Smart Healthcare Environment: Design with RFID Technology and Performance Evaluation

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Abstract

This research proposes a radio-frequency identification (RFID)-based smart hospital environment (SHE) with distributed reading capability to enhance the quality of service by improving just-in-time healthcare, patient identification, emergency message delivery, healthcare worker assignment, and rescue response. Most research on emergency healthcare has focused on pre-hospital emergency medical services, with healthcare for general in-patients seldom mentioned. In this study, an RFID-based smart suite is applied to create a healthcare monitoring system for monitoring patients in real-time. An Android-based smartphone is used for sending patient alarm messages to healthcare workers. A pilot study is used to demonstrate and simulate how the proposed system can significantly improve daily emergency healthcare operations and its benefits in the hospital.

Keywords: Radio-frequency identification (RFID), Smart hospital, Smart healthcare, Smartphone application

1. Introduction

Medical information technologies are used by healthcare workers to enhance operation efficiency and reduce their workload. The level of information technology used in medical centers and medical institutes is already quite high, but the perceived basic level of emergency medical service (EMS) workers, medical controversy, medical staff, affecting their efficiency and even causing medical negligence.

The application radio-frequency identification (RFID) in Taiwan’s medical system was sped up due to severe acute respiratory syndrome (SARS). For example, a high-frequency RFID chip was developed by the Industrial Technology Research Institute (ITRI) and applied into the body sensor networks so that when suspicious disease cases occur, possibly infected persons might be quickly tracked and isolated [1]. Sun et al. presented an integrated system of barcodes and RFID technology to enhance the precision of healthcare management [2]. Lin et al. applied RFID technology to implement a HEPA (high-efficiency particulate air) air ventilation system and it would be more helpful for the prevalence of hospital-acquired infection prevention in Chung Shan Medical University Hospital, Taiwan [3]. Chien et al. proposed two RFID-based communication protocols to improve medication safety and efficiency for medication programs in PuLi Christian Hospital, Taiwan [4]. Shim et al. proposed a specimen management system and construction design with RFID sensing technology for related clinical laboratories, such as pathology lab, microbiology lab [5]. The experimental results showed that the proposed system is useful for specimen management, stable situation of temperature and humidity changes. Unluturk and Kurtel proposed an assisted-living system that integrates RFID technology and an online web service [6]. The system can be applied in a nursing home to immediately locate patients that need help.

Most research on the application of RFID technology in medicine has focused on emergency, out-patient, and surgery. Few studies have focused on general in-patient emergency relief. Therefore, the present study uses RFID technology and mobile devices to solve some of the post-hospital medical treatment problems of patients faced by emergency healthcare institutions. The expected benefits for emergency medical care with RFID technology are: 1. positions of healthcare workers and patients are known at all times via constant long-distance RFID detection; 2. emergency alarm messages from patients can be received by healthcare workers at any time and any place via mobile devices. This research proposes an RFID-based smart hospital environment (SHE) and evaluates its performance with two experiments.

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2. Materials and methods

2.1 RFID technology and smart living

RFID is a wireless sensing technology based on electromagnetic signal detection [7,8]. RFID is an automatic identification system in which an RFID tag is attached to a target item. Radio frequencies are used for communication with other appliances or items using RFID readers. The system includes various forms of identification and various mechanisms for identifying different types of objects. As shown in Fig. 1, the two most important parts in an RFID system are RFID passive/active tags and RFID readers. During the communication process, the RFID readers will driving transmit the data to another application system with edge applications installation via RFID middleware hardware/software that would be interpreted the reader observations and before forwarding them to other application systems.

Figure 1. RFID architecture.

The RFID reader retrieves data from the RFID tag through an antenna, which is either integrated or discrete. The reader stores the raw data, and then transmits them to other application systems. The RFID tag, either active or passive, has an integrated transmitter. When it receives a particular radio frequency signal, it sends a confirmation message to the RFID reader. Passive RFID tags do not have a power supply. Active RFID tags have a power supply, enabling them to transmit data over longer distances.

Most definition with the smart space is focus on several prospects, including: self-existent behavior, adaptive dynamic environment ability, emergency situation indication and differentiated surveillance. Self-existent behavior refers to smart services autonomously interacting with end-users, resources, and other edge application services [9]. Adaptive dynamic environment ability refers to the capability of satisfying user activities and dynamical environment changes [10]. Emergency situation indication refers to the smart space having the capability to detect an emergency situation and distribute the information to users in real-time. Differentiated surveillance refers to different levels of security or service configuration for different target areas [11]. Many algorithms and protocols for security or service improvement have been proposed [12,13]. Many communication standards and wireless technologies are available for smart space construction, such as Bluetooth, IrDA, RFID, and Zigbee. RFID and Zigbee technologies have emerged as the most appropriate [14]. For example, Wada et al. (2011) proposed one new gait measuring system with novel distance presentation method for helping the blind person. As the result, the proposed shoe-type device could measure the foot position with a success rate of 90% by RFID technology [15].

2.2 Healthcare, context awareness, and computational intelligence

Computational intelligence has been applied to many real-world problems, including those in complex medicine domains, such as the diagnosis of illness and therapeutic therapies. Many context-aware system architectures have been proposed to help patients and medical workers, such as a context toolkit for application development [16], a semantic space infrastructure [17], the UC Berkeley open infrastructure for context-awareness [18], and the European SMART-ITS project [19]. These research projects provide basic infrastructure assistance for context-aware environments or application installation. In the healthcare domain, information technology is used to obtain patients’ personal information and record these information into the patients’ databases. In addition, this research adopted the three-tier computer architecture to provide the useful computational total solutions to enhance the overall quality and security issues of healthcare. Many artificial intelligence and soft computing approaches have been proposed for implementing healthcare information systems, such as expert systems [20], artificial neural networks [21], fuzzy set theory [22,23], data mining [24], and genetic algorithms [25]. However, few researchers have applied smart space technology to healthcare for general in-patients.

2.3 Healthcare workflow subsystem

This study integrates RFID technology, wireless devices, and a smart suite to create a smart healthcare environment for in-patients. The system comprises a healthcare workflow subsystem, a healthcare position subsystem, a healthcare monitoring subsystem, and a healthcare notification subsystem, as shown in Fig. 2. The functions and operations of each subsystem are described below.

Figure 2. Structure of proposed RFID smart healthcare system.

The healthcare workflow subsystem uses wired and wireless communications technologies to integrate with the other three subsystems to facilitate human-to-application and human-to-human interaction. With RFID tag detection, the transmitted information includes the patient’s identity,
healthcare worker’s identity, and positions of patients or healthcare workers. The workflow module can enhance the operational efficiency of medical workers. The potential benefits are:

The key successful factor for healthcare position subsystem is the positions of RFID readers. Because the RFID readers could detect the RFID tags which is tagged in any objects (healthcare workers, patients,...etc.) , then we can real-time track our target object according to which one RFID reader detect the target RFID tag. For the sake of guaranteeing one correct operational healthcare position subsystem, an RFID position data sheet that records the detailed positions of all RFID readers is set up. As such, detected signals from RFID tags can be transferred to positions in the RFID reader. For the healthcare notification subsystem to find the nearest healthcare worker for a patient, the relative distances between workers and the patient must be found. Thus, one data sheet recording time from one sector to another has to be set up prior to the operation of the system.

RFID tags worn by patients are used to determine patient positions and identities. Patients are given tags when they arrive at the hospital and return the tags before they leave, permitting the tags to be reused. This process requires the constant maintenance of data regarding RFID tags on patients because patients frequently enter or leave the hospital daily. If patients did not return their tags before they leave, and did not take them to the hospital in the next time. Then the data regarding RFID tags on patients will not keep the real-time or correct records.

RFID tags worn by healthcare workers are used for registration with mobile devices, such as smartphones, and for detection of worker locations. The maintenance of data from RFID tags on healthcare workers is divided into two parts: the registration of data from RFID tags as a tool for identification in regard to the healthcare notification subsystem and the deletion of data from RFID tags. Data on RFID tags are deleted before the tags are issued to new workers.

The RFID tags on patients streamline the hospital admission and discharge procedure for patients via automated approvals and notifications with RFID sensing technology. Thus, it would be more helpful to decrease the check out time and payment process of patients and improve the operation efficiency of nurses.

2.4 Healthcare position subsystem

The RFID position technology is divided into precision coordinate positioning and general region positioning. Due to a lack of a precise positioning function for the hardware used in the trial stage, general region positioning was adopted for determining workers’ positions in this research. With automatic and long-distance detection features, one RFID regional reader, depending on detection of RFID tags on workers moving around a certain space and parameter configurations installed in the RFID readers, is able to analyze this RFID reader’s position. Hence, with its position known, the RFID reader detecting one person’s RFID tag can determine this person’s position. This subsystem allows:

1) Asset tracking and management. RFID readers were placed at strategic places in the hospital, such as the main lobby, administration offices, emergency room, triage, lounge, and relative medical labs. The goal is to locate and track expensive hospital assets through this asset tracking and management application. The system can also reduce the equipment search and waiting times, and be used to forecast future inventory requirements. Moreover, this subsystem can be used to locate and trace medical workers as well as patients quickly.

2) Patient and healthcare worker locations. Despite no serious condition affecting the movement of a patient freely moving around one hospital, some uncertain incidents threatening this patient’s life may occur. If one patient has occurred uncertain incidents (like heart disease) and lay down in the hospital floor. How could healthcare workers identify who he is? What the room number is? or who his doctor is? To solve this issue, some wireless sensor technologies (RFID, Wi-Fi, Bluetooth) have functions to detect certain physiological conditions of mobile patients. The healthcare position subsystem detects the positions of these healthcare workers or patients by determining the distances between patients and healthcare workers. Owing to constant changes of positions of these mobile objects, patients and the medical care workers at different times, the system, deliberating the relative distance between both parties, will arrange for adequate healthcare workers to arrive at the target in the shortest time to assist this patient with emergency accidents.

2.5 Healthcare monitoring subsystem

In a healthcare system, raw data consists of static and dynamic data. Static data includes the patients’ profile and their preferences. Dynamic data includes blood pressure or temperature changes of patients. In this research, RFID sensing devices are used to monitor healthcare conditions that equipped on the smart suite of a patient. The goal is to recognize the patient’s activities or his/her health conditions. This research uses the software platform SPINE (Signal Processing in Node Environment) [26] to design the smart suite and retrieve these health conditions. As shown in Fig. 3, the operation of this
system has four phases: monitoring, positioning, workflow, and notification. The detailed process for each phase is described below.

The monitoring phase utilizes RFID sensing techniques to retrieve biomedical data and monitor patients’ health. The healthcare system collects the heart rate (HR), R to R interval (RR), oxygen saturation (SpO2), temperature, beats per minute (BP), and step count (SC) data. If these biomedical signals are abnormal, an emergency rescue process is triggered by this subsystem receiving these messages. This phase uses an expert system methodology. Simple IF-THEN rules are used to trigger the patient alarm message. A patient wearing the smart suite can freely move inside the hospital with his/her physiological signals constantly being monitored and signals for emergency rescue emitted from the smart suite detecting physiological abnormal signal from patient in any place.

The positioning phase can be triggered by a new event in the queue of the emergency events in the monitoring phase. Prior to the selection of the most suitable healthcare workers for response, the positions of the patient and all healthcare workers are determined by the healthcare position subsystem. The healthcare position subsystem will real-time keep the position database of all persons, especially they will walk round in the hospital.

In the workflow phase, the first priority considered by the system is response time. An unoccupied healthcare worker nearest the patient can provide the fastest care to the patient. However, busy healthcare workers are not excluded because their task may not be as urgent as the care required by the patient in need. In such a situation, the emergency messages from the system will send the emergency messages to the suitable healthcare workers and wait for their response. If the answer is ‘yes’, then the healthcare workers will go to the position of the patient and they will suspend the current tasks.

In the notification phase, the selected healthcare worker receives emergency messages via their mobile device. The mobile application constantly checks the server for emergency messages, which are shown on the screen. Upon arriving at the patient’s location, the healthcare worker will start providing care. To ensure that the system is aware of the received care, the healthcare worker should locate the patient’s tag to confirm their identity by using an RFID reader. Once the patient’s identity is verified, the system marks this emergency event as “in progress” and no additional messages are delivered.

2.6 Healthcare notification subsystem

Based on the aforementioned fact that the monitoring subsystem delivers to the healthcare worker the message of an event having occurred, the healthcare worker needs one corresponding subsystem to receive and process these emergency messages. The system is installed on mobile devices, allowing healthcare workers to receive emergency messages at any time and in any place. The workers also receive patient status updates.

4. Results and discussion

4.1 Experimental environment design

In the experimental design and environment implementation, RFID devices with far-field communication and UHF bands (865-928 MHz) were used because they provide a larger reading range and can handle complex environments with many tags. The UHF hardware adopted in this research is compatible with the EPC Class1 Gen2 standard. The compact reader (UEM005, clarIDy RFID, Taiwan) has dimensions of 110 × 91.2 × 42.5 mm and is compatible with European, U.S., Chinese, and Taiwanese regulatory standards. In the experiment, the reader was set up in the main blocks in the hospital and connected to the proposed system. It read nearby active tags by using the antennae from the smart suites.

The system uses Android-based smartphones prepared as one environment for data maintenance and for the reception of messages delivered to the healthcare workers. The Android-based smart-phones would be a convenience mobile device and let healthcare workers could receive the messages. As for the healthcare notification subsystem, the computer program is designed as one constantly executing service program displayed with Windows interfaces for the convenience in explanation and exhibition of effects and functions. As a result of deficiency in experimental equipment relating to long-distance RFID, the healthcare position subsystem integrates the well-developed RFID healthcare position subsystem with emergency messages from the well-developed smart suite incorporated for these subsystems’ integration.

4.2 Android-based smartphone operation

In this research, the healthcare notification subsystem was adopted for receiving the physiological signals from the active RFID tags on the patients’ smart suite. The physiological data are sent to the Android-based smartphones of the healthcare workers. The developed simulated functions in this system are described below.

Smartphones for emergency message delivery are registered with the healthcare notification subsystem with an account name and password. Once the registration process is completed, the system checks whether the user operating this smartphone is receiving relevant emergency messages correctly. The Android-based smartphone operation is described below:

(1) The healthcare worker can activate the healthcare notification subsystem with their smartphone.

(2) The worker then inputs their account name and password.

(3) The system verifies the worker’s identify.

(4) Once the login is completed, the smartphone will show the system’s menu, allowing the healthcare worker to select the required functions. The system then starts the message reception procedure, constantly checking for any patient alarm messages for the healthcare worker.
Once the healthcare worker has logged into the smartphone application, the system periodically checks the database for any message designated to that specific registered healthcare worker and sends such messages to the smartphone, as shown in Fig. 4. The system will send the emergency message to the worker with pop-up window, sounds, and vibration.

![Figure 4. Physiological signal message shown on Android-based smartphone.](image)

Once the healthcare worker is selected by the healthcare workflow subsystem, messages will be delivered to their smartphone, which will indicate a screen of emergency conditions. The screen will show the patient’s ID and location, as shown in Fig. 5. The healthcare worker could see the patient’s ID and location based on this message.

![Figure 5. Emergency message shown on Android-based smartphone.](image)

Upon reaching the patient, the healthcare worker can start the rescue. First, the healthcare worker must confirm the patient’s identity via their patient ID number by checking the alarm message on the smartphone. Second, the healthcare worker could check and know what the correct rescue that patient really need. The subsystem will then mark this patient on the list as “under rescue”, as shown in Fig. 6.

### 4.3 Performance evaluation

Two pilot experiments were conducted in a hospital with ten smart suites and ten smartphones to test the reliability of the proposed SHE. The first experiment evaluated the wireless communication performance of smart suites and RFID readers in the main lobby, the administration offices, the hospital floor, the intensive care unit (ICU), the emergency room (ER), triage, and the lounge. The goal was to evaluate whether the physiological signal messages from the smart suite can be correctly received by the RFID reader and whether the biomedical data can be sent to the healthcare-monitoring subsystem. 204 of the 210 tests were successful. The failures are attributed to operation within too large a space or too small or narrow a space where many patients stay together, then it would cause the incorrect detection. This shows that using a smart suite as the biomedical data transformation middleware is very reliable. The detailed experimental data are shown in Table 1.

<table>
<thead>
<tr>
<th>Location</th>
<th>Test time</th>
<th>Number of successes</th>
<th>Number of failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main lobby</td>
<td>30</td>
<td>28</td>
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<tr>
<td>Administration offices</td>
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<td>30</td>
<td>0</td>
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<td>Hospital floor</td>
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<td>30</td>
<td>0</td>
</tr>
<tr>
<td>ICU</td>
<td>30</td>
<td>30</td>
<td>0</td>
</tr>
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<td>ER</td>
<td>30</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>Triage</td>
<td>30</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>Lounge</td>
<td>30</td>
<td>26</td>
<td>4</td>
</tr>
</tbody>
</table>

![Table 1. Experimental results for physiological signal transmission.](image)

The second experiment focused on the patient alarm messages sent to smartphones in the main lobby, the administration offices, the hospital floor, the ICU, the ER, the pathology lab, and the microbiology lab. The goal is to evaluate the guarantees that patients are able to receive rescue at any time and in any place within the shortest period. 204 of the 210 tests were successful. The failures are attributed to the space being too large or too small or narrow for the large number of patients issues. This shows that using a smartphone application for emergency messages is very reliable. The detailed test data are shown in Table 2.

### 5. Conclusion

The RFID technology has now been adopted in several domestic hospitals and the research reports regarding RFID in medical treatments are published continuously. Because adopting the IT system in the medical industry results in observable improvement in medical efficiency, effects, and
quality, RFID also becomes a choice for improving medical management. Therefore, this study proposed an SHE that integrates RFID identity recognition, RFID position, and mobile communications to ensure the healthcare workers could immediately take care the patients in the hospital.

There are still some issues need to be addressed in this research. The future researches are listed in the follows. First, the systematic structure discussed in this research can be set up as part of the emergency healthcare system in other healthcare institutes such as senior citizens' care centers. Second, the approach can be verified and extended by implementation with patients in independent living situations, and the results can then be used for making future improvements. Finally, adopting other artificial intelligence methodologies to implement a context-aware healthcare environment could be considered.

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References


Table 2. Experimental results for emergency message transmission.

<table>
<thead>
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<th>Location</th>
<th>Test Time</th>
<th>Number of Successes</th>
<th>Number of Failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Lobby</td>
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<td>30</td>
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<tr>
<td>Offices</td>
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<tr>
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