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ORIGINAL PAPER

Applied Patent RFID Systems for Building Reacting HEPA Air Ventilation System in Hospital Operation Rooms

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Abstract RFID technology, an automatic identification and data capture technology to provide identification, tracing, security and so on, was widely applied to healthcare industry in these years. Employing HEPA ventilation system in hospital is a way to ensure healthful indoor air quality to protect patients and healthcare workers against hospital-acquired infections. However, the system consumes lots of electricity which cost a lot. This study aims to apply the RFID technology to offer a unique medical staff and patient identification, and reacting HEPA air ventilation system in order to reduce the cost, save energy and prevent the prevalence of hospital-acquired infection. The system, reacting HEPA air ventilation system, contains RFID tags (for medical staffs and patients), sensor, and reacting system which receives the information regarding the number of medical staff and the status of the surgery, and controls the air volume of the HEPA air ventilation system accordingly. A pilot program was carried out in a unit of operation rooms of a medical center with 1,500 beds located in central Taiwan from Jan to Aug 2010. The results found the air ventilation system was able to function much more efficiently with less energy consumed. Furthermore, the indoor air quality could still keep qualified and hospital-acquired infection or other occupational diseases could be prevented.

Keywords HEPA ventilation system · RFID · Indoor air quality · Operation room · Hospital

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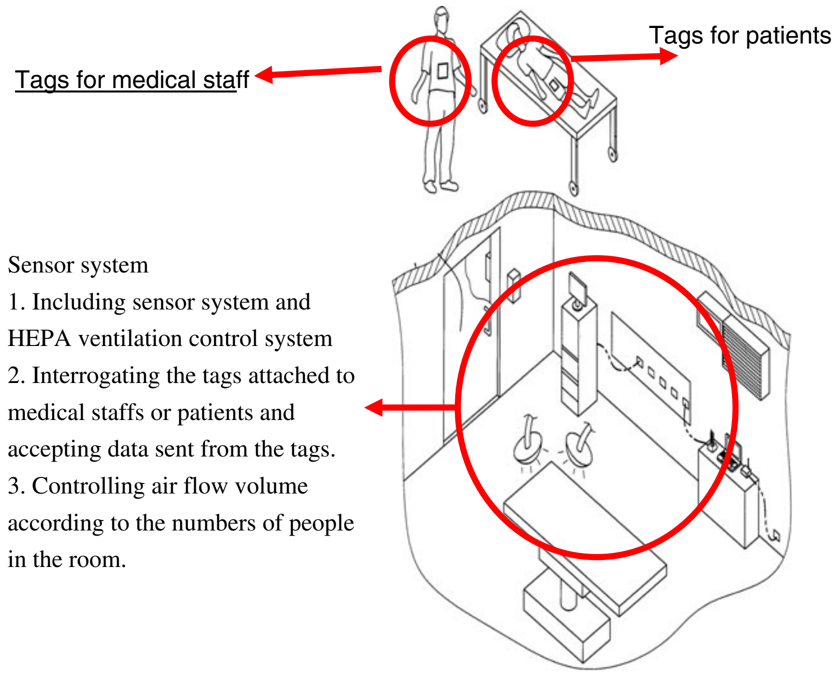
Introduction

RFID (radio frequency identification) technology, an automatic identification and data capture technology to provide identification, tracing, security and so on, is composed of radio-frequency readers and tags [1]. The former has antenna emitting radio waves and is used to interrogate radio-frequency tags; the latter is usually attached to people or assets and responds the reader by sending back its data. The RFID technology was developed in 1940s, but its commercialization started in 1980s. In healthcare industry, RFID technology are used to track, identify or monitor patients or medical staffs to improve patient safety and reduce medical errors [1–4], applied in medication administration process to enhance patient medication safety [5–8], or attached to capital equipments, facilities or drugs in hospitals for asset or resources management [9, 10]. In Taiwan, the first application of RFID technology in healthcare was to monitor patients and medical staffs to enter and leave the quarantine areas during the SARS outbreak period to prevent disease from spreading.

It is of vital importance for hospitals to ensure healthful indoor air quality to protect patients and healthcare workers against hospital-acquired infections and occupational diseases [11, 12]. To maintain qualified indoor air quality in hospitals, especially in operation rooms (ORs), the HEPA (high efficiency particulate air) ventilation system shall be employed and running all the day [13]. However, due to the energy efficiency policy promoted by the government and the cost issue, some hospitals would turn off the HEPA air ventilation system when the ORs are closed. This will raise some problems. For example, manpower will be needed to turn on or turn off the system. Meanwhile, the ORs air quality could not reach the clean room standard (Class 1000 to Class

Fig. 1 The layout of Reacting HEPA ventilation controlling system for Patent M369438



10000), especially when an emergency surgery is being performed. Also, the high humidity in Taiwan encourages the prosperity of bacteria, fungi or infected contaminants in the air when the ventilation system is turned off. Furthermore, hospital-acquired infection may happen when indoor air quality was not qualified [14]. Wang et al (2006) describe Taiwan's RFID application as follows: Chang-Gung Memorial Hospital (CGMH) in Taipei, Taiwan, has begun using passive HF RFID to identify surgical patients. The 13.56 MHz tags used in this application are embedded in plastic wristbands manufactured by Precision Dynamics Corp., and are compliant with ISO standard 15693. Surgical patients are issued a wristband upon arrival. A nurse scans the wristband to capture the patient's arrival, and then the wristband is canned several subsequent times at key points before, during and after the operation. For verification purposes, the software records the time of each scan as well as identification of the doctor or nurse that performed the scan. All scans are performed using Hewlett-Packard iPAQ PDAs, which are equipped with RFID interrogators [15].

Therefore, this study aims to apply the RFID technology to offer a unique ID identification and air condition control system in order to reduce the cost, save energy and prevent the prevalence of hospital-acquired infection.

Material and methods

The RFID technology was applied in this project to help hospitals control the air flow of HEPA ventilation system automatically according to the numbers of medical staffs or patients in a specific space such as the ORs, intensive care unit (ICU) or special treatment rooms. The system named Reacting HEPA ventilation controlling system (Taiwan patent number M369438, patent duration: December 2009 to December 2019, with confirmed patent technical report: May 2011 on http://www.tipo.gov.tw), a competitive work with great response in 2010 Taipei International Invention Shows & Technomart, employs state-of-art DC motor, which can save up to 40% of electronic power compare with the tradition AC motor. This patent also won Silver Award on *2011 Life Invention Green Growth Contest in Korea* on August 1, 2011.

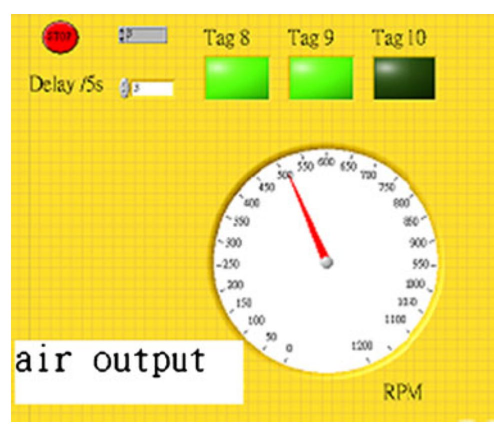


Fig. 2 Layout of the HEPA air control system. Tag8 and Tag9 are shown in green color, meaning that medical staffs with Tag8 and Tag9 entered into the room. The panel indicates the airflow volume which was regulated by the control system according to the numbers of people and the patents in the room. The air output are classify into high, median, and low. During the midnight or weekend, when the ORs are empty, the air output turn into low. During prepare time, or only one medical staff stay in ORs, the air output can automatically turn into median. When more than two patient/ medical staffs are going inside ORs, the air output turn into high volume

The system was composed of two main parts (see Fig. 1). One was the RFID tags attached to medical staffs and patients and responded to the sensor system by sending back its data. The other was sensor and reacting system which includes sensor system and HEPA ventilation control system. The sensor system or device was installed in the entrance of a room to interrogate the tags attached to medical staffs or patients and received data sent from the tags. The data detailed the numbers of peoples entering or leaving the room and their titles or status. The HEPA ventilation control system automatically regulated the airflow volume of ventilation system in ORs according to operation stage. In other words, when there is no person in a room, the system will regulate the HEPA airflow to the minimum level. And, the system will add the HEPA air output with the increase of numbers of people in ORs (Figs. 2, 3).

The Active 434 MHz normal tag supports "read and write". The functions are as follows: (1) Transmission interval is programmable; the tag is programmed by wireless; the digital RSSI/LQI data can be provided, the low battery indicator is shown and the tag signal is indicated by LED visual indication. (2) The function includes signal transmission, and ON-OFF Tag.

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Algorithm HEPA air control
Input: RFID tags
Output: airflow volume
    signal = tag, minimum = 2, maximum = 4
     If signal < minimum
      regulate the airflow volume to the minimum level
       else if signal > maximum
        regulate the airflow volume to the maximum level
         else regulate the airflow volume to the second level
          return airflow volume
```

No RTLS methods have been used to identify patients and medical staff, and therefore, no reference for RTLS was mention. There are two readers in one operation room. When the tag sends the message to the reader, the reader will send signals to the central information system to adjust the HEPA air flow.

Note: Real-time locating systems (RTLS) are a type of local positioning system that allows to track and to identify the location of objects in real time.

RSSI(receive signal strength indicator): received signal strength indicator (RSSI) is a measurement of the power present in a received radio signal.

LQI(link quality indicator): The LQI measurement is a characterization of the strength and/or quality of a received packet.

Results

A pilot program took effect from Jan to Aug 2010. The whole system was installed in an operation room of a medical center with 1,500 beds located in central Taiwan. An active RFID reader (Model type: ARUnew01, see Table 1) was installed at the entrance of the room.0 About 20 medical staffs were requested to wear the active RFID tag (Model type: ACUnew01-Passlt, see Table 2) when they were on duty and patients had to wear the tag if a surgery was needed.

The frequency we use for active RFID is 433 Mhz. RF chips, which use DSSS method and FSK Modulation to design RFID reader and tag, are low power. In order to increase the distance between read and write, the reader in active RFID matters. The directivity of the antenna can be enhanced to promote the antenna effects, the emissive power can be improved, and sensitivity of the reader can also be

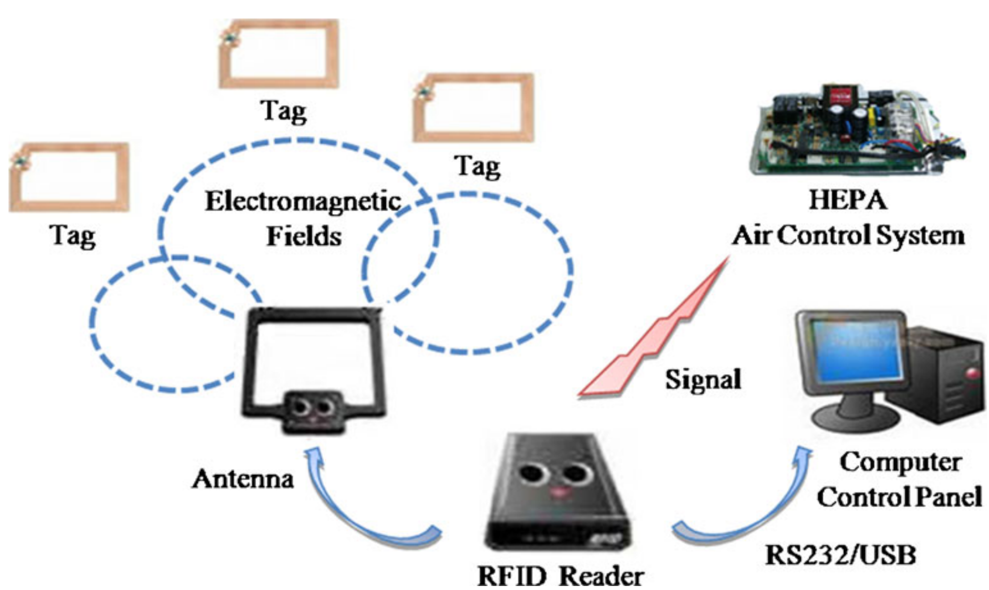

Fig. 3 Components of the HEPA air ventilation system infrastructure

Table 1 reader specification

Reader specification	
Frequency	434 MHz
Modulation	FSK
Distance	100 m (open space)
Power consumption	3.0 mA
Transmission power	10 dBm
Receiver sensitivity	−103 dBm
Interface	Support USB/RS232/RS422/RS485/TCPIP
Software	Provide WinXP/VISTA/Win7/WinCE/Linux SDK library for software development
Antennas	50 Ω. One for each reader
Interface with the HEPA	RS-485/RJ-45/RS-232

advanced. However, the cost of the reader is increased at the same time. The optimized receive sensitivity supports read range up to 30 ft and RFID tag read rate of 400 tags/sec.

Reader architecture. Figure 4 shows the block diagram of the 433-MHz reader. The characteristics of the 433-MHz reader are listed in Table 1. The reader can be connected with two data transmission interfaces: RJ-45 and RS-232. It provides three different socket modes which are available: transmission control protocol (TCP), dynamic host configuration protocol (DHCP), and user datagram protocol (UDP) mode.

Tag architecture. The 433-MHz tag includes a micro controller unit (MCU), an 8-Bit analog-to-digital convertor (ADC), an 8-bit digital-to-analog converter (DAC), a motion sensor, a temperature sensor, two CR2303 batteries; the tag can support motion detection, and temperature sensing. The operating frequency is 433-MHz tag. The Modulation is FSK and the Power consumption is 3.0 mA and Transmission power is 10 dBm, Receiver sensitivity is −103 dBm. The characteristics of the 433-MHz tag are listed in the Table 2.

Table 2 Tag specification

Tag specification	
Frequency	434 MHz
Size	86*54*6.35 mm
Modulation	FSK
Distance	100 m (open space)
Power consumption	Active 3.0 mA, Power down 1 uA
Transmission power	10 dBm
Receiver sensitivity	−103 dBm
Battery life	3 years (300 s for each transmission), 5 years in standby mode. Default setting
Battery type	CR2032(200 mA)*2 pieces
Battery life cycle	6 months, 2 s for each transmission.

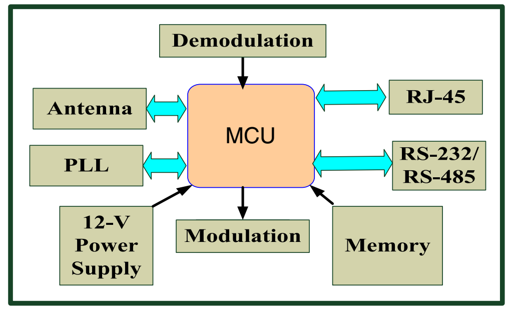

Fig. 4 Block diagram of 433 MHz Reader

In this program, two kinds of control mechanisms were developed and adopted. One is time control mechanism in which the system will keep the airflow volume at the minimum level to avoid the deadweight loss of energy during the off hours, such as after 11:00 pm and weekends. The other one is RFID control mechanism (see Fig. 2); the system will monitor the numbers of people in a room and regulate the airflow volume of HEPA ventilation system accordingly.

For example, an emergency case happened during the off hours and thus an operation room was requested for surgery. When the first medical staff entered the room to make a preparation, the attached tag will be interrogated by the RFID sensor system and responding by sending back its data. The sensor system will send information and instruction to HEPA ventilation control system to trigger the airflow volume into median level. And, when the patients and other medical staff entered into the room later, the airflow volume will be regulated to the optimum level. In this way, the indoor air quality of the operation room will be clean and ready for surgery.

In the first stage of this study, only one reader was installed in one OR, and we found the correct read rate for this one reader system was only 88% to 92%. Sometimes the signal was not received by the reader. Therefore, we installed two readers in one OR, and the correct read rate can reach to 98% to 99% in the end.

Since the RFID signals are floating, the reader may receive other tag signals. Though the correct rate can reach 98% to 99%, some signals are still missing during the test or the mistaken results may occur. The reviewers are experienced to

Table 3 The air power consumption for operation rooms

Air output	Using power	Using time	Sum
High	1	30%	0.3
Median	0.7	32%	0.224
Low	0.5	38%	0.19
Sub total		–	0.714
DC motor	0.7	–	0.714*0.7=0.4998

address the issue for us to modify our system. Usually we will design an RFID Locator to enhance the stability in the system, such as RFID Locator plus IR.

Limitations

There are two limitations of this system. First, the correct read rate for this system only can reach to 98% to 99%. Some signal are still missing during the test.

Second, the cost to install this system is high. One reader costs 600 USD, the tag costs 20 USD. Also, the software system which is connected to the health information system adds another 50,000 USD. Therefore, the complete equipment for 10 operation rooms with two readers for each ORs, and 50 tags, will reach to 20,000 USD.

Discussion

The pilot program was finished in Aug 2010. This program showed that the air ventilation system was able to function efficiently with less energy used. It is estimated that 50% of energy was saved compared to the old system. The 50% energy-saving details are listed on Table 3. By adding the DC motor, which can save 30% of power, it finally uses 0.4998 of power. The HEPA filter has to be changed once a year before this project because the HEPA change standard is based on the air flow quantity. Besides, since the ventilation works more intelligently, the engineer examines the HEPA filter and uses the statistical extrapolation method to get the 5 months, 40% more filter life conclusion. Also, a comparison of wireless communication systems is listed on Table 4. The infection rate for surgery are maintain in the same standard, and therefore, this system can maintain the same clean air quality for operation rooms as well as for the infection rate.

Most important of all, the indoor air quality will be maintained qualified and hospital-acquired infection and other occupational diseases could be prevented from spreading. Meanwhile, patients' safety will be secure since the patient identification can be double confirmed by RFID system.

According to hospital planning, this system will apply to other areas in the hospital, including ICU, clinical offices, and delivery rooms in 2012. Also, the reacting HEPA air ventilation system will deploy to another two medical centers in Taiwan in 2014.

Table 4 A comparison of wireless communication systems

HEPA air ventilation system	Hsu's system [16]	RFID Journal [17]	Vation Network [18]	Our system
Wireless communication system	Bluetooth	Zigbee	Wi-Fi	RFID
IEEE communications protocol	IEEE 802.15.1	IEEE 802.15.4	IEEE 802.11.b	ISO 18000-4
Frequency	2.4 GHz	2.4 GHz/915 MHz/ 868 MHz	2.4 GHz	433 MHz
Modulation	GFSK	O-QPSK	CCKPBCC	FSK
Transmission distance	10 m	30 m	100 m	100–300 m
Transmission speed	1 Mbps	250 Kbps	11 Mbps	256 Kbps
Network capacity	7 node	65536 node	32 node	Limitless
Stack capacity	<250 Kb	16~256 Kb	<1 M	Limitless
Battery life	Several days	Several years	10 h	Several years
Motion sensor	N/A	Motion	N/A	Motion
Temperature sensing	N/A	N/A	Yes	Yes
Extension interfaces of sensors	N/A	N/A	Yes	Yes
Control	N/A	N/A	N/A	HEPA
Personal identification	N/A	N/A	N/A	Yes
Practical implementation in hospital	N/A	N/A	N/A	Yes
Node cost	20 USD	Less than 5 USD	0.5 USD	0.05 USD
Advantages	The best way to transmit voice data	Low power consumption	Using the current network	Low cost and none power consumption
Disadvantages	Each network has 8 nodes at most	No products on the market	High power consumption	Readers and data memory are needed for RFID systems
Application	Data, video	Measurement control	Wireless LAN	Identification and control
Market	earphones	Energy conservation	Assess management	Health care

Appendix

Table 5

Dimension	Focus	Focus of Your Paper (Put a cross into the appropriate cell(s). You can have many cells)
Applications		
Asset management	Centered on applications related to the tracking and tracing of critical healthcare assets (e.g., asset identification, blood bags identification in hospitals to ensure blood type matching, medicine tracking, provision of e-Pedigree, real-time inventory count, and location tracking and tissue bank operations)	X
Patient management	Centered on the improvement of the management of patients within the healthcare supply chain (e.g., accurate patient identification, critical information to the patient, dementia outpatients tracking and tracing, tracking and tracing of hospitals for patient flow monitoring, and tracking of drugs supplies and procedures performed on each patient)	X
Staff management	Centered on applications such as better staff time utilization, improved error prevention, improved labor productivity, reduced processing time, staff identification, staff monitoring, staff tracking, and workflow optimization in hospitals	X
Issues		
Technological issues	Covered issues such as the lack of required wireless infrastructure within healthcare facilities to support RFID-enabled healthcare projects, the potential interference of RFID systems with medical equipments, the difficulty to clearly define the scope of RFID-enabled healthcare projects, and the technical realization of such projects	
Data management, security and privacy issues	Covered issues such as RFID data integrity and reliability, management of huge amounts of data generated by RFID systems, RFID-enabled business intelligence	
Organizational and financing issues	Covered issues such as the lack of cost-benefit analysis frameworks for RFID-enabled healthcare projects, the cost of RFID system, change management, training, and skills to support emerging RFID-enabled healthcare processes, integration of RFID with healthcare organizational complexity, culture and norms	X
Benefits		
Efficiency gains	Covered benefits such as capital expense reduction, inventory reduction, operating cost reduction, labor cost savings, increased patient management	X
Quality gains	Covered benefits related to the improvement of patient care quality such as the elimination of wrong patient and wrong medication errors, elimination of wrong patient and wrong procedure errors; the improvement of the coordination between healthcare stakeholders	X
Management gains	Covered benefits such as improved compliance with various regulations, the reduction of insurance premiums, the improvement of process and event audit capacity as well as of forecasting capacity	X

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