Enhancing Medication Safety and Reduce Adverse Drug Events on Inpatient Medication Administration using RFID

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Abstract: - At any time, over 1.4 million people worldwide are suffering from infections acquired in hospital. Approximate 380,000 to 450,000 preventable Adverse drug events (ADEs) occurring annually in the United States. Therefore, patient safety has become a serious global public health issue. The purpose of this paper attempts to improve medication safety and reduce ADEs using RFID technology. For improvement of medical service quality in hospitals and reducing medication error, adopting RFID technologies has progressively become a trend. Medication errors and ADEs could be prevented by building a safer healthcare system. Accordingly, we developed the RFID on Inpatient Medication Administration System (RIMAS) and reengineering the inpatient medication processes. The RIMAS system integrating RFID into the existing Hospital Information Systems (HIS) may improve the efficiency of hospital management and medication safety, as well as decrease the risk of adverse drug events thereby increase higher quality of patient care.

Key-Words: - RFID, Patient safety, Medication safety, Medication error, Adverse drug events

1 Introduction

Patient safety is a serious global public health issue, in developed countries as many as one in 10 patients is harmed while receiving hospital care. Estimates 1.4 million people worldwide suffer from infections acquired in hospitals [33]. Approximate 380,000 to 450,000 preventable Adverse drug events (ADEs) occurring annually in the United States [4, 7]. To err is human, the report of the Institute of Medicine (IOM) in 2000, indicated that adverse events occurred in 2.9 to 3.7 percent of hospitalizations in U.S each year. In the investigation about frequencies of medical adverse events made by U.S., U.K. and Australia, the percentage of occurring adverse medical events is from 2.9% to 16.6% and the average percentage is about 10% [28]. For improving patient safety and reducing ADEs have cost some countries between US$ 6 billion and US$ 29 billion a year [33].

A medication error is any preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is in the control of the health care professional, patient, or consumer [21]. Medication errors occurred as errors in drug ordering, transcribing, dispensing, administering, or monitoring [17]. Adverse drug events (ADEs) defined as an injury resulting from medical intervention related to a drug [18]. Assuming conservatively an annual incidence of 400,000 in-hospital preventable ADEs, each incurring extra hospital costs of $5,857, yields an annual cost of $3.5 billion in 2006 dollars [3].

A recent surge of research on Radio frequency identification (RFID) has given us new opportunities and challenges. RFID is an automated data-capture technology that uses low-power radio waves to communicate between readers and tags on items [19]. The application of RFID are categorized in terms of the major benefits they provide, which include security and authentication, safety, convenience, and process efficiency [5]. RFID is used for a wide variety of applications such as parking management system [13], food or product tracking [2, 30], motion detect for security system [16], retail stock management [26], location tracking [14], blood transfusion [8], and drug supply [24].

For improvement of medical service quality in hospitals and enhancement of safety control for patients, integrating RFID technologies into information systems has progressively become a trend. To effectively incorporate RFID techniques

maturing with the existing HIS (Hospital Information Systems), the Taichung Hospital is conducting the integrated RFID automatic tracking operation into the routine medical care. By the advanced information technologies of RFID, We intend to construct a system integrating RFID into the existing HIS to improve the efficiency of hospital management and improve patient safety of inpatient medication.

The remainder of this paper is organized as follows. The next section reviews the patient safety, adverse drug event, and the application of RFID. Section 3 presents the original inpatient medication administration processes. Section 4 describes System architecture of RFID on Inpatient Medication Administration System (RIMAS). Finally, Section 5 provides the conclusions.

2 Literature review

2.1 Patient safety

Patient safety has to do primarily with the avoidance, prevention, and amelioration of adverse outcomes or injuries stemming from the processes of health care itself. It should address events that span the continuum from what may be called "errors" and "deviations" to "accidents" [22]. For patient safety, the general measures are to reduce any design, operation and action involving unsafety in systems. Within the 2009 National Patient Safety Goals regulated by the Joint Commission [15], we can find two important principles, Goal 1: improve the accuracy of patient identification and Goal 3: improve the safety of using medications. Thus, the patient safety is very an essential issue.

The performance of hospital needs cooperation of staffs from various departments, therefore adopting RFID technologies for hospital's supply chain systems can improve efficiency and serve patients more effectively [12]. After a patient completes a registering process, the hospital will provide a RFID wristband to this patient for wearing on patient's wrist. At this moment, the patient's data will be inputted into the HIS and patient's basic information as well as anamnesis records can be collected via systems. Thereafter, through RFID readers and wireless networks scattering over the hospital, the system can detect the patient's next processes of medical treatment such as the patient's location and other relevant information and offer real-time information about medication as well as nursing records to reduce human errors and promote drug safety and medical quality for patients [27].

2.2 Adverse drug event

Effective definition in common practices of ADEs is "Harm caused by a drug or the inappropriate use of a drug" [23]. Bates et al. investigated two tertiary care hospitals of U.S. over a 6-month period in 1993 and extrapolated that event rates were 6.5 ADEs and 5.5 potential ADEs per 100 nonobstetrical admissions. Of all ADEs, twenty-eight percent were judged preventable. Errors resulting in preventable ADEs occurred most often at the stages of ordering (56%), transcription (6%) and dispensing errors (4%), and administration (34%) [4]. Zebra technologies reported incidence of medication errors at the stages of ordering (7-20%), transcription (7-10%) and dispensing errors (10-15%), and administration (50-75%) [24]. At the final stage of this process, during which the nurse administers the medication, using RFID technologies to execute five rights checking can prevent errors.

2.3 RFID Technology and Applications

A basic RFID system consists of three components [29]:
(1) A tag made up of a powered or non-powered microchip with an antenna.
(2) A reader with an antenna that communicates with the tag sending and receiving information.
(3) Middleware that records and transmits the tag information to a central repository.
RFID tags fall into two general categories, active and passive, depending on their source of electrical power. Active RFID tags contain their own power source, usually an on-board battery. Passive tags obtain power from the signal of an external reader [32]. Table 1 highlights differences between active tag and passive tag [29].

Table 1 Difference between active tag and passive tag

Active Tags	
Advantages	Disadvantages
Longer read ranges	Larger size
Self-activated in presence of a reader	Limited operational life
Tags are write/re-write	Higher cost
Passive Tags	
Advantages	Disadvantages
Smaller size	Short read ranges
Long operational life	Needs higher-powered reader
Lower cost	Most read-only

The common RFID frequency ranges are Low Frequency (LF) at 135KHz or less, High Frequency (HF) at 13.56MHz, Ultra High Frequency (UHF) starting at 433MHz, and Microwave Frequency at 2.45 GHz and 5.8GHz [3]. In general, the frequency defines the data transfer speed between tags and readers. The lower the frequency is, the slower the transfer rate becomes. For a system applying low frequency, its cost will be low but the reading distance will be short. Consequently, the selection of equipment with specific frequency is based on requirement of application. The RFID signals are forwarded to the local computer from tags, through antennas of the reader and then integrated with other back-end information systems to support various applications. In Table 2, RFID characteristics and applications [3] are listed for various frequencies.

Table 2 Characteristics and applications of common RFID frequency ranges

Frequency	Characteristics	Application
Low Frequency (LF) 135KHz or less	Low data transfer rate Read range measured in inches	Industrial automation Access control
High Frequency (HF) 13.56MHz	Low tags cost than LF Longer read range than LF tags (3+ feet)	People identification and monitoring Smart shelf
Ultra High Frequency (UHF) 433MHz and 860 to 930 MHz	Longer read range than HF tags (10+ feet) Very long transmit ranges for active 433 MHz systems (up to several hundred feet)	Supply chain and logistics: Inventory control Warehouse management Assert tracking
Microwave 2.45 GHz and 5.8GHz	Fast data transfer rate Read range is similar to UHF Common in active modes	Industrial automation Access control Electronic automation

According to investigations of Gartner, Global RFID revenue in 2007 hit $917.3 million, and will growth to $1.2 billion in 2008, marking an almost 31% increase over and it will reach $3.5 billion by 2012 [10]. By the forecast of Harrop and Crotch-Harvey [11], the market for RFID tags and systems in healthcare will rise rapidly from $120.9 million in 2008 to $2.03 billion in 2018.

To promote efficiency, acquire competition advantage and chase enterprises' active power, the government and enterprises of each country, especially participants in the supply chain such as Wal-Mart [6], Unilever, Ford Motor, Toyota and the Port of Singapore, are energetically developing RFID techniques [1].

In addition to commercial applications, RFID is extensively applied into various fields such as chemical or biological agents and detection of dangerous materials like radiation [31].For hospital management, to enhance efficiency and reduce medical errors via RFID is a striving direction by the medicine field. At present, many hospitals and suppliers offering solutions are proceeding to various tests such as drug control, patients' contact histories, patient identification, monitoring of doctors' orders, prevention of medical negligence, monitoring for quality of blood bags and error prevention in pharmaceutical processes.

For example, to ensure patient identification and reduce mistakes, the Palm Beach Orthopedic Institution pastes Surgichip on the patient' body and read relevant information before an operation [20]. Other examples include: the Presbyterian Healthcare Services applies RFID technologies to track 6000 mobile medical equipment; the University of Chicago Comer Children's Hospital use same systems for inventory control [9]. In addition, other RFID applications in medical care such as tracking of medical equipment, medical resources, patients and products as well as inventory control are being developing actively [26].

3 Original Inpatient Medication Administration

Medication processes in hospital are very complicated, because lots of complex procedures such as physicians' prescriptions, pharmacy dispensing and administration at nursing stations are involved. In case of any negligence during these procedures, patients' life will be threatened and medical malpractice will be raised.

3.1 Original inpatient medication administration processes

Following are descriptions of the original inpatient medication administration processes, we also represent the flow chart shown as Figure 1:

(1) When a patient is in a ward after completion of hospitalization processes, the nursing station will

prepare an identification wristband for patient.

(2) Physicians used computer-based order entry system (CPOE) for prescription, and the prescriptions are classified into standing order, stat order, and PRN (as needed) order.

(3) The inpatient pharmacy adopts Unit Dose (UD) packing as a standard process. The dispensing packing machine will automatically pack pharmaceuticals and print details of medication on the packing. Then pharmacists will check up those UD packing. The nursing staffs will receive these UD packing after finish the checking.

(4) The nursing staffs at the nursing station ought to fill in the Medication Administration Record (MAR) recording relevant information such as patient's hospital bed and prescription content after physician entry the prescription. At medication exchange, the nursing staffs should use the UD cart to check drugs with pharmacists of the inpatient pharmacy and record on MAR, and then bring the UD cart back to the nursing station, preparing for medication administration. Figure 2 illustrated inpatient medication processes from pharmacy to nursing station.

(5) Before medication administrating, the nursing staffs in the nursing station have to execute the following steps: verifying the five rights checking (right patient, right medication, right dose, right route, and right time), confirmation of change order or renew order, and change of hospital bed. Then put the inspector's signature to MAR.

(6) During medication administration, the nursing staffs will push the UD cart into wards, after ensuring the patient's information on the wristband, then repeatedly execute right dose checking, right medication checking by Drug identification card, right time checking, and right route checking. Finally, medicines will be distributed to the patient. The nursing staffs recorded medication time and signature on MAR. Ward medication administration Processes are presented in Figure 3.

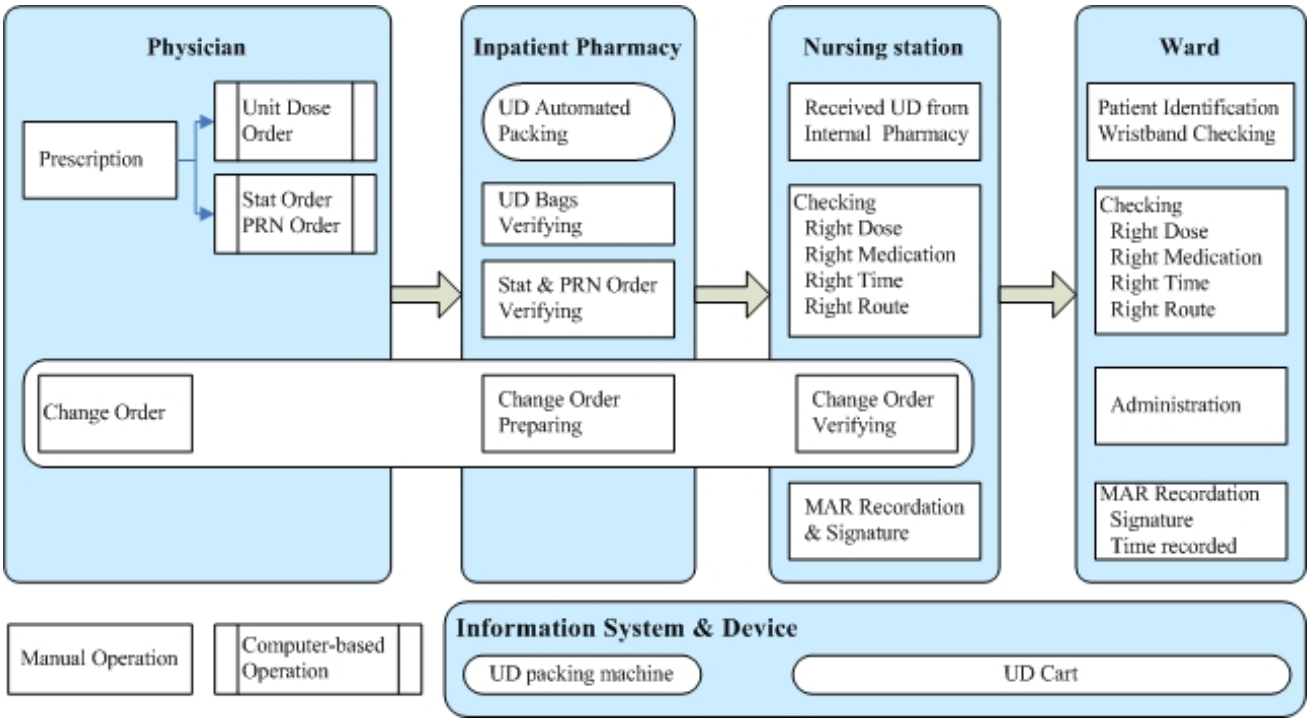


Fig. 1 Original inpatient medication administration processes

3.2 Negligence occurred during medication process

Negligence or errors frequently occurred during inpatient medication administering processes are described as follows:

3.2.1 Negligence on five rights checking

Pharmacists and nursing staffs must follow five rights checking at medication administration: right patient, right medication, right dose, right route and right time. In clinical practice, the similar appearance

of drugs easily causes errors during medication dispensing and administration by pharmacists and nursing staffs.

3.2.2 Failure to receive change order immediately

While patrolling wards, physicians may change order such as prescriptions and dosage by patients' clinical conditions. Under normal procedures, after completely packing new unit doses, the staffs of the pharmacy department will forward messages of change orders to the nursing staff that will adjust medications of new orders and record this change on MAR. Sometimes, the staffs of the pharmacy department fail to inform the nursing staffs at once. Although the orders have been modified, patients do not acquire correct medications at proper moment, because the nursing staffs fail to receive the real-time messages and distribute new medications.

3.2.3 Incorrect patient identification

When a patient is in hospital, the identification wristband will be worn on patient wrist (Figure 3-A). During processes of medical care, patient identification must be confirmed before execution of some necessary medical items such as administering medications or blood products, taking blood samples and other specimens for clinical testing. In general, information on the identification wristband is displayed on a computer-printed or handwriting sticker. However, blurred information resulting from sweat, bathing and hand washing, the identification wristband easily cause incorrect patient identification. In clinical practice, patients' language barrier, unconsciousness, and deafness will restrict them to clearly declare their identifications and adjustment of hospital beds will likely lead to risk of patient identification.

A. Inpatient pharmacy UD Packing machine

B. Nurse Checking UD Packing

C. Nurse checking change order or renew order

D. MAR recordation

Fig. 2 Inpatient medication processes from pharmacy to nursing station

A. Patient identification using wristband

B. Nurse checking UD bag using Drug Identification Card

C. MAR recordation

Fig. 3 Ward medication administration processes

4 System Architecture

4.1 RFID on Inpatient Medication Administration System (RIMAS)

This paper developed the RFID on Inpatient Medication Administration System (RIMAS). The major equipment is the mobile medication cart, containing some necessary tools such as notebook, RFID reader, and blue tooth. The notebook communicates with HIS through wireless networks. PDA, equipped with the passive reader, communicates with the notebook via the blue tooth. In each ward, RFID tags are installed at the entrance. The structure of management systems of medical

care operation employing RFID tools consists of the following and overall perspective of the RIMAS illustrated in Figure 4:

1. Computer-based five right verification and MAR recordation.
3. Inpatient pharmacy drug distribution system
3 Nursing station dispensing management system
4. Ward drug distribution system
5. Patient identification management system
6. Drug image database and Drug interaction screening system

4.2 Processes of RIMAS

Processes of RFID on Inpatient Medication Administration System (RIMAS) are described as follows. Figure 5 illustrates the flow chart of RFID on Inpatient medication administration system.

(1) Inpatient pharmacy drug distribution

In accordance with the existing systems, the inpatient pharmacy receive prescription from HIS, using the dispensing packing machine for tablet packing, and add RFID tags in UD packing. Pharmacists using RFID reader reading tags to receive prescription information and drug image database for verifying UD packing.

When received UD packing in internal pharmacy, nurses as well as pharmacists using RFID reader reading tags for UD list information and rechecking. RFID can aid pharmacists and nurses for identification of drugs and automatic drug reception and record.

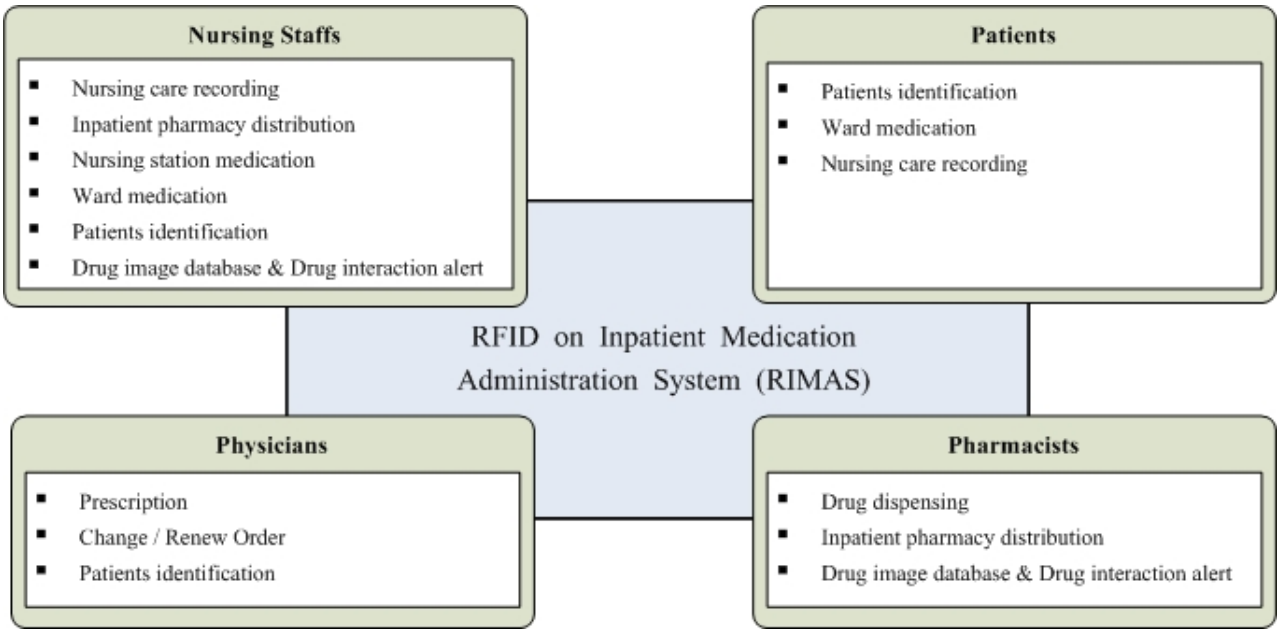


Fig. 4 Overall perspective view of RFID on Inpatient Medication Administration System

(2) Nursing station medication process

Before ward drug distribution, in nursing station, nurses need to verify UD bags using RFID, such as five right and change order. The mobile medication cart, that is, the UD medication cart equipped with RFID readers, can aid nurses for drugs identification and automatic record in MAR. Figure 6 depicted Inpatient Medication Processes from pharmacy to nursing station using RFID.

(3) Ward drug distribution

During medical care and drug distribution, the nursing staffs use the handheld PDA with a RFID reader to scan the patient's wristband for the patient identification and hospital bed; read tags on the UD packing; verify orders with the content of UD. In case of any change in orders, the nurse can receive real-time information to replace the content of medications and record the change in MAR. With all procedures completed, the drugs will be distributed to the patient.

Using RFID technologies, the nurses can verify correctness of medications because they can watch the drug image on the computer's monitor and click on adequate drug names can dynamic link image displaying on the monitor. If names and dosage for some medicines conform to requirements, the nursing staffs can click on those drugs on the monitor

and register administration records. Furthermore, during medical care, the nurses need to record relevant data of patients like body temperature as well blood pressure by hand. Thus, nurses need to conduct excessively human operations. By means of the full functional mobile medication cart that data can be inputted to the notebook or PDA, the nursing staffs' loading can be substantially reduced. Ward Medication Administration Processes using RFID represented in Figure 7

(4) Mobile medication cart

The mobile medication cart with RFID reader can automatically record nursing staffs' identity, patients' identity and administration time. In addition of automatic record, the mobile medication cart information system can provides drug image and drug interaction information, reduce the error in administration. In case of change orders, errors in medication administration processes of UD bags or patient identification, the administration record systems can automatically alert the nurse, and simultaneously save them into databases so that auditing management can be acted upon the medication error items of realistic patient safety reporting operations.

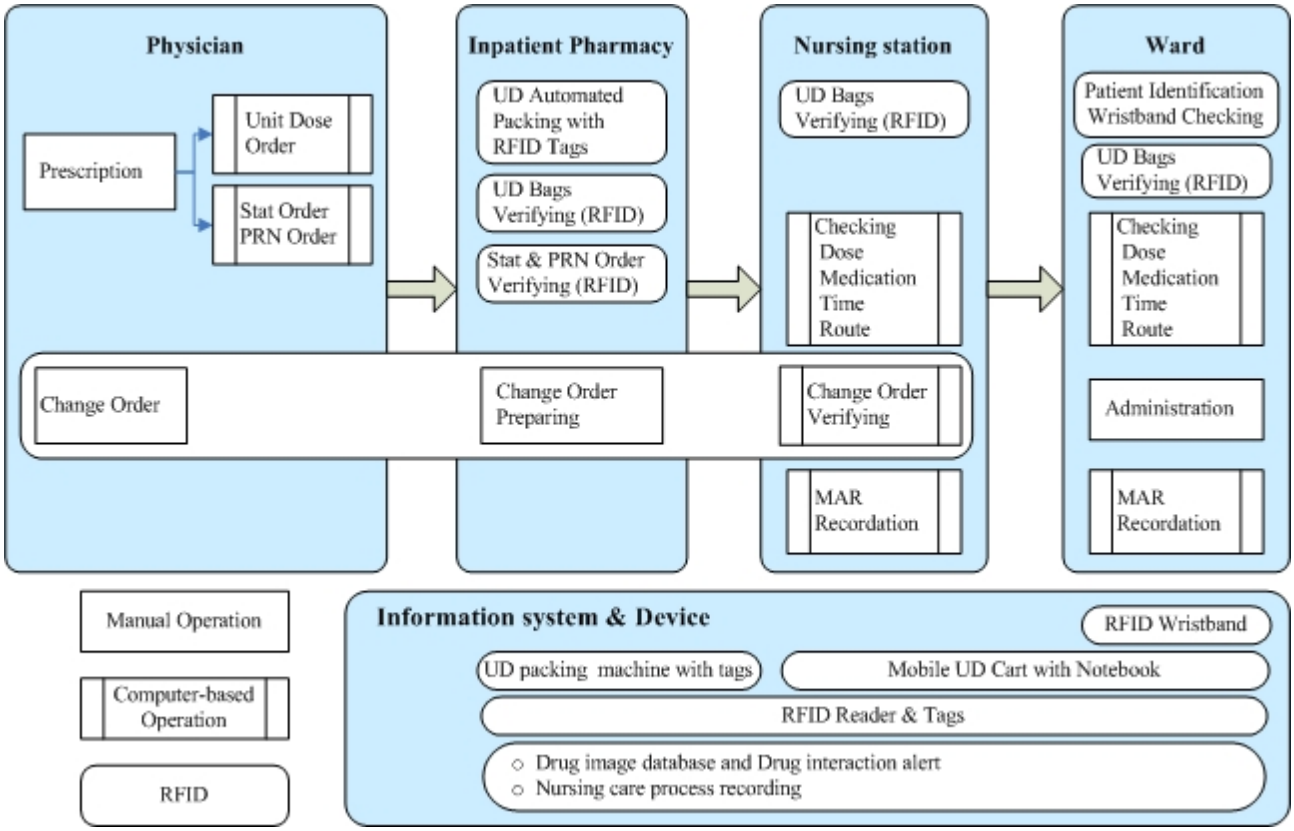
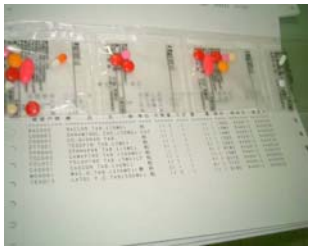


Fig. 5 Processes of RFID on Inpatient Medication Administration System (RIMAS)

A. RFID tag

B. UD Packing with RFID tag



C. UD packing verifying by reading RFID tag

D. Display information on computer-based Monitor & MAR recordation

Fig. 6 Inpatient Medication Processes from pharmacy to nursing station using RFID

A. Patient identification using RFID wristband
B. Nurse checking UD bag.
C. Display information on computer-based Monit
D. MAR recordation on computer

Fig. 7 Ward Medication Administration Processes using RFID

(5) Patient identification

When executing medication administration, nurses can use the patient's RFID wristband (Figure 7-A) to identify the inpatient's information and any updated record like hospital bed turnover from mobile medication cart information systems as well as HIS. The correct identification rate for the patients can reach 100%.

(6) Drug image database and Drug interaction alert

This study will setup of the drug image database combining drug-drug interactions in HIS databases, and patients' allergy records for specific medications. With this information system containing above content completed, the nurses can receive real-time drug image information about pharmacopoeias (Figure 6-D) that can replace the original Drug image and information card and employ RFID to contrast patients' records. The comparison of Original inpatient medication administration and RIMAS are presented in Fig. 8.

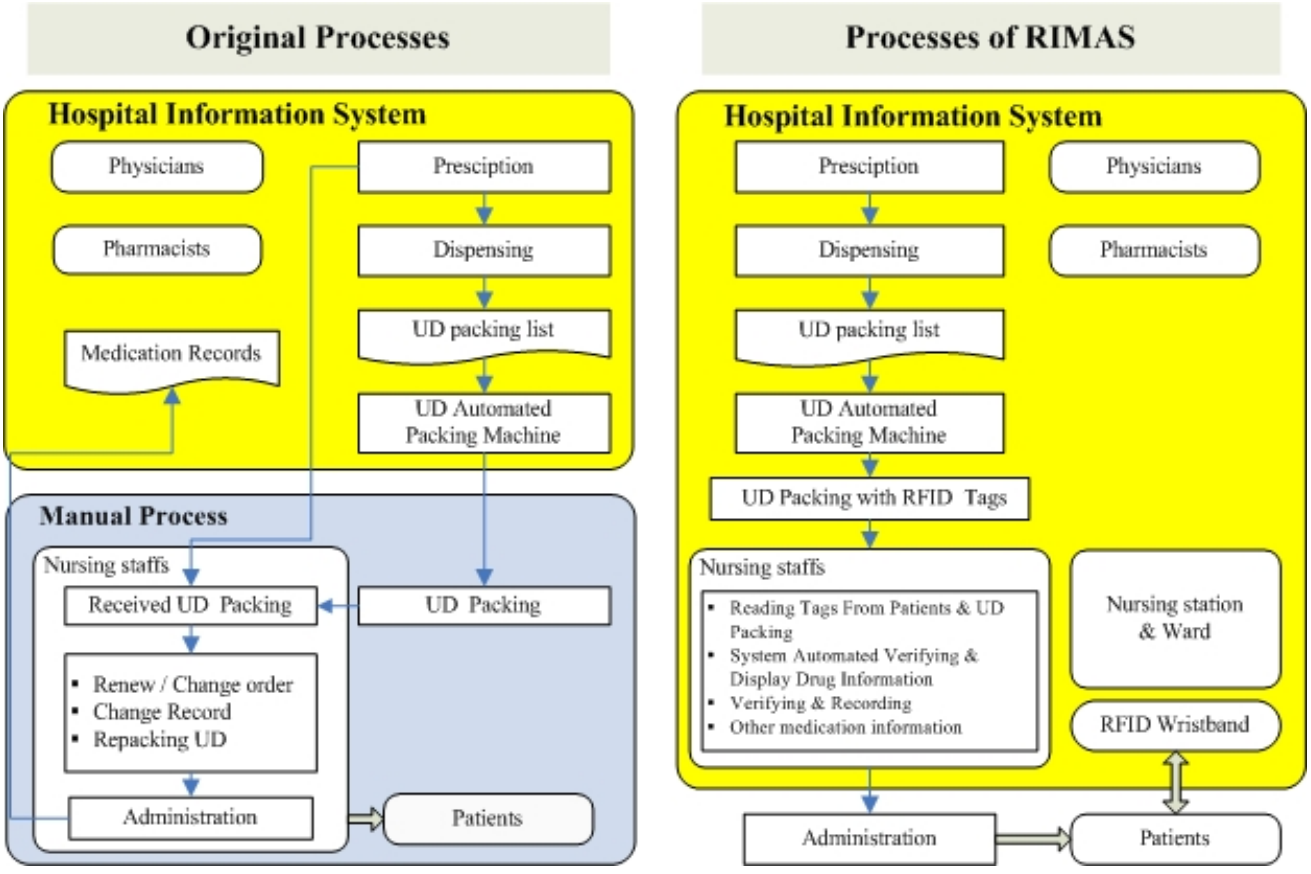


Fig. 8 Comparison of Original inpatient medication administration and RIMAS

5 Conclusion

The RFID on Inpatient Medication Administration System (RIMAS) integrating RFID technologies into the hospital information systems, conducting advanced network communications as well as information technologies and reengineering of medication processes can accomplish automatic inpatient medication operation, automate identification, as well as completeness of inpatient medication for continuously medical care and real-time information to nursing staffs. The drug image databases and drug interaction alert system can verifying drugs on the computer's monitor for the reduction of errors. While doctors' orders changed, the nurses can grasp changed information through system records displayed on computers of the nursing cart after renewal of HIS systems immediately.

RIMAS can strengthen inpatient medication safety; effectively reduce medication errors of hospital; avoid human negligence resulting in serious dispute and loss in life or property; promote medical quality. Using the mobile medication cart combining RFID readers, and nursing systems can improve patient identification; verify drug distribution; alert variation of doctors' orders; offer real-time information of medications and on-the-spot nursing records; reduce human errors; enhance inpatient medication safety and quality of medical care.

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