Enhancing Chemical Inventory Management in Laboratory through a Mobile-Based QR Code Tag

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Abstract. The demand for a greater inventory management system which can provide a lot of useful information from a single scan has made laboratory inventory management using barcode technology more difficult. Since the barcode technology lacks the ability to overcome the problem and is not capable of providing information needed to manage the chemicals in the laboratory, thus employing a QR code technology is the best solution. In this research, the main idea is to develop a standalone application running with its own database that is periodically synchronized with the inventory software hosted by the computer and connected to a specialized network as well. The first process required to establish this centralized system is to determine all inventory available in the chemical laboratory by referring to the documented data in order to develop the database. Several customization and enhancement were made to the open source QR code technology to ensure the developed application is dedicated for its main purposes. As the end of the research, it was proven that the system is able to track the position of all inventory and showing real time information about the scanned chemical labels. This paper intends to give an overview about the QR tag inventory system that was developed and its implementation at the National Defence University of Malaysia’s (NDUM) chemical laboratory.

1. Introduction

Inventory management is an operation which monitors and tracks the flow of stock items in an organization. It has evolved over the past few decades, from paper-based recording system to the using of barcode technology which was first introduced in 1948 by Bernard Silver [1]. Managing inventory and chemicals in the laboratory can be a heavy task. Due to its reactivity, handling of chemicals must be done carefully since some chemicals tend to become unstable after a long period. According to [2] there are at least 10,000 chemical entries that can be found in a typical chemistry department and tracing the specific chemical can be difficult for a non-centralized chemical resources.

Considering the increase in a number of chemicals and equipment available in the NDUM’s chemical laboratory, therefore there is a need for a systematic way to manage those items with a reliable method. The main purpose of developing a chemical inventory system based on QR code technology is to enhance the productivity and efficiency in managing the inventory at the NDUM’s chemical laboratory by adopting a mobile technology that can be used by the user, especially the laboratory assistant on the go. Late chemical waste disposal from the schedule is always related to the...
poor inventory management. The chemical which does not dispose on time will produce an unpleasant smell that can spread all over the building.

This can be hazardous for the people who accessed the laboratory if the chemicals were not taken out and started to produce poisonous gas or even serious, an explosion might occur. Most cases in the past event where an accident in laboratory happened are due to the failure of keeping track those spoiled chemicals, which are also closely related to the poor chemical management. In order to promote best practices, a safety measure must be taken which includes the proposing of standard operating procedures in handling, storage, and transport of chemicals as well as chemical disposal in a timely manner [3]. Through enhancement of the chemical inventory management system, this can highly contribute to the chemical safety.

Conventional barcode technology has been widely used in many laboratories for managing inventory [4], [5]. The barcode itself has a unique number which identifies the item that it was assigned to [6]. Labelling the barcode onto products requires the development of a centralized database that keeps track of all information regarding the inventory [7]. Although it has become the basis of many inventory management system, the single dimension (1D) barcode however is not capable of storing many details. To be concise, the barcode could not be read if the scanner is not connected to the database or if it does not contain the information of that particular item [8]. Information storing is immensely dependant on the database operation [9]. Without the data, the barcode is merely a unique label that does not exhibit any useful information [10].

The introduction of Quick Response code, often abbreviated as QR code in 1994 by Denso Wave has made it possible to store information in a two-dimensional (2D) matrix barcode label [11], [12]. The QR code can store information about the item to which it was assigned without the database. It can be read by using smartphone’s camera and display all information about the item although the smartphone is not connected to the internet. The benefit of using QR code is clear that it can store information on the label independently and make it much faster than traditional barcode label when it comes to retrieving information thus overcoming the aforementioned problems [13]. The next section of this paper will further explain the benefit of using QR code for the chemical laboratory inventory management system and how this implementation boosts the efficiency in handling chemicals.

2. Literature Review

Procuring hazardous chemicals requires a thorough supervision. Educational institutions such as university have become the centre for scientific research as well as the main centre where teaching and learning in higher education take place [14]. For that reason, various chemical substances and extra facilities were built at the National Defence University of Malaysia’s chemical laboratory to fulfil the needs. In the past, the laboratory still make use a manual paper-based method to record all information about the inventory [15]. As the number of inventory increases, this could make it harder to keep and search for information about the inventory such as the expiry date of chemicals, the quantity of instruments and volume of chemicals, together with the position of such items in the laboratory [16]. All chemical containers were tagged with a sticker label with the name of the chemical or chemical formula and are fully handwritten.

Such information is insufficient to tell the user if the chemical is still safe to be used or if it was contaminated. Some of the chemicals with different concentration might be mistakenly used if it is not labelled correctly, and this situation had once happened in NDU’s laboratory which caused a minor explosion. Apart from that, one of the contributing factors which caused laboratory accident is due to the delayed disposal of some chemicals from the schedule [17]. Since there is a big number of chemicals in the laboratory, therefore it was difficult for the person in charge or the laboratory assistant to keep track all chemicals at once. Misplaced chemicals that could not be found in the laboratory might be mistakenly used by students as there is no detailed information put on the chemical containers. Thus, conducting experiments using chemicals with unknown status would lead to an unwanted chemical reaction and could harm them.
There are also several chemicals stored in the laboratory which tends to become unstable over time and has been classified as hazardous [18]. Those chemicals must be handle carefully and to be disposed by the authority according to the maintenance schedule. Failure in locating those expired chemicals in the laboratory has to be disposed on time can cause undesired incidents such as fire, explosion, and poisonous gas leak [19]. Some chemicals are placed in cabinets with locks and the rest is put on the table due to the limited space. Anyone can use the inventory without the need to write on the log book. This can be difficult for the laboratory assistant to identify which equipment or chemicals that have been used. Besides, the chemical is hard to determine when the sticker label is torn off or fade. Another problem with current security is the chemical sometime being misplaced by the students after it was used, thus make it tougher to locate the inventory.

Safety in the laboratory has become the key aspect which emphasises the importance of following rules that could help to prevent unwanted events [20]. Negligence of safety precaution could expose workers or students to dangers that may result in fires and explosions. Although every precaution have been put into action to reduce the risk in a laboratory, however, there is no guarantee that any incidents would not happen. Consequently, the Civilian Research and Development Foundation (CRDF) Global has come out with the initiative to improve the safety of chemical facilities at academic institutions by providing funds under the Chemical Security Improvement Grants (CSIG) for the proposed project [21]. It has been foreseen that one of the main causes of laboratory accidents in NDUM is due to the poor inventory management. Hence, there is a need for developing an inventory management software as in this project to ensure that the chemicals can be track easily and managed in a systematic way.

The use of QR Code has been expanded by the growth of camera-equipped device such as smartphone technology [22]. It is even easier nowadays for a smartphone user to install the application into the smartphone and use it on-the-go. The portability and capabilities offered by both technology have made it the best selection for developing an inventory management system. One of the primary features of QR code where information can be self-contained has made it less dependent on the use of database [11]. Current practice in most laboratory make use the original 1D barcode to tag the chemical containers and other equipment. This method has been applied for many years and proven to be effective in keeping track the flow of inventory.

But this situation had changed in recent years as the demand for chemical supplies at the NDUM’s laboratory increases. The abundance of chemicals substances, whether it is hazardous or not, had caused the task of tagging the containers become much complicated. It is not because of the limitation that arises from the use of traditional barcode technology, but more of a problem in monitoring and keep up to date with all chemicals available in the laboratory. In order to get the information of a specific chemicals, the laboratory assistant has to scan the barcode with a barcode scanner which is connected to a computer that hosts the database. This procedure nevertheless has revealed that the 1D barcode alone is not capable of storing necessary information since the unique code is just a reference to the record in the database which the barcode was assigned to [23]. Apart from that, most barcode scanners used in the laboratory are hooked up to the computer and because of that, the movement of its user is limited at a fixed place.

Another option that the user had is to write down the barcode of a chemical without the need to carry the container near the scanning point and entering the number into the system. This method also allows information to be retrieved, but in exchange, the process eliminates the automation by the barcode technology [24]. On the contrary, QR code can be used as a standalone feature often with a smartphone, which is well-known for its portability. Using QR code in inventory management system allows the user especially laboratory assistant to identify chemicals and retrieve all information instantly without having to refer on the computer. Updating information is also possible using the QR code as shown in the next section of this paper.
3. Methodology
Reviewing current inventory management process at the NDUM’s laboratory allows more information to be collected as a requirement. By identifying the input and output for the system, therefore it is easier to determine what is needed to develop the system.

3.1. Designing inventory database
Since there is no database software ever used at the chemical laboratory in NDUM, hence the first task would be designing and establishing the database for all inventory. For sampling purpose, only a few information was added into the database such as the name of chemicals, quantity, manufactured date, and expiry date. Every single chemical will be assigned a unique primary key identity number.

3.2. Generating QR code
From the list of chemicals recorded in the database, the QR code will be then generated by storing the identity number rather than storing the whole information of a chemical. The main reason for this referencing is to ensure that the scanning of QR code could show the latest information about an item when the data was updated.

3.2. Establishing network structure
The process of updating the information in this system requires synchronization between the smartphone, which was used as a QR tag reader and a computer; that host the database via a network. Similarly, the QR tag label is also carrying a unique identification number as the barcode. The QR tag can be produced at a very large quantity without exhausting the resource. By adding some restriction to the QR tag generated for labelling chemical inventory in this research, this will ensure that the code is only capable of being read and exposing information to the dedicated QR tag scanner that was developed. In addition, QR tag scanner has been programmed to read information from a registered QR tag label produced specifically for the mentioned purposes.

3.3. Deploying the system
The deployment of the mobile application is aiming to gain feedback from the user about the technology that will take over current practice in the laboratory inventory management process. The user acceptance test will be conducted to examine user satisfaction on the graphical user interface (GUI) of the application, whether it is too hard for them to learn using the technology or the opposite.

4. Implementation
For the inventory software, the package was first installed into the computer and the configuration was made to allow connection with the dedicated device. The procedure was then followed by the installation of QR tag reader application into the smartphone which was developed in this project. The database has been partially filled with all data on the chemicals and instruments available in the laboratory. This was done in accordance with the testing made for the QR Code Scanner.

There are actually two implementations of databases that exist in this system which can be seen in Figure 1. The first was configured into the main computer using the MySQL software, a type of Relational Database Management System (RDBMS) while the next one resides within the QR scanner application itself, known as the SQLite. The purpose of using dual database system is to ensure the data could be updated swiftly from the smartphone. A mechanism to synchronize both databases was defined and regularly updated to avoid ambiguity, thus adding the ability of the application to run independently in some circumstances where connection to the main database is not possible. Once the connection has been restored, the data which was updated from the smartphone, for instance the quantity of chemicals, is also updated to the computer’s database record.
The QR code generated does contain general descriptions about some chemicals or equipment. It can be read by any QR code reader application, but still, can withstand any alteration to the information contained in the QR tag. The advantage offered by this application is that it can read the information directly from the QR tag label and retrieve extra information about the scanned chemicals from the database concurrently. The information that was retrieved from the database at the time of scanning is the status record of the inventory such as chemical quantity or volume, date purchased, disposal scheduled, and the vendor which are shown in the system flow diagram in Figure 2.

**Figure 1.** The QR tag inventory system on the computer and the mobile application of QR Scanner.

**Figure 2.** System flow diagram
The scanner application will fetch information from the QR code based on the text fields defined by the program itself, thus strengthening the security of the system from being easily read by any third party QR code scanner. The mobile-based QR code scanner application is also equipped with a login system which authorized the laboratory assistant as the user to manage the content of the inventory management system. Establishing a private network infrastructure in the chemical laboratory would definitely help to secure the connection between smartphone and computer that acts as the scanner and the centralized database respectively. Besides, the application is capable of sending a reminder to its user through the dedicated smartphone about the schedule on the chemical disposal. It will also notify the user to take out the chemicals which are about to expired out of the shelves, thereby preventing accidents that mostly occurred due to poor chemical usage.

During the project, each chemical containers were labelled with a colour-coded QR tag stickers. This technique allows the laboratory assistant to classify the chemicals into several groups according to its reactivity. Higher reactivity denoted hazardous chemicals that must be handled with extra careful. The placement of the chemicals is also based on the attached QR tag colours. For the beginning, the colours used were green, yellow, and red that reflects the level of chemical reactivity.

5. Conclusion
A fully functional QR Code inventory system that was developed in this research has proven that the QR code is capable of managing information efficiently at the National Defence University of Malaysia’s chemical laboratory. The system managed to run as it is and able to operate as planned in this research. Several testing were done prior to the full implementation of this whole new system into the chemical laboratories at the NDUM. Since this is the first time that the management had migrating to a new electronic system, there might be some flaws that have to be taken into consideration. Some customization will be applied to the software to better fit the requirements. Overall, users of this system are satisfied with the transformation and hope more features to be added into the application.

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