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Radio-Mama: An RFID based business process framework for asset management

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ABSTRACT

This paper discusses a framework (called Radio-Mama) using a FRID technology for real-time management of mobile assets. We decompose an asset management system into atomic or composite business processes (BPs). Triggered by RFID events, the business events are invoked automatically. Data gathering from RFID receivers are used to fill in required parameters specified in the descriptions of the BPs. The main idea behind the framework is a separation of business logic from sensor technologies for gathering data. This separation allows changes of BPs without effects on gathering sensor data and vice versa. We evaluate our approach through the development of a system for asset management called CSCE-AMS which can be thought of as an instance of Radio-Mama. The framework facilitates the rapid development and extension of sensor based systems.

1. Introduction

Automatic tracing of mobile objects plays an increasingly important role in managing the usage, safety, and maintenance of facilities within enterprises. RFID technologies have become the cornerstone for enabling this functionality. RFID tags can provide identification of objects (including people) they are attached to.

Radio-Mama is an RFID based business process framework for the development of asset management systems. The framework decomposes the functionalities of an asset management system into business processes (BPs) which are invoked by RFID events. We investigate both passive and active tags for capturing data. The scanned tags are then translated into meaningful business events and their data are used to fill in required parameters in BPs' specifications which are described in the ANSI/CEA-2018 standard specification (Assoc, 2008). ANSI/CEA-2018 is a new standard which allows runtime execution and has mechanisms for binding activities to devices' functionalities.

We investigate the suitability of different types of RFID tags (e.g., active and passive tags), receivers (e.g., different coverage distances), and their placement (e.g., single controlling zone, multiple controlling zones, overlapped controlling zones) for asset tracking.

The structure of the paper is as follows. We first give a brief overview of RFID technologies. Section 2 presents related work. Section 3 elaborates on the proposed framework, and presents the prototype implementation of the asset management system, which we view as a particular instance of Radio-Mama. Section 4 presents evaluation and discussion about the framework and our contributions. Finally, Section 5 concludes the paper and draws out future research.

1.1. RFID technologies

1.1.1. RFID tags

Radio Frequency Identification (RFID) technology is an automatic way to collect product, place, time, or transaction data quickly and easily without any human interaction. These systems consist of a reader that uses an antenna to transmit radio waves to interrogate a transponder (a radio tag or RFID card). Most RFID tags store some sort of identification, from which the reader identifies a radio tag. A reader retrieves information about the ID number from a database and acts accordingly.

There are two broad categories of RFID systems—passive and active systems (Weinstein, 2005). Active RFID tags contain their own source of energy, usually an on-board battery. On the other hand, passive tags rely on external power source such as external readers. Because of their own power source, active tags transmit a stronger signal and readers can access them from long distances (20 – 100 m). Due to in built power source active RFID tags are larger and more expensive. These types of tags are generally used on large items tracked over long distances. Because of power

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source inside the tag, active tags operate at high frequencies—commonly 455 MHz, 2.45 GHz, or 5.8 GHz depending on the application requirement.

Passive tags are inexpensive as they are simple to build. Because of less complex circuits, passive tags can also be quite small. As passive tags do not have capabilities to transmit signals by themselves, a passive-tag reader which can constantly broadcast signals need to be setup. When the readers' signal reaches a passive tag, it stores the energy in an on-board capacitor and will send a signal when it has enough energy to transmit signal to the reader. Because of low energy signals, passive tags are used only in small distance applications. Because of small memory capacity passive tags are considerably lower in cost making them ideal for tracking lower cost items (RFID Basics by Paxar Americas Technical Paper).

Basically there are two types of chips available on RFID tags, read-only and read – write. Read-only tags consist of information which is hardcoded during manufacturing process and cannot be changed at any time. Whereas in read – write tags, user can read or write into tags when the tags are in the range of a reader. Read – write tags are much more flexible and are programmable according to user applications, but these tags are much more expensive than read-only tags. A simple dual frequency LX1004 tag is shown in Fig. 1.

1.1.2. RFID readers

RFID readers consist of one or more antennas, via which data are received or transmitted to RFID tags. Sometimes, due to high sensitivity requirements, RFID readers can have separate paths for sending and receiving. The RFID readers need to be well positioned to read all the tags in a given application domain. Tag orientation can also affect the read range as the antenna on the reader may not be able to receive proper signals, based on the orientation. RFID readers can be a simple stand-alone device that can communicate with a host system via a serial interface.

A reader can be connected to multiple antennas to identify tags better and also to cover a wide area. Readers can also use wireless communications, but need to deal with multiple tags sending and receiving at the same time. This can sometimes cause collision and some data may be lost due to collision. In this case, a collision avoidance system needs to be implemented and ensure that the communication is structured in such a way that such collisions are avoided. A simple LX2002 Radio receiver is shown in Fig. 2. The tags and readers/receivers need to operate on a compatible frequency in order to send and receive effectively. The transmission power of the receiver can alter the distance it can read from and distance it can transmit to. By carefully calibrating the power of the reader/receiver, a user can adjust the covering range of the system.

Fig. 1. LX1004 tag.

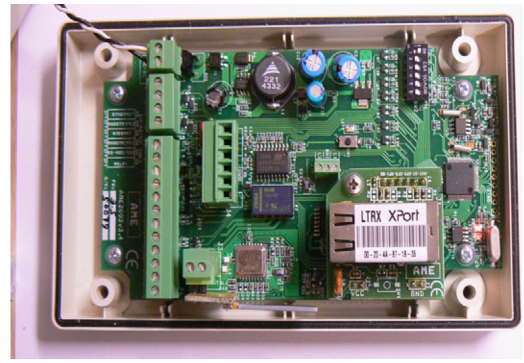

Fig. 2. LX2002 radio receiver for dual frequency tag.

2. Related work

2.1. RFID based asset management systems

RFID technology identification can be used in many different ways to create value for a business and also for personal applications (Roussos and Kostakos, 2009). One of the major advantages of having RFID technology is that it requires no human intervention, and can be used in real-time applications. The RFID technology provides huge advantages to manufacturers by offering tools and technology to plan production and respond quickly to market demand. Using RFID tags, retailers can track the stock level and potentially reduce stock-outs and at the same time can also reduce thefts by tracking stocks.

Several pieces of work have applied RFID technologies to asset management. Hakim et al. (2006) employ a passive RFID mechanism for tracking assets in a hospital. NEC (Tsuji et al., 2004) introduces an asset management solution based on RFID. Recently, Meng et al. (2009) develop an RFID-based asset management system which is able to display spatial information of assets on an electronic geographical map and to provide automated notification of malfunction alarm through SMS. There are also a few commercial systems dealing with automatic asset tracking such as WiseTrack,[1] Xterprise,[2] Reva Systems,[3] and Insync Software.[4]

All the systems described above do not separate business logics of asset management from the implementation of functionalities for gathering sensor data. This is not flexible because the policies of managing assets in an enterprise often changes rapidly to adapt to the advances of RFID technologies and the enterprise's general policies. Our approach aims to address these problems by taking the specifications of BPs into the system. Therefore, the changes of BPs will not require the changes of sensor reading implementation and vice versa.

Fernandez et al. (January – February 2009) develop an asset management using the RFID technology which is used to manage moving mechanical parts such as rail vehicles, chassis, axles, bogies, couplings, and swap bodies in the rail freight industry. They propose a layered processing scheme for turning tag readings into significant information. The disadvantage of this method is specifically coupling each layer with the business processes. This may prevent the system from adaptation to the changes of enterprise's policies. This is different from our approach which uses a model of a finite state machine for handling RFID generated events and for automating the

[1] www.wisetrack.com
[2] www.xterprise.com
[3] www.revasystems.com
[4] www.insyncinfo.com

transformation of physical RFID readings into semantic data linked to business processes. By the separation between the events, the states, and the logic processes it is possible for the system to adapt to the changes of asset management policies.

2.2. RFID event based business process

A business process (or BP, for short) is "a collection of related, structured activities that produce a service or product that meets the needs of a client" (Davenport and Short, 1990). One way to automate business process is to develop applications that execute the required steps of the process, but sometimes this approach may also need human intervention. Individual business process can be monitored for their state and statistics.

RFID events result in automating BPs, or tasks within a BP, or even signalling completion of tasks within a BP. Then the parameters passed by these RFID events are used to fill the required data in the specifications of the BPs being executed. The execution of a business process may return another event. A number of systems combine database or enterprise resource planning functionality with RFID and sensor technology, such as SAP's Auto-ID Infrastructure (Bornhoevd et al., 2004), Sybase[5], and Oracle.[6] Our framework, however, is lightweight (does not require extensive computational resources or cost), and specialized for asset management involving business processes. Zhao et al. (2009) propose a method for enhancing business process automation by integrating RFID data and events into business process-based systems. However, their work is based on the event calculus while our approach uses a finite state machine for business rule modelling, event handling, and process operation invocations.

3. CSCE-AMS: a prototype implementation of *Radio-Mama*

Our fundamental aim of implementing an asset management system is to demonstrate the usage of the Radio-Mama framework for developing RFID based systems. There could be multiple implementations of *Radio-Mama* for tracking different objects. We call the prototype we describe below CSCE-AMS (short for "Computer Science and Computer Engineering" (our department name) Asset Management System) to differentiate it from possible future implementations of *Radio-Mama*. CSCE-AMS was developed to manage assets in our department.

3.1. Functional requirements

CSCE-AMS is used to monitor the usage of assets (e.g., laptops and projectors) in our department. Our traditional system for managing assets relied on papers and an administrator for recording transactions. The disadvantages of this system were the cost for papers and administration. Also, it did not support well for the analysis of asset usages, booking, and scheduling. CSCE-AMS aims to address these problems.

CSCE-AMS is tracking who borrows what assets at what time and returns what assets at what time. It can send reminders by e-mail and SMS to those who have not returned the borrowed assets on time. It also allows for remote asset bookings. The system needs to be adaptable to changes of business scenarios in the future and to provide flexible means at the business logic layer to respond to abnormal situations.

The overall goal of the system is to minimise human intervention in transactions of borrowing and returning assets. It also supports for reminding, booking, and analysing the usages of assets. The system needs to work with different types of assets such as projectors, and laptops.

3.2. System analysis and design

According to our proposed framework, CSCE-AMS is a finite state machine. Its business processes are triggered by RFID generated events. These events cause to transit the system's states correctly. To transit from one state to another state, the system needs to execute appropriate business logics. In this section, we present the analysis and design of a finite state machine for our system.

The system must process events that come from the raw flows of tag readings in order to turn them into significant business-profitable information. We use a model of a finite state machine to support us for analysing, designing, and checking the correctness of the system at the design time.

A finite state machine is a quintuple $\langle K, F, \Sigma, \Delta, S \rangle$, where K is a finite set of states, $F \subseteq K$ is a set of final states, Σ is a finite set of events, $\Delta \subseteq K\Sigma K$ is a finite set of transition relations, and S is the initial state.

The input of the system design process is the requirements which contain a set of rules and policies of business logics for governing the asset loan within our department. The elements of the finite state machine are built up from the extraction of these rules and policies. An example of these rules is to specify how long an asset can be borrowed and what happens if one will not return a borrowed asset in time.

Table 1 describes the set of states in our finite state machine, i.e., $K=\{s_1, s_2, s_3, s_4, s_5, s_6, s_7, s_8, s_9, s_{10}\}$. The initial state, $S=s_1$, the set of final state $F=\{s_1, s_2\}$, and the set of events $\Sigma=\{e_1, e_2, e_3, e_4, e_5, e_6, e_7, e_8\}$ as described in Table 2, and the set of transition relations Δ is defined in Table 3. This finite state machine is depicted in Fig. 3.

3.3. Enhanced business processes based on RFID events

AII RFID readings are associated with specified mapping rules and metadata in the specifications of the business processes.

Table 1
Definitions of states.

State	Description
s_1	The available asset is in the store and no user is identified
s_2	The available asset is in the store and a user is identified
s_3	The available asset is in the active zone while no user is identified
s_4	The available asset is illegally taken away
s_5	The asset has just been borrowed and is in the active zone
s_6	The borrowed asset is in the inactive zone (i.e., taken away for usage)
s_7	The borrowed asset is overdue and a reminder has not been sent.
s_8	The borrowed asset is overdue and a reminder has already been sent

Table 2
Definitions of events.

Event	Description
e_1	The available asset enters the active zone
e_2	The available asset leaves the active zone
e_3	The borrowed asset enters the active zone
e_4	The borrowed asset leaves the active zone
e_5	A user is identified
e_6	The session user identification is expired
e_7	The borrowed asset is overdue
e_8	A reminder is sent

[5] www.sybase.com/products/rfidsoftware
[6] www.oracle.com/technology/products/sensor_edge_server/

Table 3
Transition relations.

	s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8
e_1	s_3	s_5		s_3				
e_2			s_4					
e_3						s_1	s_1	s_1
e_4					s_6			
e_5	s_2		s_5					
e_6		s_1						
e_7						s_7		
e_8							s_8	

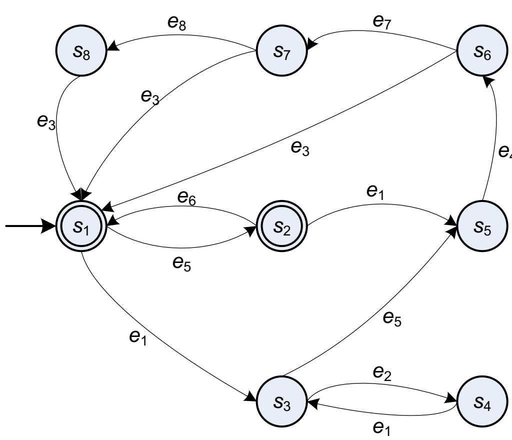

Fig. 3. The diagram of the finite state machine.

These mapping rules allow the system to appropriately select predefined business logics to be executed.

The system starts from the state s_1 where the assets are in the store and no one is identified. The business process called Asset Borrowing is triggered to be executed when someone brings an asset(s) into the active RFID zone (i.e., the asset is tagged and when it is brought within range of the reader), generating the event e_1 described in Table 2 and Fig. 3. Then the whole system will operate by following the model of the finite state machine. The following is a code fragment which causes a BP to be execute on an occurrence of an RFID event.

```
RFIDEvent onEvent (EventObject eo) {
    ProcessObject process=DicisionMaker.Selection process
    (eo);
    EventObject new_eo=process. execute {eo.getData {}};
    if {neweo !=null }
     return new_eo.fireEvent {new_eo};
    else
     return null;
}
```

There are five main BPs (or subprocesses of the whole process) in our system: *Borrowing Process*, *Returning Process*, *Reminding Process*, *Alarming Process*, and *Overdue Checking Process*. The decision maker uses the transition relations to select appropriate processes to be invoked on each corresponding RFID event.

Borrowing Process is the operation of borrowing a single asset. The process can be repeated for multiple borrowing. This process is invoked by the event e_1 to transfer the status $s_2 - s_5$.

Returning Process is the operation of returning a single asset. The process can be repeated for multiple returning. This process is invoked by the event e_3 to transfer the statuses s_6, s_7, and $s_8 - s_1$.

Reminding Process is to send reminder messages (e-mails or SMS) to the borrowers who have not returned assets having being borrowed on time. This process is invoked by the event e_8 to transfer the status $s_7 - s_8$.

Alarming Process is a security solution in case of illegal borrowing. This process is invoked on the event e_2.

Overdue Checking Process is a special thread which operates silently and continuously in background. It is not caused by any RFID events but can fire the event e_7 to transfer the status from s_6 to s_7. The event e_7 will be fired when the process detects that there is an overdue asset and a reminder message has not been sent to the corresponding borrower yet. We assume that only one reminder is sent in case of an overdue.

This means that the business processes are driven by RFID events detected in the right contexts, i.e., when the system is in the appropriate state.

3.4. Architecture

The CSCE-AMS architecture consists of four key elements (see Fig. 4): an asset identification system, a user identification system, a database that hold information about assets, users, and loan transactions (i.e., borrowing and returning transactions), and the software that executes asset management business processes triggered by RFID generated events. In the following subsections, we describe each of these elements and how they are designed to meet the functional requirements of the CSCE-AMS.

3.4.1. Asset identification system

We use ARYGON's Linx system[7] as the asset identification system in our system. The most advantage of this system is its high reading distance (our experiment shown that the coverage was up to 60 m for outdoor environment and 12 m for indoor environment). The Linx system is made of three different devices (Fig. 5):

- the activator LX2101, a microwave transmitting unit,
- the active transponder LX1004, a double frequency tag, and
- the receiver LX2002, a radio frequency receiving unit.

The active transponder (or called RFID tag) is normally quiescent, until it gets activated by the activator that awakes it. Only then the active tag starts up, reads the signal transmitted by the activator, runs all the necessary operations, and then transmits its code to the receiver.

The activator is based on 2.45 GHz technology. It is used to energise the transponder. It comes with an RS422 interface and looks the same as the receiver.

A transponder is an active dual-layer tag (i.e., battery is needed), which upon activation by the activator can receive data from the reader (uplink) and transmit its own 32-bit ID code, followed by other data (downlink). Each tag is tied to each asset in our system.

The receiver is a control centre whose operating modes can be programmed and parameterised. The receiver is in permanent reception of data transmitted by the transponders. The receiver is connected to our CSCE-AMS software on a PC via an Ethernet interface.

[7] http://www.arygon.com/wEnglish/products/active_system/

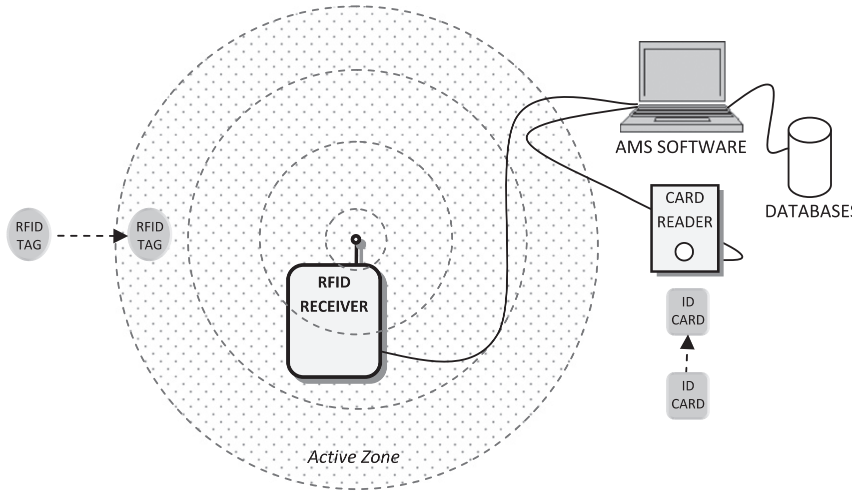

Fig. 4. The implementation architecture of the system.

Fig. 5. The activator LX2101 and a transponder.

Fig. 6. The Mifare Reader/Writer and smart cards.

Column Name	Datatype	NOT NULL	AUTO INC	Flags	Default Value
ASSET_ID	BIGINT(20)	✓		☑ UNSIGN	NULL
ASSET_NAME	VARCHAR(255)	✓		☐ BINARY	NULL
ASSET_DUE_TIME	INTEGER	✓		☑ UNSIGN	1440
BORROWED	TINYINT(1)	✓		☐ UNSIGN	0
LASTBORROWEDBY	VARCHAR(255)			☐ BINARY	NULL
BATTERY_START	BIGINT(20)			☑ UNSIGN	NULL

Fig. 7. The structure of ASSET_TABLE.

3.4.2. *User identification system*

The MIFARE® system[8] is used for the user identification system in our system. The MIFARE® system complies with the ISO/IEC 14443A standard. It has two different devices (Fig. 6):

- the Mifare Reader/Writer, and
- the passive smart card, an ISO/IEC 14443A RFID tag.

The Mifare Reader/Writer is a high frequency reader/writer. It utilises an existing PC standard for USB and uniquely for RS232 interfaces which is used to connect to our CSCE-AMS software on a PC. It supports transponders from various suppliers including our existing staff and student cards in our department. The reader has a maximum effective distance up to 5 cm. No external power is needed; it is powered from the USB port.

The ISO/IEC 14443A RFID tag is a passive contactless smart card according to ISO/IEC 14443A standard. No battery is needed. Its high data transmission rate allows complete user identifying transactions to be handled in less than 100 ms. The card may also remain in the wallet during the transaction, even if there are coins in it.

Special emphasis has been placed on security against fraud. Mutual challenge and response authentication, data ciphering and message authentication checks protect the system from any kind of tempering. Serial numbers which cannot be altered guarantee the uniqueness of each card.

3.4.3. *Database*

The database stores data about asset and user information as well as borrowing and returning transactions. We use MySQL Database Server[9] to manage the database in our system. The database contains three main data tables: ASSET_TABLE, STAFF_-TABLE, and TRANSACTION_TABLE.

The ASSET_TABLE holds data about assets. The table structure is shown in Fig. 7. The ASSET_ID attribute holds the code number of the corresponding RFID tag tied to an asset. ASSET_NAME describes about the asset (e.g., name). The ASSET_DUE_TIME attribute represents how long in minutes a specific asset can be borrowed (e.g., the default is 1440 min∼1 day). All these attributes are modifiable by the administrator of the system. The BORROW attribute specifies the availability status of an asset. The LASTBORROWEDBY attribute gives us a quick check who are the last staff borrowing the asset. Finally, BATTERY_START indicates the time when an asset is replaced a new battery. The system daily checks this attribute to decide whether an asset

[8] http://mifare.net/

[9] http://www.mysql.com/

needs to be replaced its old battery. If this is the case then the system will alert a message for the administrator. The lifespan of a battery depends on how many times the asset bought into the active zone, hence the times that the asset has been borrowed. We recorded that a new battery can last for approximate 20 h in the active zone and that a transaction of borrowing and returning takes about 30 s (i.e., a staff collects an asset from the store, stops to sweep his/her staff card over the card reader in the active zone, then goes away). Therefore, the maximum of transactions an asset can have before its battery should be replaced is 2400 (i.e., $20 \times 3600/30$). Our trial period of a month is not long enough for us to test this feature.

The STAFF_TABLE holds basic information about staffs in our department (Fig. 8). The information of a staff includes staff card ID, staff name, his/her e-mail address (used for overdue reminding), and his/her mobile phone (also used for overdue reminding).

The TRANSACTION_TABLE holds information about transactions of borrowing and returning assets. The table structure is shown in Fig. 9. The USER_ID attribute records the identification number of the corresponding id card of a staff. The ASSET_ID attribute represents a borrowed asset. The START_TIME attribute and END_TIME attribute record the time of borrowing and returning an asset. REMIND_SENT indicates whether a reminding message has been sent to the corresponding staff in the case of an overdue. If REMIND_SENT is true, then the reminding message will not be sent again. This avoids staffs from receiving repeated messages for the same overdue asset. The *Overdue Checking Process* takes REMIND_SENT, START_TIME from the TRANSACTION_TABLE and BORROWED, ASSET_DUE_TIME from the ASSET_TABLE as inputs to check overdue assets and to decide sending reminding messages.

3.4.4. Software

We developed software that incorporates the hardware components and the database described in the previous subsections. The software executes asset management business processes triggered by RFID generated events.

There are two main RFID generated events: the presence of an asset in the active zone and the identification of a user. The event of user identification has effective only if it happens following an event of asset's presence in the active zone. The software operates according to the diagram of status transition as discussed previously.

If a currently detected asset is new to the system, it will ask for information about this new asset. Similarly, if the system detects a new ID card, it will ask for information of the corresponding user. Fig. 10 presents these two dialog windows.

Column Name	Datatype	NOT NULL	AUTO INC	Flags	Default Value
USER_ID	VARCHAR(20)	✓		☐ BINARY	NULL
USER_NAME	VARCHAR(255)	✓		☐ BINARY	NULL
EMAIL_ADDRESS	VARCHAR(100)	✓		☐ BINARY	NULL
MOBILE_NUMBER	VARCHAR(10)	✓		☐ BINARY	

Fig. 8. The structure of STAFF_TABLE.

Column Name	Datatype	NOT NULL	AUTO INC	Flags	Default Value
BORROW_ID	INTEGER	✓	✓	☑ UNSIGN	NULL
USER_ID	VARCHAR(20)	✓		☐ BINARY	NULL
ASSET_ID	BIGINT(20)	✓		☑ UNSIGN	NULL
START_TIME	BIGINT(20)	✓		☑ UNSIGN	NULL
END_TIME	BIGINT(20)			☑ UNSIGN	NULL
REMIND_SENT	BOOLEAN	✓		☐ UNSIGN	

Fig. 9. The structure of TRANSACTION_TABLE.

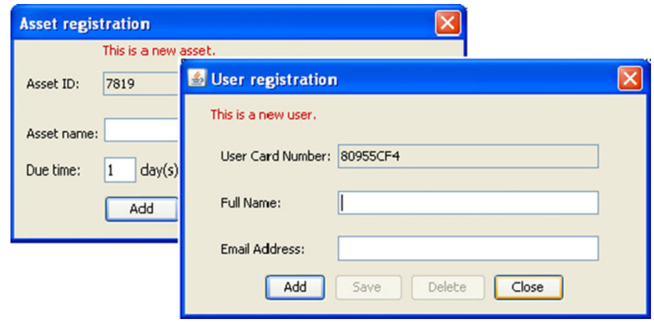

Fig. 10. The dialog windows for newly detected user and asset.

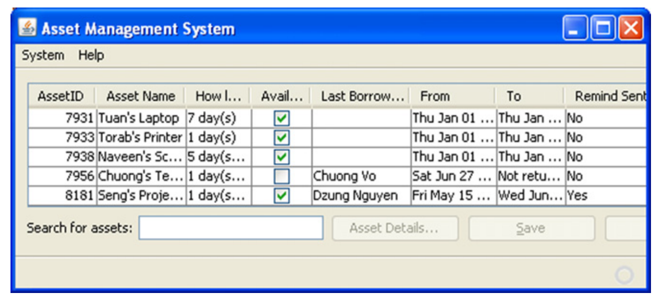

Fig. 11. The main user interface of the system.

The main user interface (Fig. 11) allows the administrator to monitor loans. It allows searching for information about any assets, who borrowed them at what time, whether they have been returned, whether reminders have been sent for late returning, etc.

3.5. System deployment

We deployed and used CSCE-AMS in our department office for a month. The system setting is shown in Fig. 12. The reason to separate the storage room from the active zone is to maximise the lifespan of tags attached to assets. We have experimented that our active tags (LX1004 tag using Maxell CR2032 batteries) cannot last longer than 20 days when they are continuously in the active zone. By having the tags out of the active zone, unless brought in, we save on battery power. After the trial period, we have received several feedbacks from the staff and administrators. Accordingly, some problems need to be considered. First, there is a need for checking the integrity of an asset when it is returned. This requires us to use smaller tags which are attached to some parts of an asset. The second is the loss of RFID tags. To solve this, we use RFID tags which can be stacked securely on parts of assets. Also, we use double tags for each tracked part.

3.6. System operation

To borrow an asset, the user takes two simple steps: (1) bring the asset into the active zone; (2) sweep his/her ID card over the card reader. For more convenient in our system deployment, the user is required to just walk through the door and swipe his/her ID card over the card reader next to the door. The user identification is finished instantly by giving a "beep". The system will confirm the borrowing transaction by saying "borrowed". If the user has not presented his/her ID card, then the system will say: "please swipe your card" and wait for user identification in some seconds. If the waiting time is passed without a user identified, the system will give an "alarm" to inform an illegal borrowing (i.e., someone stolen an asset).

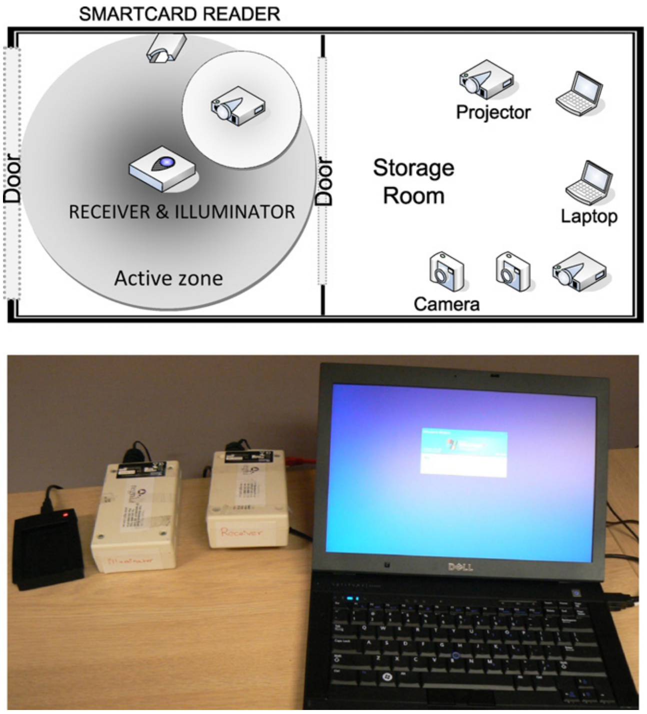

Fig. 12. Deployment of the system: receiver, illuminator, card reader, and store, and the devices next to the laptop.

To return an asset, the user (not need to be the user who has borrowed the asset) bringing the asset walks through the active zone and places the asset on the shelf in the store room. A speech output of "returned" is to confirm the returning transaction.

4. Evaluation and discussion

So far, our current findings and outcomes relate to the pragmatics and architecture of deploying process-based RFID systems, as follows.

In order for RFID-generated detections to be meaningful, the detections have to be embedded within the context of a state-based business process (which can be modelled using a state-transition diagram).

Ambiguity in tag readings can occur especially in the border of two (or more) readers; positioning of readers cannot be determined easily theoretically but through trial (since the range of reads is sensitive to the physical features of the environment) in the actual environment of deployment. The notion of zones in which objects are detected is needed.

In order to deal with unintended RFID-tag readings, or to prevent tag readings from being interpreted wrongly by the system, there has to be proper design of physical position of readers and state semantics (keeping track of a (short) history of reads—a read of the same tag can mean different things in different stages of a business process; and a first read has different semantics from a second read). Also, repeated tag reads (occurring in close time proximity with each other) must be filtered.

The architecture of a loan equipment tracking system needs the following components: ID card readers, one RFID-tag reader (one is adequate), tagged objects, and a computer hosting a database, and the continually running software (realizing a state-transition diagram representation of a business process for loan equipment tracking). The database should incorporate user information and is extensible to include new objects to be tracked or new users who will use the objects. The software can also include reminder services for borrowers (as dictated by the business process design).

There has been pragmatic issues with battery life—we measured the battery life for our RFID tags and this information needs to be incorporated in the system for reminders about battery replacement, etc., and also pragmatic issues with the range of the RFID tags we have The tags could be shorter range, but the ranges were found to be uncontrollable via software. Hence, a pragmatic lesson learnt is that the choice of RFID technology to use is important for different business processes, and governed by the parameters such as battery life (or even should battery-based tags be used), range of reads, and easy controllability of reading ranges.

Introducing an emerging technology into any organization is challenging. Resistance from staffs has been mentioned as inhibitor for deploying the system. Staffs were acting with a considerable level of autonomy. We (as developers) and staffs (as administrators) have worked together for not only gathering requirements but also for the explanations of what can be improved and automated in the whole business process by using the RFID system.

Since RFID uses radio waves and is tagged to moveable objects, it inevitably is affected by its physical environment and the objects tagged. The following issues or factors need to be taken into account: the layout of the deployment environment (e.g., two-zone layout or one-zone layout, the gap between zones); the radius of the radio range; the placement of readers; the size of the tags; the possible movements of tagged objects (including abnormal movements); and finally, the integration of the existing staff identification system (i.e., existing staff ID cards) into the new system.

Generalizing from CSCE-AMS to *Radio-Mama*: We found that our approach can be generalized to other asset management applications which are to be embedded within one or more business processes, and we name this conceptual framework *Radio-Mama*, of which CSCE-AMS is an instance. Generalizing from CSCSE-AMS, the key ingredients of *Radio-Mama* are as follows:

(1) The *roles involved in a business process framework* for asset management are users, assets, and the system.
(2) The *events* (e.g., a detection (or non-detection) of an asset at a particular location) needs to be identified. In general, there are events which relate to the real-world behaviour of assets (detected via RFID) and events related to system actions. Note that, in general, an event detected via RFID is basically a triple (TimeStamp, TAG-ID, Location of Reader).
(3) One or more *business processes modelled via a finite state machine* $\langle K, F, \Sigma, \Delta, S\rangle$, where K is a finite set of states recording the status of assets, corresponding to the result of the occurrences of real-world events, the states acting as "memory" of such events or event sequences, where, $F \subseteq K$ is a set of final states, Σ is a finite set of events (identified in (2) above) corresponding to business process events (the semantics of the events are assigned by the business process) but the events correspond to RFID reads, and or system actions (e.g., a reminder sent), where $\Delta \subseteq K\Sigma K$ is a finite set of transition relations, and S is the initial state. The state machine representation also ensures that detected events are responded to in the right way. Work in Wang et al. (August 2009) studied complex RFID event interactions using declarative specifications with temporal constraints, but we employ an FSM technique. The FSM technique also allows the process to be amenable to formal analysis, though we did not carry this out in this paper.
(4) The *mapping of particular RFID reads and system actions to business process events* then needs to be given. In CSCE-AMS,

this is done within our code, in the prototype implementation, but a more explicit mapping using XML rules can be used.

(5) We take an event-oriented approach to process RFID data, by driving business processes by RFID events in a finite state machine. This approach allows us to formalise the semantics of RFID events, greatly simplifies the work of RFID data processing, and significantly reduce the cost of RFID data integration.

(6) We also present a methodology for designing an RFID based asset management by using a finite state machine. The model facilitates us (developers) and the department (customers) in verifying the correctness of the system behaviours before deployment. This can reduce the risk of misbehaviours of the system at runtime, hence increasing the security level.

5. Conclusion and future work

We have presented CSCE-AMS, a prototype system which we have deployed for asset tracking of laptops and projectors that are borrowed by staff. We also provided a general model of a business process framework for asset management called *Radio-Mama* and identified its key ingredients.

Future work will involve applying the framework to deal not just with asset tracking but also with tracking workflows involving tagged documentation/devices, and/or also tracking people involved in workflows (e.g., as they progress through a museum tour, conduct an inspection of a series of items), and also consider alternative RFID technologies for different workflow tracking applications. We will also investigate scalability issues with tracking a larger number of assets, though in principle, our approach scales (e.g., the business process remains essentially the same regardless of the number of assets being tracked), and composition of RFID-based business processes (specified as automata). While we use the basic FSM, richer modelling of temporal constraints can be explored with timed automata. This could be another future work to include Suggestion/Recommendation process into our system (i.e., a person who borrows A also borrows B). Future work can look at the specifications of the BPs described in XML files conforming to the ANSI/CEA-2018 standard (Assoc, 2008).

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