Improve the Management of Pharmaceutical Inventory by Using an IoT Based Information System

Yu-Tso Chen and Hao-Yun Chang

***Abstract*—The gradual development of medical technology advances the better medical industry meanwhile increases a variety of medicines to treat various disease. However, a great amount of medicines make the management works more complex due to their different types and functionalities. How to efficiently manage the pharmaceutical inventory is therefore a critical issue in a hospital information system. The Internet of Things (IoT) consisting of many sorts of sensors to help deal with complex problems is a considerable means of advancing existed service and systems. This paper presents a conceptual design of a pharmaceutical inventory management system that utilizes the characteristics of IoT. The proposed IoT based system not only provides the pharmaceutical inventory management functions on a framework constructed by Arduino and NFC devices; it also indicates a valuable research direction of inviting the strength of IoT to improve the performance of hospital management operations.**

***Index Terms*—IoT, pharmaceutical inventory management, NFC, hospital information system.**

I. Introduction

How to efficiently manage the pharmaceutical inventory is a critical issue for the modern hospital management. With the gradual development of medical technology, the types of medicines have increased year by year. Moreover, the scope of business expansion also makes the type and quantity of medicines more complex. The pharmaceutical inventory which is regarded as a hospital medicine supply center needs to be efficiently controlled and managed. An Effective pharmaceutical inventory management can not only accurately reflect the consumption status of the medicine but also avoid the problem of expired medicines to keep the safety stock for the use of medicines.

In practice, hospitals or medical institutions must rely on their experienced staff experience or well-operated information system to make good management of pharmaceutical inventory, mainly replenishing storing, recording, and picking the medicines. However, with the great development of medical science, the increasing types of medicines make the management works more complex than before. It has been significantly raised the workload for example to find a medicine in a very huge storeroom. In brief, the problem is the great amounts of medicines violate the efficient control and management of the pharmaceutical inventory. And most of the hospitals are trapped in such troubles.

A real example is an inventory management problem of traditional Chinese medicine in Taipei City Hospital. Figure 1 on the left shows the space of the inventory shelves are usually not optimized, and Figure 1 on the right displays a number of traditional Chinese medicine have to be placed on the ground except on the inventory shelves due to insufficient space. Such fact indicates that the Taipei City Hospital is lack of good management on pharmaceutical inventory for traditional Chinese medicine. An extended problem is that, due to the uncertainty of the placement of medicines, it makes the worker who is in charge of managing the pharmaceutical inventory for traditional Chinese medicine waste his time to handle the mistakes occurred according to the problem of inventory optimization.

Fig. 1. The status of placement of traditional Chinese medicine in Taipei city hospital.

In brief, three main problems of pharmaceutical inventory management for hospitals are summarized as follows.

1) Lack of well-designed information system for optimizing the pharmaceutical inventory management.
2) Hard to intelligently manage the medicine stock with considering the issue of expiration of medicine.
3) Hard to smartly find the appropriate space for stocking the medicine.

In recent years, Industry 4.0, also known as the fourth industrial revolution, is a mainstream emphasizing the features of automation and data exchange in manufacturing. It relies on the concepts of cyber-physical systems, Internet of things (IoT) and cloud computing. The main purpose of applying Industry 4.0 is to create "smart factory". Within the modular structured smart factories, cyber-physical systems monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the IoT architecture, cyber-physical systems may communicate and cooperate with each other/humans in real time. Via the Internet of Services, both internal and cross-organizational services are offered and used by participants to smarten their works. For deploying more smart applications, the IoT-based system or service has been rapidly emphasized. The trend of using a variety of devices to connecting to each other has become more obvious.

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In order to solve the problems above, this paper presents a systematical concept of pharmaceutical inventory management that utilizes the strength of IoT to build a conceptual framework of smart inventory. The conceptual framework introducing the use of Arduino boards, sensors, and NFC technology will be beneficial to improve the performance of pharmaceutical inventory management, especially to solve the problem of space optimization for the inventory shelves.

II. Literature Review

A. IoT Based Smart Computing

The primary purpose of adopting IoT technology is to design and implement smart computing applications. Ray et al. [1] introduced a paradigm changing for computing under the influence of IoT. In their statements, the basics of IoT as well as its applications, challenges, and how it may change the way of computing are described. Besides, a comprehensive introduction focuses on two major design constraints, security and power management, are also discussed.

B. Pharmaceutical Inventory Management System

For large-size hospitals, medical centers, and pharmaceutical research institutes, the pharmaceutical inventory management is a key issue has to be comprehensively investigated. In addition, for advancing the performance of pharmaceutical inventory management, the information and communications technology (ICT) is frequently considered to be adopted in designing suitable systematical functions.

Çakıcı *et al.* [2] proposed a RFID management system for pharmaceutical inventory to deliver the contribution of system optimization and shrinkage control. A RFID application enables more accurate real-time visibility than the traditional barcode solutions, which in turn creates potentials of process improvements. In [2], the incremental benefits of RFID technology over barcodes for managing pharmaceutical inventories and the impact of automatic counting are analyzed. Moreover, the system redesign critical to optimizing the inventory policy and eliminating shrinkage are fully discussed. Their research result not only showed that continuous review is superior to periodic review whenever accurate real-time information is available at no additional cost, but also explained how RFID-enabled strategies vary with inventory parameters and provides a cost-benefit analysis for the implementation of RFID for the radiology practice

In addition, Uthayakumar and Priyan [3] discussed the issue about pharmaceutical supply chain that may contribute to inventory management strategies for a pharmaceutical company and a hospital. The research background is that a high level of service for medical supplies and effective inventory policies are essential for all healthcare industries. Medicine shortages and improper use of pharmaceuticals will not only cause financial losses but make a significant impact on patients. According to the experience from hospitals, it's not easy to solve the problems about how to manage, supply, and use the medicines. Therefore in [3], an inventory model that integrates continuous review with production and distribution for a supply chain involving a pharmaceutical company and a hospital supply chain was presented. Their proposed model considers multiple pharmaceutical products, variable lead time, permissible payment delays, constraints on space availability, and the customer service level (CSL). Based on this model, a procedure for determining optimal solutions for inventory lot size, lead time, and the number of deliveries to achieve hospital CSL targets with a minimum total cost for the supply chain is thus developed.

Similarly, Kelle *et al.* [4] studied the pharmaceutical supply chain specifics and inventory solutions for a hospital case. In common, the pharmaceuticals represent a large portion of the costs in the healthcare industry due to the significant costs of these products and their storage and control requirements. In [4], the authors discuss the pharmacy supply chain and managerial practices in a case hospital, examine the often conflicting goals in decision making amongst the various stakeholders, and explore the managerial tradeoffs at the operational, tactical, and strategic levels of decision making. Their research focus is on the inventory management at a local storage unit within an individual Care Unit. They provide the reorder point and order up to level (calledmin and max par levels) that control the automated ordering system for the operational inventory decision. These parameters are based on a near-optimal allocation policy of cycle stock and safety stock under storage space constraint. In terms of tactical decision support, it is emphasized on the relevant tradeoffs amongst three key performance indicators including the expected number of daily refills, the service level, and the storage space utilization. The research result concludes the decision support tool facilitates improvements to the management practices through analyzing the tradeoffs amongst the refill workload, the emergency workload, and the variety of drugs offered.

The reviewed articles implicate that the main objective of applying pharmaceutical inventory management system is to optimize the management works of pharmaceutical inventory, including the space management. Furthermore, it will be valuable if some sort of automatic operations can be delivered with concerning various related parameters and situations.

C. ECA Rule-A Rule Based Methodology

Both in common theory and practice, a rule based mechanism is frequently used to achieve automation operation with inviting related factors and situational data as the parameters. Among the rule based approaches, the event-condition-action (ECA) scheme is a popular solution. The ECA approach is one of the means that are applied in coping with dynamic problems. ECA rules have been designed for the systems that need automatic response to certain conditions or events. As Isazadeh *et al.* [5] mentioned, the development of intelligent control systems will be useful for decision by computing the input data. Some of these systems used commonly in dynamic environments are rule-based architectures. For taking care of the changes of environmental conditions during the time and users demands of the systems that vary over time, intelligent rule learning is required for ECA rules to maintain the efficiency of the system.

Based on Chen *et al.* [6], the ECA approach was often

adopted in IC designs but less applied in advancing human-centered IoT applications; one of the main problems is the difficulty in directly generating ECA rules from human-centered application scenarios. Hence, they proposed a scenario-triggered, state-based rule generation (shortly S2RG) process which enables a complete but simplified way to conduct ECA rule for human-centered IoT applications.

D. Summary

The reviewed literatures highlight the following ideas which will merit the design of an IoT based pharmaceutical inventory management system.

1) An IoT system with the sensor-attached Arduino devices will be a good method of delivering smart and automatic operations.
2) An effective and efficient pharmaceutical inventory management system is required to cope with the problems due to the increasing amount of medicine, so that make a better usage of inventory storage facilities.
3) ECA rules will play a critical role of making situational smart computing easily implemented. A suitable ECA-based rule generation scheme will be a key feature to convert the functional requirements into realistic rules in a complex operation environment.

III. The Design of the System

A. The IoT Architecture for Pharmaceutical Inventory Management

All information systems should be performed in a well-deployed physical environment, particularly with necessary devices configured and managed. Because pharmaceuticals need good control to play a good effect, there is no way to complete assist medical staff through the current information system.

In order to reduce the human resources, improve the speed of inventory control and enhance the safety of using medicines by patients. The design of hardware architecture is suggested to leverage the strength of IoT to automatically run the smart computing, and thus accelerate the efficiency of medical staff. The IoT architecture as depicted in Figure 2 is composed of computation devices, communications modules, and terminal devices.

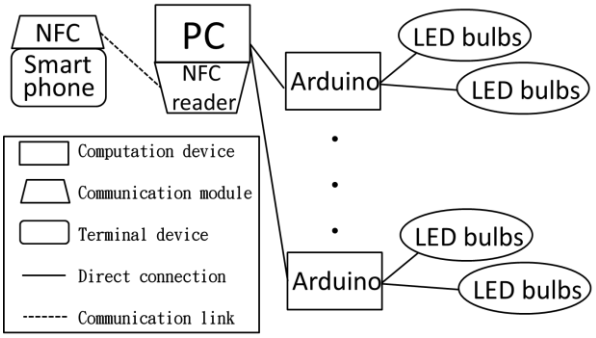

Fig. 2. The IoT-based design for pharmaceutical inventory management.

- Computation device: two types of device, PC and Arduino Uno are adopted. A PC is in charge of being a gateway host executed. The PC host serves database service and ECA operation mechanism. Arduino Uno is used to directly connect the LED bulbs, control the light on or off after identifying the state of the space placement. And Arduinos are attached to medicine cabinets.
- Communications module: NFC and NFC reader are attached on the computation device and terminal device for interchanging messages with each other.
- Terminal device: terminal device like smart phone can be used to send commands or receive message by application end users.

B. The Functional Requirements

From reviewing and observing the current operation process and discussing the related concerns with the staff with the Taipei City Hospital; the functional requirements of an IoT based pharmaceutical inventory management system for traditional Chinese medicine is designed in the form of event table as partially described in Table I and the form of use case as drawn in Fig. 3.

TABLE I: The Event Table Describing the Detailed Requirements

Event Title	Trigger	Source	Process (key works)	Response	Destination
Add Inventory Data	new purchase Info	hospital staff	To check available space	1.esponse display 2.added data	1.hospital staff 2.DB
Delete Inventory Data	inventory ID	hospital staff	To delete inventory data	response display	hospital staff
Search Inventory Data	Keywords for searching	hospital staff	To search inventory data	response display	hospital staff
Update Inventory Data	inventory data for update	hospital staff	To update inventory data	1.esponse display 2.updated data	1.hospital staff 2.DB
Add Medicine Item	new medicine info	hospital staff	To check if the item is existed	1.esponse display 2.added data	1.hospital staff 2.DB
Search Medicine Item	Keywords for searching	hospital staff	To search medicine data	response display	hospital staff
Delete Medicine Item	medicine ID	hospital staff	To delete medicine data	response display	hospital staff
Update Medicine Item	Medicine info for update	hospital staff	To update medicine data	1.esponse display 2.updated data	1.hospital staff 2.DB

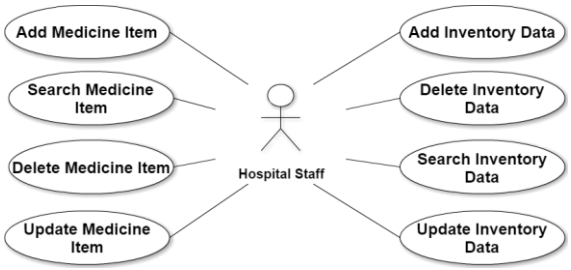

Fig. 3. The use case diagram presenting the use case of the required functions.

IV. The Scenarios of System Operation

The conventional inventory management systems which tend to be manual are limited on the weakness of showing the current number of the medicine, searching of inventory placement and checking where the inquired medicine is placed. The new system on the strength of IOT operations would be expected to solve the above constrains. The

conceptual operation would include firstly using the terminal device to select services, store data which are selected in the phone's NFC. Next, connecting with the host of the NFC reader to exchange data and sent the data to the database simultaneously. After reading the database, the parameter indicating the right location will be sent to the PC. Finally, sending the parameter to the Arduino controlled LED lights.

Through the completion of the ECA rules operated, the overall operation can be categorized into three main scenarios, storing the medicines, picking up the medicines, and inventorying the medicines. These scenarios are detailed as follows.

A. Storing the Medicines

The operation steps of this scenario, when the user is going to put the medicine in the inventory, is depicted as Figure 4 and introduced as the follows.

Step 1: use smart phone and select storing the medicines, then enter the name and quantity of the medicine;

Step 2: exchange information to the database through NFC;

Step 3: the database will check whether the space has excess space;

Step 4: transmit the parameter of corresponding placement to the PC;

Step 5: control the Arduino light bulb. The place where the light is on is the basis for the user to place;

Step 6: place the medicines to the medicine shelves;

Step 7: use the system to enter the storing information;

Step 8: record their location to database at the same time.

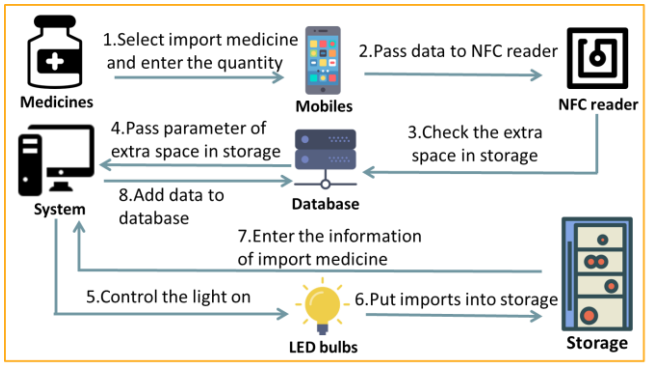

Fig. 4. The process of storing the medicines.

B. Picking up the Medicines

The operation steps of this scenario, when the user is going to pick up the medicine, is drawn as Figure 5 and introduced as the follows.

Step 1: use the smart phone and select picking up the medicines, then enter the demand and the quantity;

Step 2: exchange information which is selected with NFC to the database;

Step 3: the database will search whether this demand is stored in the inventory;

Step 4: transfer the parameter of medicines placement to the PC from database;

Step 5: transfer the parameter of location to the Arduino, the Arduino will find the corresponding location of the light bulb and control the light on to help users quickly find the demand;

Step 6: pick up the medicine demanded;

Step 7: use the system and enter the information of medicines which is picked up by a user;

Step 8: Update the data to the database.

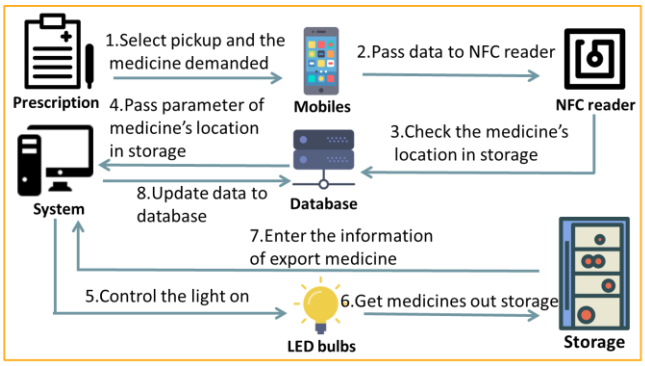

Fig. 5. The process of picking up the medicines.

C. Inventorying the Medicines

The operation steps of this scenario, when the user is going to inventory the medicine, is displayed as Figure 6 and introduced as the follows.

Step 1: user use smart phone and select inventorying the medicines first;

Step 2: exchange information to the NFC;

Step 3: transfer to the database;

Step 4: the database will transfer all the information of medicines to the PC;

Step 5: transfer the parameter of location to the Arduino, the Arduino will find the corresponding location of the light bulb and control the light on to help users quickly inventory;

Step 6: check the practical quantity of inventory and the information in system is the same.

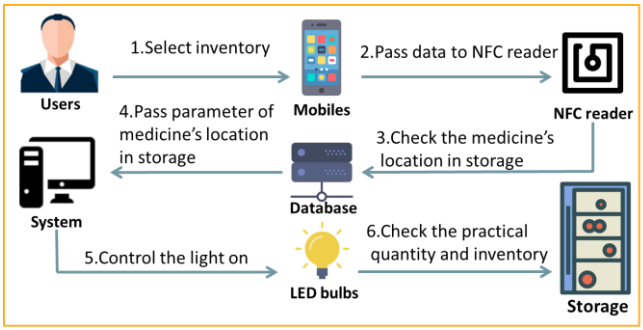

Fig. 6. The process of inventorying the medicines.

V. Discussion

A. The Compatibility Concerns of IOT Based Pharmaceutical Inventory System and the Existed HIS

A hospital information system (HIS) is general name of a system covering all the administration needs. On the implementation point of view, a HIS is perceived as a comprehensive, integrated information system designed to manage all the aspects of a hospital's operation, such as medical, administrative, financial, and legal issues as well as the corresponding processing of these services.

Since a HIS system is a complete system frequently having 20 to 30 sets of subsystems, each branch subsystems may has different approaches to fulfill the operation of their needs. Accordingly, how to keep the compatibility of the subsystem, like the proposed IoT based pharmaceutical inventory system, working within the existed HIS system is a big challenge.

B. The Contribution of Using S2RG Process to Help Generating a Pharmaceutical Inventory Management System

A good pharmaceutical inventory management system must have a strong and well-defined rule to support. A rule is a statement that tells you what is allowed or what will happen within a particular system. Many information systems adopt some type of rule mechanism to smarten their designed functions with the ability of automation. It's no exception that the ECA rule used by the S2RG process. In its process, the concept of Finite State Machine and the Flow Chart are invited to produce the complete process for each situation. Because these complete outputs allow the system to be automated, also completely support the difficulty in working for medical personnel.

C. The Value of a Pharmaceutical Inventory Management System

In general, the design of a pharmaceutical inventory management system is to optimize the pharmaceutical inventory, reduce unnecessary inventory and management spending. Dosing is a daily care activity performed by a caregiver in clinical practice. Potential errors may occur at any point by medical personnel during the course of administration. The reasons lead to dosing errors is a lot, such as improper medicine administration, excessive backlog of overstocked or expired standing medicines. In addition to medicine deterioration or expiration, it is also difficult to manage the inventories which lead to increase the cost of medical resources and medical expenses. Therefore, when a pharmaceutical inventory management system cannot properly help managing the status of the medicines, the system will not be workable and accepted.

VI. Conclusions

In order to optimize the pharmaceutical inventory management, intelligently manage the medicine stock with considering the issue of expiration of medicine, and smartly find the appropriate space for stocking the medicine, this paper presents a systematical concept of pharmaceutical inventory management that utilizes the strength of IoT. The conceptual framework introducing the use of Arduino boards, sensors, and NFC technology will be beneficial to improve the performance of pharmaceutical inventory management; in addition, it also indicates a valuable research direction of inviting the strength of IoT to improve the performance of hospital management operations.

The contribution of this proposed IoT based approach is to demonstrate the potential improvement of pharmaceutical inventory management. However, some considerable issues that might merit future investigations are listed as follows.

1) This paper mainly discusses the pharmaceutical inventory management system as a subsystem of a HIS. It is found that the application level of HIS is rather wide but lacks depth, which means that the sub-system cannot completely support the medical personnel to work smoothly. With the rapid development of technology, the medical needs can be easily resolved. So, how to integrate such system into a well-defined HIS will be a valuable issue to be studied.
2) The proposed conceptual framework should be further implemented as some sort of prototype to be tested in a real area with using some experience feedback approach.
3) How to compare the performance of such design with the traditional operation is also an interesting topic.

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