for every person [3]. In 2002, 48,500 tonnes of steel cans were recycled in Australia. That is enough steel to rebuild the Sydney Harbour Bridge almost 4 times. Each person uses approximately 57 sheets of toilet paper a day [5].

Waste (e.g., garbage) collection and disposal is a major environmental problem, especially now in urban centers in Australia. Waste collecting vehicles normally collect garbage from various households and take it to a landfill site for disposal. Landfill disposal sites also become expensive to operate and tend to fill up over time, thus needing to be replaced. With the rising costs and concerns about landfill sites, the landfill operators are likely to increase fees charged for disposing garbage at such sites.

In the current system, municipalities in Australia set the fees and charges (i.e., flat rate) for waste collection. These fees are based on bin sizes (i.e., garbage, recycling and green), especially in residential waste management services. Municipalities normally measure weights of waste for the number of streets or a suburb and then average them for each household/customer. This may not be an accurate assessment. As the costs of waste disposal continue to climb year after year, waste producers (customers) are demanding that costs not be charged using a flat rate. Many waste producers argue that they expect to be charged according to the amount of waste they dispose of rather than by a particular bin size, which is not fair. In addition, there are also concerns from a number of municipalities that a large number of waste (i.e., garbage, recycling, and green) bins are going missing or are stolen, costing them hundreds of thousands of dollars per year (Source: City of Casey, Melbourne).

In recent years, waste management services have made a concerted effort to use information technology to reduce waste management costs and to identify missing/stolen bins. To reduce the cost and improve efficiency, intelligent systems can play a significant role in providing intelligently processed and personalized information about customers, waste management administrators and services. The application of these principles can be facilitated by the use of mobile technology such as Radio Frequency Identification (RFID), load cell sensor, and so on.

RFID is a modern and fast growing mobile technology that uniquely and accurately identifies a RFID tag (waste tag) attached to, or embedded in, a waste bin (e.g., garbage) [2, 7].

This paper is structured as follows: Section II outlines the RFID and sensor model used for developing RFID and sensor based Real-time waste management systems. Section III outlines the five layers of the waste management systems architecture. Section IV illustrates the application of the waste management systems architecture using an RFID and sensor based WIWSBIS. Section V addresses the security concerns of the waste management system. Section VI illustrates the implementation of WIWSBIS application. Section VII concludes the paper.

II. RFID AND SENSOR MODEL FOR WASTE MANAGEMENT SYSTEM

Unlike previous identification techniques such as barcodes/registration numbers, RFID technologies do not need line of sight and the RFID waste tag can be read without actually seeing it. Also, waste tags are able to store much larger amounts of data easily and more rapidly than a barcode system. They are very effective in being read through a variety of substances and conditions such as extreme temperature, soil, dust and dirt, snow, fog, ice, paint, creased surfaces, and other visually and environmentally challenging conditions, where barcodes technologies would be useless [6].

Radio waves bounce off metal and are absorbed by water at ultrahigh frequencies. That makes metal objects or liquid containers difficult to tag and track with a RFID system. The RFID tag is also affected by objects surrounding it especially metallic objects. But low- and high-frequency tags work better on products with water and metal [18]. Even for the UHF which operates at 915MHz, Gao, et al. (2007) have proposed a new method using electromagnetic band gap (EBG) material to insulate the UHF RFID tag from backside objects, so that the tag could work on a water surface and even a metal [15].

An RFID-based waste management system mainly consists of a smart waste (RFID) tag, a Reader and a waste management IT system (i.e., WMITS). Each unique RFID waste tag can be passive, semi-passive or active [12]. Passive tags can be used for both reading/writing capabilities by the reader and do not need internal power (i.e., battery). They get energized by the reader device and have a read range from 10mm to almost 10 meters [6]. Passive tags are cheap, ranging from $0.25c to $0.40c each and life expectancy is unlimited. We suggest the use of passive waste tags (13.56 MHz ISO 15693 tag) with the read range of one meter, both fixed and handheld RFID readers, and HBM SSC Load cells for the Waste Management System (WMS) application.

The driving force behind the selection of a 13.56 MHz (High Frequency) solution was to lower the waste tag cost, required read range (i.e., 1 meter) and address applications of high quantity tags usage compared to Low Frequency (30 – 300 KHz) tags with read ranges, typically in inches. A HBM SSC (STRAINSENSE calibration) load cell is used to record the weight of bulk waste from each waste bin. The SSC (i.e., Compact Digitized) load cell may be installed on the arms of waste collecting vehicle and waste weight will be recorded in the PDA [16]. The main components of the RFID-based Waste Management System are as shown in Figure 1.

The antenna picks up radio-waves or electromagnetic energy beamed at it from a reader device attached to the PDA (Personal Digital Assistant) or a smart phone placed in waste collector vehicle (garbage/recycling truck) and enables the chip to transmit its unique identification to the reader device [17], allowing the bin to be remotely identified. The PDA is a small, low-cost, highly versatile mobile computer such as a Pocket PC. A PDA-based RFID reader on each waste collector vehicle will ensure that the weight and identity of the waste is passed to the PDA and automatically logged into an integrated database server using a wireless network without the driver having to leave their truck and manually input this data, thereby improving accuracy and efficiency. The PDA-based RFID reader can also request any additional information from the waste tag that is encoded on it [6]. The PDA-based RFID reader converts the radio waves reflected back from the waste bin into digital information (i.e., bin ID) that is then recorded in a PDA, which is located on the waste collecting vehicle. When robotic/lifting arms in the waste collector loaded onto the vehicle (truck), then the weighting system (e.g., SSC) measures the weight of each bin. The data (bin ID) is then used to calculate actual waste disposal charges for each individual household and sends it to the PDA for temporary storage after emptying each bin.

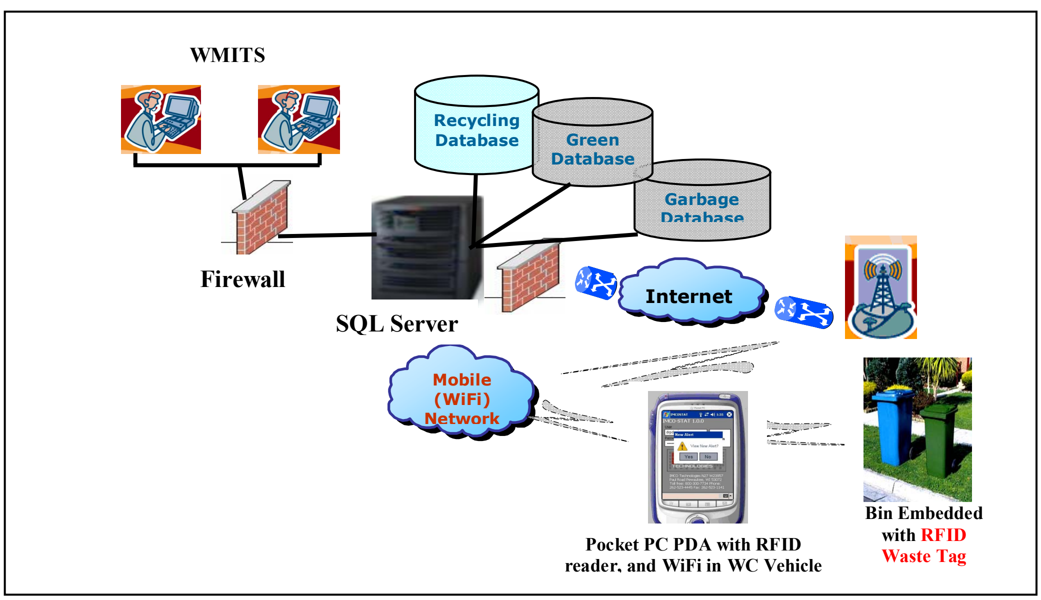

Fig. 1: Main components of RFID and sensor based waste management system

When the driver of the waste collecting vehicle finishes his/her work shift, the PDA then transfers all the data to a SQL back-end server for storing and processing the waste (e.g., garbage) data in real-time. Such a waste data transfer is carried out using a WiFi (wireless fidelity) connection and the internet. WiFi offers an end-user-centric, decentralized approach to service provisioning to deliver wireless Internet access, unlike 3G, which allows mobile operators to offer integrated data and voice services over mobile networks. WiFi is designed for the wireless Ethernet 802.11b standard for WLANs (wireless local area network) that trade the range of coverage for higher bandwidth, making them more suitable for ‘‘local hot spot’’ service. In contrast, 3G offer much narrower bandwidth but over a wider calling area. There are high costs of obtaining 3G licenses, the lack of 3G handsets, increased deployment cost expectations, and diminished prospects for short-term revenue, whereas the large installed base of WiFi provides substantial learning, scale, and scope economies to both the vendor community and end-users [10].

The commoditization of WiFi equipment has substantially lowered prices and simplified the installation and management of WiFi networks, making it feasible for non-technical users like waste management staff to self-install these networks [10]. The waste back end SQL server includes a DBMS (Data Base Management System) for control of all data from the waste collector vehicles. This PDA-based RFID enabled waste management system is also used to identify a large number missing/stolen waste bins in each municipality.

III. MULTI-LAYER ARCHITECTURE FOR WASTE MANAGEMENT SYSTEMS

Figure 2 shows the multi-layered (i.e., five layer) RFID and sensor based waste management systems architecture, namely, physical layer, middleware layer, process layer, data access layer and user interface layer.

The physical layer consists of the actual RFID hardware components that include RFID waste tag, reader and antennas (both tag and reader).

Middleware layer is the interface between the RFID reader, load cell sensor and waste management service providers (i.e., waste collectors, and municipalities) IT system. The middleware layer is an important element of RFID and load cell sensor systems, which is viewed as the central nervous system from the waste management system perspective. This layer enables waste management service provider’s (e.g., waste collector) a quick connectivity with RFID readers and load cell sensors. Middleware layer lowers the volume of information that waste management system applications need to process, by grouping and filtering raw RFID and load cell data from readers and sensors respectively. The middleware layer also provides an application-level interface for managing RFID readers, and load cell sensors for processing large volumes of waste data for their applications. In addition, the middleware layer is responsible for monitoring physical layer components and supports International Standardization Organization (ISO) standard [6].

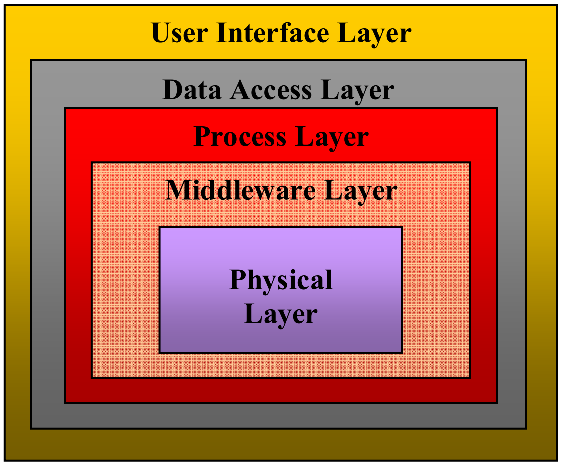

Fig. 2: Multi-layer architecture for waste management system

The Process Layer drives waste management services to deploy RFID and sensor based waste management system (business) processes that provide real-time integration into their existing systems. This layer enables data mapping, formatting, business rule execution and service interactions with databases. The data access layer is composed of a RDMS (Relational Database Management System) and applications that allow waste management service providers to create an RFID and sensor “events”. This layer interacts with the SQL server and includes a data query/loading approach using SQL and customized data (i.e., customer/household information) that are presented to the waste management service provider (i.e., waste collector) for fast and accurate waste (e.g., garbage, recycling, and green) identification [11].

Finally, the user interface layer is comprised of an extensible GUI (graphical user interface), which allows RFID devices (e.g., waste tag, reader) and load cell sensors in a uniform, user-friendly way to work seamlessly in a Windows environment.

IV. RFID AND SENSOR BASED WASTE MANAGEMENT SYSTEM APPLICATION

Figure 3 shows a PDA-based (RFID and load cell) automatic waste identification and weight measurement interface for the WMS using C# in Microsoft Visual Studio.net 2003 environment. The driver of a waste collecting vehicle needs to start a session to setup a system by clicking the “Start” button at the beginning of each shift. This is shown in figure 3(a). The PDA-based interface uses the unique ID transmitted by RFID waste tags as a key to information and perhaps other information (e.g., customer/household ID, address, and so on) stored in the waste management administrators back-end databases. For example, an RFID waste tag only contains a unique tag ID, which a PDA-based waste management application can use to retrieve a household/customer's record (i.e., personal information) stored in the backend waste database.

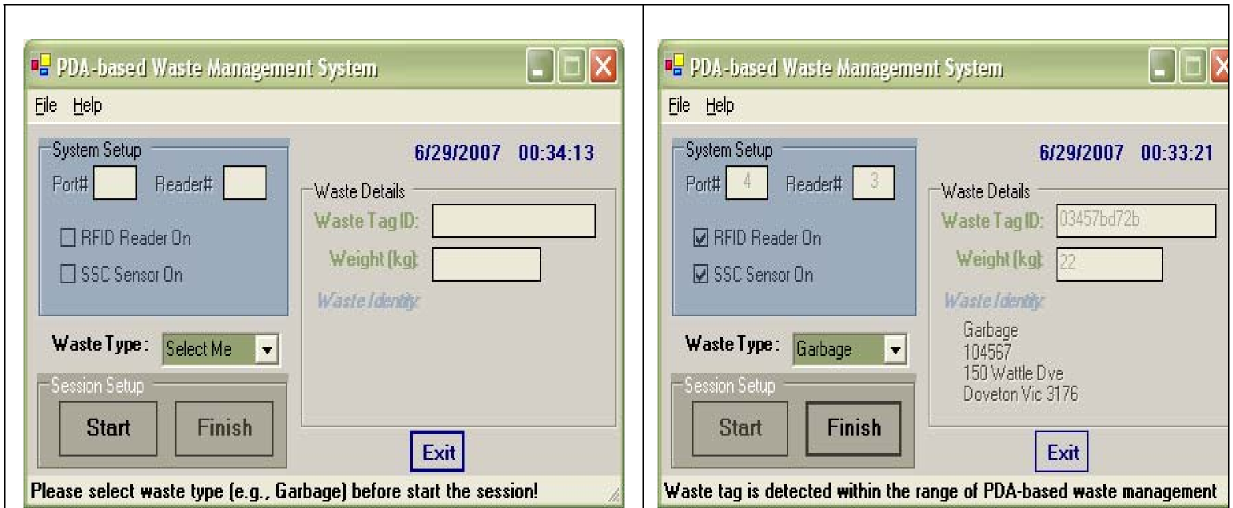

Fig. 3(a) Fig. 3(b)

Fig. 3: PDA-based (RFID and load cell) Waste Management Systems application

Fig. 4: RFID-based Waste Management Administrator application

When robotic arms in the waste collector load onto the vehicle (truck), a PDA-based RFID reader and load cell sensor automatically read and store the identity and weight of the waste respectively at a distance (i.e., wireless communication). At the same time, the identity of the household is retrieved from the database via wireless communication and displays it along with the waste tag id and weight is shown in Figure 3(b). The driver in the waste collecting vehicle then verifies the retrieved information (e.g., address) with the actual bin address/location for each household. The driver will also be able to identify missing/stolen bins using such information. A driver finishes his/her shift or session by clicking the "Finish" button. This results in stored weights in the PDA for waste identities being transferred automatically to a relevant database (i.e., garbage) via a wireless network (e.g., WiFi connection) before shutting down the PDA-based waste management system.

In addition, waste management administrators (e.g., municipalities) can assign an RFID waste tag to, and remove from, a bin (e.g., garbage) using password protected authentication for greater data security. The administrator is also able to search for a particular customer or household number or write the customers personal information (e.g., name, address, date of birth, etc.) to the waste tag using the "Write to Waste Tag" button as shown in Figure 4. The waste tag (RFID) can be removed from a damaged/rejected bin using 'Remove Tag from Bin' button. The available waste tag from such a bin can be reused.

V. SECURITY OF WASTE MANAGEMENT SYSTEM

While RFID provides promising benefits such as business process automation, some significant challenges (e.g., security concerns, and process and manage RFID data) need to be addressed before these benefits can be realized. To overcome this challenge, sophisticated security measures are needed. Without security, illegal activities that cheat RFID systems are easy because of using air interface between waste tags and RFID readers, and between RFID readers and the back-end database system. In addition, user privacy is also an issue, since anyone can intercept communication between the waste tags and readers (RFID), between readers and back-end system, and obtain information about a waste tag holder. To remove security vulnerabilities and protect user privacy, a number of existing RFID security systems can be considered and adopted as a measure of security.

In our waste management system communication between waste tags and readers, readers and back-ends are one way. Our waste tags are passive, inexpensive and have a minimum amount of memory. We are keeping very little information in the waste tag e.g., just Tag ID only. The Pocket PC (PDA-based RFID reader) is installed in the driver cabin of the waste collecting vehicle. When waste collectors pick-up the bin using vehicle lifting arms and immediately before putting the waste in the waste cabin of the vehicle, the PDA-based RFID reader reads and records the waste tag ID. This will happen when the waste tag/bin comes in to contact with the reader within a range of one meter. Within this proximity and with the mobile environment, there will be no scope to intercept communication between tags and a reader. In the worst case situation, if an intruder intercepts and gets the tag ID, he/she gains nothing because the tag does not contain any additional information.

As waste tags are ISO standard, the PDA-based RFID reader support and communicate with these (ISO 15693) tags. If more than one waste tag answers a query sent by a PDA-based RFID reader, it detects a collision. An anti-collision is performed to address this issue if multiple instances of waste tags are in an energizing field. The proposed RFID reader has a feature to detect different types of ISO 15693 waste tags and can handle them individually. However, our waste management smart system is designed to handle only one instance of waste tag at a time.

For the secure transfer of waste data from Pocket PC (i.e., PDA) to back-end database server, we are using a Hash Function-based Mutual Authentication Scheme [14]. This scheme, utilizing a hash function, is widely used for secure communication between readers and back-end SQL servers in a RFID-based environment.

VI. IMPLEMENTATION OF RFID AND SENSOR BASED WASTE MANAGEMENT SYSTEM

A RFID-based Secured Real-time automatic Waste Identity, Weight, and Stolen Bins Identification system (WIWSBIS) can be implemented in any municipality in Australia and in the western world, for better management of its environmental services. The waste management service (e.g., municipality) can use this system for automating and streamlining waste bin identification, measuring the amount of waste produced by each household in the region of its responsibility, and creating/producing an automatic invoice for each household based on the amount it has actually used.

At present, we are in the process of discussion with the Environmental Services (i.e., Waste Management) administrator in the City of Casey, Melbourne, Australia to install a RFID-based Automatic Waste Weighting, Identity, and Stolen Bins Identification system. The City of Casey is located in the South-East of Melbourne, which is Victoria's most populous municipality; the population is estimated at 231,783 (as at October 2007) [8]. The City of Casey is 400 square kilometers in area. Over the past five years the City of Casey was Victoria's fastest-growing municipality. It was also the third-fastest in Australia behind the Gold Coast and the Brisbane municipality over the same period. Currently, almost fifty families move to the City of Casey every week or, approximately 8,000 people each year. The expected future population is 350,000 by 2021, making it as big as Canberra, Australia, is today [8].

The City of Casey currently manages 80,000 waste bins (i.e., garbage, recycling and green) for its customers (i.e., waste producers). It appoints contractors (i.e., waste collection company) to collect both household and business waste. Waste collectors normally collect and process on average 37,787.95 tons of garbage, 19,140.50 tons of recycling and 18,311.43 tons of green waste per year (Source: City of Casey, Melbourne) as shown in the table 1.

Table 1: SUMMARY OF WASTE COLLECTION FROM 2003 – 2007 IN THE CITY OF CASEY

	2003/2004	**2004/2005**	**2005/2006**	**2006/2007**	**Average (tonnages)**
Garbage	36497.26	38249.96	38153.54	38251.06	**37787.95**
Recycling	7268.00	20030.79	22929.97	26333.23	**19140.50**
Green	8125.01	22784.28	23905.37	18431.07	**18311.43**

There are approximately seven hundred and fifteen waste bins missing or stolen in the City of Casey each year, that cost the council over $25,000.00 ($35.00 - $50.00 each bin) per year (Source: City of Casey).

The City of Casey is keen to attain a higher degree of sensitivity for individual waste generation and to lower the total amounts of waste they need to handle. It is also eager to reduce/identify the number of missing/stolen waste bins using an automatic identification system such as RFID and sensor based smart waste management system.

VII. CONCLUSION

In this paper we have described multi-layer waste management system architecture for design of a RFID; sensor based real-time automatic WIWSBIS. We have shown the application and implementation of the above system. Using WIWSBIS, waste management service providers (e.g., municipalities, waste collectors) have a chance to track a waste identity (i.e., customer), weight, missing/stolen bins quickly and accurately without human intervention. This system also helps service providers to automate customer invoices, enhance cost savings and improve security.

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