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Mobile Healthcare Service System Using RFID

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Abstract

SARS (Severe Acute Respiratory Syndrome) has seriously hit to the worldwide over pass several months. At this time, we do not have a full understanding of the natural course of illness and the mode of transmission has not been precisely defined yet. Presently, precautions are processed by the standard guidelines but still lack of extensive system to identify and trace isolated persons, contact history of patients and infected disposals. To shorten the tracking time and increase the accuracy of infection, we introduce in this paper a MHS (Mobile Healthcare Service) System, a platform that uses RFID (Radio Frequency Identification) technologies and mobile devices for positioning and identifying persons and objects both for inside and outside hospital when disease taken place. Also, based on the applications for SARS Infection Control Precautions, this system demonstrates how to receive patient's location and bio-information by using RFID technology for hospital and government to react a real-time infection control measures from the auditing mechanism among isolated patients in households or residential settings. Further, this model shows the possibility to bring medicare service becoming ubiquitous crossing geographic barriers and enable medical information technology from e-Medicare to m-Medicare for future development in medical industry。

Keywords: RFID, SARS, Wireless, Mobile Healthcare Service, Community Medicine

1. Introduction

On 26th February 2003 in Vietnam where an American business man came to hospital with atypical pneumonia and died after in Hong Kong, and over the next few months, new cases of atypical pneumonia with respiratory distress syndrome were continuously reported in Hong Kong, Vietnam [6]. This new illness is highly suspected caused by a novel corona virus, a syndrome of respiratory distress, which is much more severe than existing atypical pneumonia caused by recognized virus and bacteria. Therefore, from the symptoms of such disease, the World Health Organization has named this new illness as SARS – Severe acute respiratory syndrome.

When SARS spreads, people face the health threat all over countrywide and alone with this disease from which the national economy has been gravely affected. How to minimize the risk for SARS by taking appropriate infection control precautions becomes an important issue for both government as well as the local health departments. The summary in Table 1 is the probable SARS cases with onset of illness from 1st Nov. 2002 to 31st July 2003 published by WHO for the five most affected areas and countries [8]:

Table 1. The statistics of SARS fatality ratio

Areas	Cases	Deaths	Fatality ratio
China	5327	349	7%
Hong Kong	1755	299	17%
Taiwan	346	37	11%
Canada	251	43	17%
Singapore	238	33	14%

In general, SARS begins with a high fever and some people also have respiratory symptoms (e.g., cough, shortness of breath, difficulty breathing) at the outset and some people experience with chills or other symptoms including headache, general feeling of discomfort and body aches. According to current evidence, the primary way that SARS appears to spread is by close person-to-person contact especially like the health-care workers (around 90%) or patient's family (around 10%) who have developed mostly similar illness [6].

The outbreak of SARS challenged severely the infection control process and managerial mechanism to medical institutes. The virus can spread when a person touches a surface or object contaminated with infectious droplets but the quantity of virus that may cause infection is still now unknown. From this point of view, the existing network cannot support further extensive health care service from hospital to community for outpatients. Nevertheless, for the SARS Infection Control Precautions, each detail of patient's contact history is ultra essential; therefore, the most important thing needs to be solved is to transfer the medical information applications extended to wireless to satisfy various applications while fighting with this new disease. By using the wireless technology like GSM, GPRS, PHS, CDMA and RFID (Radio

Frequency Identification), the communication over applications is unbounded that allows all messages transmission of system become much more active [6].

As SARS brings much challenge, to initiate an efficient RFID infrastructure system and develop a MHS (Mobile healthcare service) system in medical industry can bring much advantage to overcome this disease till the epidemiology of disease transmission is better understood. The objective of this research is to apply the MHS platform and to develop various applications in future for medical industry under a safer environment. If SARS was to re-emerge, this system is capable to reduce effectively the affected numbers of medical professionals and the difficulty of infection control among infectious patients.

Further, based on the Mobile Healthcare Service as core and use RFID technologies for medical industry to develop positioning and identification applications while applying wireless technology. As far as infectious patients concerned, from this system, the real-time information can be received and offers the tracking mechanism to trace the complete contact history of SARS patients, people are able to learn how to protect themselves correctly and reduce their anxiety while taking medical care in need.

With wireless technologies, it's easier to receive the geographic information of medical personnel and patients, but the key successful point for this application depends on whether those people will carry all the time with wireless devices. If bio-message (like temperature) can be embedded to wireless devices and send it back timely to hospitals, it's feasible to detect if the wireless device is untied or not. Further more, medical officers will be able to provide suitable healthcare services and diagnosis to patients from those real-time bio-messages. On the other side, the body temperature's observation is the first step for SARS Infection Control Precautions. If the temperature of patients can be controlled correctly, it can expect a greater improvement of effectiveness for precautions, also, can prevent the leakage of people from taking antipyretic in private when they have fevers.

The rest of this paper is arranged as follows. The following section introduces the RFID (Radio Frequency Identification) related researches. Section 3 introduces the characteristics of our RFID Infrastructure to be implemented inside and outside hospital. Section 4 shows the architecture of MHS system. Section 5 illustrates two example applications of MHS platform. Section 6 summarizes the results of this research. The last section is the conclusion and future development of system.

2. Literature Review

According to the frequency band (Hz), the most commonly used of RFID system are classified as 0-135KHz, 6.78MHx of ISM frequency band, 13.56MHX, 27.125MHz, 40.6Mhz, 433.92MHz, 916.5MHz, 2.45GHz, 5.8GHz and 24.125GHZ etc.. While using the frequency for certain application, it needs to follow the localized regulations among different areas where the policies of frequency applications are different [4].

From conceptual point of view, RFID tags can be regarded as bar codes but offer more outstanding advantages rather than bar codes stating as below [5]:

1. Data rewritable: Unlike bar codes, the information stored on existing RFID tags can be changed, added, updated and deleted without limitation.
2. Data easy to be transmitted: For bar code, reader receives information from scanner in short distance with obstacle free condition. Products that contain RFID tags enable stored information to be transferred from an RFID tag to a remote reader through radio frequency waves within a range of electromagnetic field without having to be separated and scanned individually.
3. Greater storage capacity of data: One-dimension bar codes have a storage capacity of 50 bytes, while two-dimension bar codes can store approximately 2-3000 data characters. A typical RFID tag can easily store data up to several MB.
4. Reusable: Life-cycle of bar codes are deemed dysfunctional when they have been torn, disfigured, or detached from objects, whereas the information of RFID tags can be updated and rewritable that make them reusable and durable.
5. Greater reading range: Bar code reader collects individually each time of data in short distance. RFID reader offers a larger reading range and receives signals simultaneously from multiple tags for information collection.
6. Security: RFID tag provides higher security because each tag is extremely unique and almost impossible to counterfeit.

RFID technologies are found more reliable and durable than bar codes in different application and functionality. Further, RFID technologies offers a broader wireless means than bar codes for information collection and transfer to track and identify between objects where the information is communicated electronically via radio waves and does not require contact or line-of-sight to transmit stored date between RFID tags and readers [2]. Those fundamental properties eliminate manual data entry and introduce the potential for automated processes to increase productivity even under difficult working environments. Besides, the technology of RFID tags is hard to counterfeit and break which ensure a higher security protection.

The continuous communication and virtually limitless capacities of RFID enabling electronic tags to be tracked in real-time to identify the object's status for user defined applications included: management automation of animals, inventory management, electronic toll system and quality management, authentication and tracking system, package tracking system, cars and motors tracking and identification on moving trains, medical services and post-sale service etc. In Taiwan, every family raising dogs is obliged to inject microchip into dogs for tracking and identification by following the 「Animal Protection Law」, which is a typical application of RFID technologies.

3. RFID Infrastructure

In general, a RFID system includes tags that carry data in suitable transponders and, an RFID reader that retrieves the data from the tags. The data is written to the RFID tag enabling to identify and characterize an object with a specific application. A RFID reader scans and acknowledges the information from RFID tags when they are within range of an electromagnetic field and to perform a user-defined functionality.

RFID Reader

The reader is designed for fast and easy system integration without losing performance, functionality or security. The RFID reader consists of a real-time processor, operating system, virtual portable memory, and transmitter/receiver unit in one small self-contained module that is easily installed in any convenient location. The RFID reader used in this research contains following features

- Memory: 10 Megabits
- Multi tag read capability: yes
- Operating frequency from tag: 916.5 MHz
- Wake up frequency to Tag: 433 MHz
- Communication standard: RS 232 and RS 485
- Tag read range: 3 to 85 meters depending on reader sensitivity setting
- Self contained database
- True anti-collision capability
- Immunity to noise and interference

RFID Tag

The RFID tags are used for tracking people or items in a facility, locating staff or instruments in a hospital, keeping track of patients in care facility or automatic tollbooth activation. The tag always expects an acknowledgement from reader following each transmission of tag data. It can be configured to continuously its data till reader acknowledgement is received. In this research, the RFID tag embedded chip is able to measure body temperature and transfers this record to a remote RFID reader. The RFID tags used in the research contain following features:

- Tag type: active, credit card size
- Memory size: 48 Bytes with option of 8k bytes
- Wake up frequency: 433 MHz produced by Field Generator
- Field-initiated wake-up range: 3-33 meters, depending on field generator strength setting
- Tag read range: 3-85 meters, depending on reader sensitivity setting

Field Generator

By attaching an RFID tag onto or inside items, their movement passed patrols through the facility can be tracked. Our Tracker software can restrict asset/people movement to a specific owner, and produce an alarm if the asset/person is identified without the assigned owner's badge being present. Our tags can be programmed to wake up and report their presence on a scheduled basis. The field generator in the research contains following features:

- Applications: to wake up active tags
- Functionality: to produce 433 MHz field to wake up active tags
- Multi tag read capability: yes
- Operating frequency: 433 MHz
- Tag wake up range: 3-33 meters depending on field generator strength setting
- Much lower cost than RFID readers
- Provides flexibility to establish a cost effective tracking system.
- Flexible strength setting allowing adjustment of wake up range
- Optional motion detection

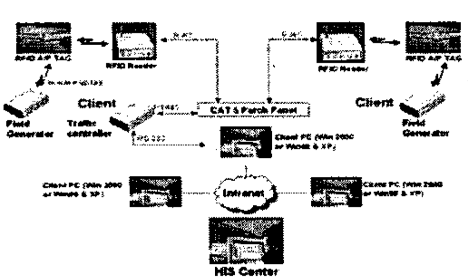

Figure 1 RFID Architecture in Hospital

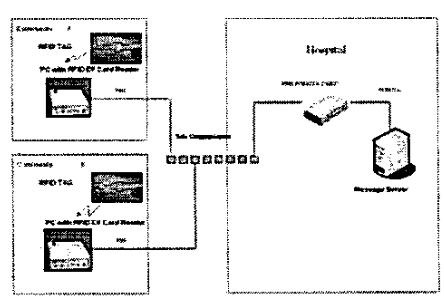

Figure 2 RFID Architecture in Community

RFID Layout in hospital

When *RFID* tags are activated by *Field Generator*, tag and generator's ID, bio-signal and tag untied record stored in tags will be transferred to RFID reader. Later, the RFID reader will retrieve this information from tags and connect to CAT5 Patch Panel through RJ45 and connect to Traffic Controller via RS485 after. Finally, the Traffic Controller transfers information via RS232 to Client PC where to store information in MIS Database Server by its RS232. The architecture is shown in Fig. 1.

RFID Layout in Community

For the SARS isolation taken place in community and households, the RFID infrastructure will include indoor monitoring mechanism and Internet network. The architecture is almost the same as the one settled in hospital, i.e. RFID tags are activated by RFID generator, and RFID reader retrieves information from tags after. The only difference from this architecture is implemented environment where the most isolated areas selected are far away from cities where are commonly not Internet ready at all. Therefore, in the research, we use the PHS as the wireless device for information transmission to operate with RFID technologies. The architecture for SARS isolation in households of community is described in Fig. 2.

Physical Layout

The RFID infrastructure in hospital should include RFID *reader positioned at strategic points and RFID tags* fastened to people or objects. The example layout of RFID in the outpatient and emergency department is shown as in Fig. 3.

RFID Positioning

There are many floors and areas in hospital where each floor is generally designed for specific purpose such as Emergency Dept., Outpatient Dept., Inpatient Dept., Operation Room and Instance Care Unit and so on. In this research, we extend the algorithm proposed in the LANDMARC system [1] for multi-floor and multi-area building by using landmark tags. Within an area, suppose we have r RFID reader, l landmark tags and m moving tags. As proposed in LANDMARC, we define the Signal Strength Vector of a moving tag as $\vec{S} = (S_1, S_2, ..., S_r)$ where S_i denotes the signal strength of the moving tag sensed by reader $i, 1 \le i \le r$. Similarly, the Landmark vector denoted as $\vec{\theta} = (\theta_1, \theta_2, ..., \theta_r)$ for the landmark tags. For each moving tag, we define $E_n^m = \sqrt{\sum_{i=1}^{r} (\theta_i^m - S_i^n)^2}$ as the location relationship between the m-th landmark tag and the n-th moving tag. LANDMARC used k nearest landmark tags' coordinates to locate the moving tags. The moving tag's coordinate (x, y) is obtained by: $(x, y) = \sum_{i=1}^{k} w_i (x_i, y_i)$ that w_i is the weighting factor. The weight is given by: $w_i = \frac{\frac{1}{E_i^2}}{\sum_{i=1}^{k} \frac{1}{E_i^2}}$

In order to increase the positioning accuracy, we divide the Field Generator into three types: Normal Generator, Floor Generator and Area Generator. Floor Generator is installed within staircase; Similarly, Area Generator is installed between the interfaces of adjacent areas. The detection range of Area and Floor Generator must be controlled in shorter range to make sure that moving tags are truly passed the boundary of area or floor. On the other hand, the detecting duration has to be as shortest as possible to ensure every moving tag is sensed. Suppose we have f floor inside a building and f_i areas in the i-th floor, i.e. there are $\sum_{i=1}^{f} f_i$ areas in this building. The adjacency between areas is recorded by the adjacent matrix A, $A_{ij} = 1$ if area a_i and a_j are adjacent, each normal generator belongs to one defined area. The correlation array C, $C_i = j$ if the i-th normal generator are located in area a_j. The record of every moving tag will stay in standing area. Any event generated by floor or area generator will trigger the area assignment algorithm where use the algorithm proposed by LANDMARC system to calculate its position in the specific area from correlated landmark tags. The higher precision will be

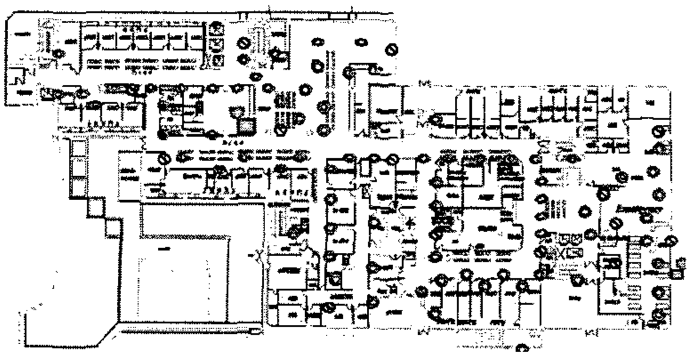

Figure 3 Physical Layout

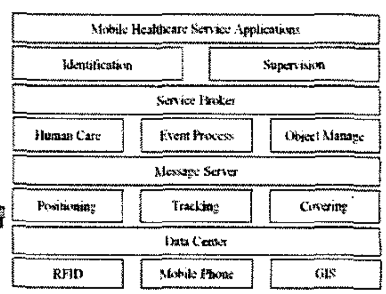

Figure 4 The MHS System Architecture

realized accordingly.

4. MHS System Architecture

There are two important aspects of applications in MHS system, which are ."Identification" and "Positioning". Though MHS in this research is initially designed for the SARS infection control, the concept of hospital management is brought into this system as the base for various medical applications. Using the positioning and identification function of MHS, all data information transferred crossing over point, line and area can identify and trace what medical objects carried by whom and where to break through the geographic barriers. The system architecture is described as in Fig.4.

The mobile healthcare service system uses Web Service to provide determined services, hardware devices deliver information through the agents of respective hardware to collect data information and deliver which to database center. Based on this architecture, lower level infrastructure of mobile healthcare service is able to integrate with various wireless communication technologies. Data begin for post processing after hardware agents deliver data information to database center.

By tracing algorithm, MHS system can record positioning information over point, line and area. The positioning information publishes to message server via Pub/Sub services of Message-Oriented Middleware (MOM) that is an asynchronous mechanism to interact among various messages. On this object level, according to the characteristics of whom, what and where; required objects receive information from positioning level through subscribing from message server. Service level transfer information from object and positioning levels to perform identification and supervision services for user defined applications.

There are five major modules designed in the MHS platform as below:

1. Position Module: The patient will give his position via the positioning function of wireless device to the position module where will store the data.
2. Vital Information Module: The patient will give his/her vital signs, such as blood pressure, heartbeat, temperature, blood sugar, EKG pattern, muscle tone, and fetal heartbeat via the vital function of wireless device to this vital information module where will store the data.
3. Map Module: The module contains the coordinating system and e-map integration. It reacts as a navigator of geodetic information between managers and the audited objects.
4. Message Module: It communicates with information among SARS patients, healthcare providers and isolated members, and send datum to medical workers in real time. Depending on the demand of various applications, this module will receive position and vital information of the patient to perform defined medical service.
5. Alert Module: The module contains simple decision support system and defines the threshold of warning messages. It monitors position and vital information of the patient who could receives safe and proper medical care. Through the decision of this module, the warning message will be sent to healthcare providers.

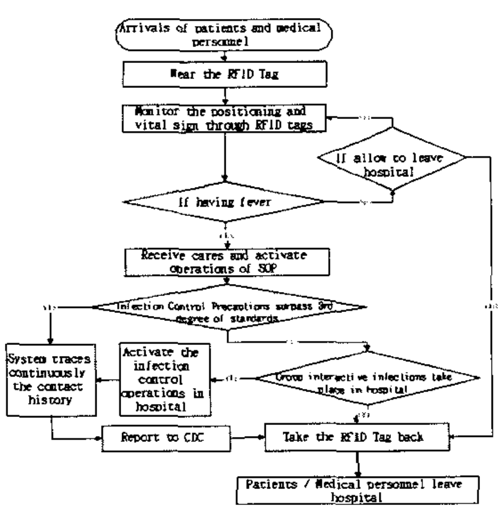

Figure 5 The Flow of Infection Control System in Hospital

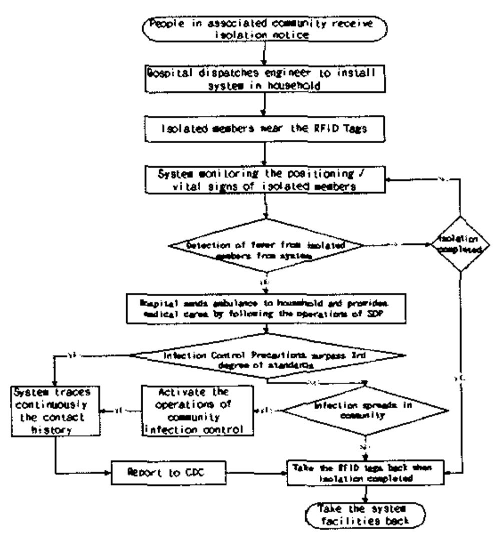

Figure 6 The Flow of Infection Control System in isolated community

5. MHS Application System

This research uses RFID technologies as basic infrastructure to build up MHS system according to the demands of medical services. Further, based on medical positioning system, hospitals can use the MHS system for SARS Infection Control Precautions and Community Medicare system to improve the capacity of SARS infection control. Below are the scenarios of this system applied for SARS Infection Control Precautions in hospital and household in isolated community.

Infection Control System in Hospital

As soon as the CDC announces to activate the measures of SARS Infection Control Precautions, all patients and medical personnel entering hospital have to wear a RFID tag measurable of vital sign. From the information stored in RFID tags, when the infection takes place in hospital, the system can monitor and suggest in few minutes for medical officers to isolate infected persons or objects by different isolation levels from the Standards and Guidelines. If hospital has to be shut down or to isolate certain areas inside hospital, this system is also capable to provide round-the-clock information in monitoring the entire situation in hospital among infected areas, suspect areas and clean areas. The flow is described as in Fig. 5.

Infection Control System in isolated community:

For people who need to be isolated in households of community, hospital can help government to provide them related facilities to operate the RFID and PHS reporting system. The system promises the proper medicare quality for isolated people who need to receive cares in households, also, the healthcare providers can be informed through vital sign transferred via RFID and PHS to arrange appropriate measures actively if household members are detected with fevers. Further, this system offers more services such as meals delivery that may help to reduce the anxiety of people while being isolated. On the other side, with the positioning and tracking technologies, system sends alert immediately if isolated members in households leave out of home without permission, particularly for those who are regarded as the A grade isolation. The flow of how system works for this application is shown in Fig. 6.

6. Conclusions

RFID systems have been applied in various fields to simplify objects identification and tracking when objects move from one location to the other. RFID is set to position parts or objects according to its specification and characteristic. However, there are problems to use RFID to locate objects beyond the detectable range like people's movement, across different buildings or floors, and so on. In most cases, such environmental factors reduce the location sensing accuracy. Therefore, the MHS designed in this research extend the algorithm proposed in the LANDMARC system to the application of multi-dimensional environment and confine the objects or persons positioning within single detectable area to increase the accuracy. Although the first attempt of MHS system is designed for the SARS Infection Control Precautions among governments and local departments crossing frontiers, we believe there are more advantages for future development of this system by integrating with existing medical infrastructure such as electronic medical record, decision support system and hospital information systems. For industries, this MHS system brings wider perspectives for different categories of applications and also, strengthens interactive communication both for vertical and horizontal integration to drive medical services from e-Medicare to m-Medicare.

Reference

1. L.M. Ni, Y. Liu. Y.C. Lau and A.P. Patil, LANDMARC: Indoor Location Sensing Using Active RFID, In *Proceedings of the 2003 IEEE Annual Conference on Pervasive Computing and Communications* (PerCom 2003), Dallas, Texas, March 2003.
2. Harald Vogt. Efficient object identification with passive RFID tags. In F. Mattern and M. Naghshineh, *International Conference on Pervasive Computing, volume 2414 of Lecture Notes in Computer Science*, pages 98–113, Zurich, August 2002. Springer-Verlag.
3. Vince, S. *Pervasive Computing Goes the Last Hundred Feet with RFID Systems*. IEEE CS and IEEE ComSoc, pages 1536-1268, 2003.
4. Yang Chan-Han (2002). *RFID card reader designed in 0.35um CMOS integrated circuit technology*. Master thesis of Electronic and Engineering Department of Yuan Ze University, Taoyuan Taiwan.
5. RFID smart library management system. (2002). BOOKTEC Information Company. Retrieved October 8th 2003, from http://www.library.com.tw/product/rfid01.htm.
6. SARS infection control information website.(2003). TZU CHI UNIVERSITY. Retrieved October 8th 2003,from http://www.tcu.edu.tw/sars/.
7. C. S. Tsai (2002). *RFID introduction and applications*. Retrieved October 8th 2003,from http://www.mem.com.tw/serial/2002-5-194/m19407.html.
8. World Health Organization—*Cumulative Number of Reported Probable Cases of Severe Acute Respiratory Syndrome (SARS) — Summary of probable SARS cases with onset of illness from 1 November 2002 to 31 July 2003* (revised 26 September 2003). Retrieved October 8th 2003,from http://www.who.int/csr/sars/country/table2003_09_23/en/.