An Automatic RFID and Wireless Sensing System for Hazardous Material Inventory and Security Monitoring

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***Abstract*—A RFID and wireless sensing network have been developed to improve a GHS-based intelligent management platform deployed on campus, which monitors the hazardous chemicals inventory at a number of laboratories. The developed RFID and wireless sensing system can automatically update the inventory of monitored chemicals periodically or respond the server's request instantly to check the usage and storage of the chemicals so that ignorance or misconduct of laboratory operators can be prevented or detected shortly to assure the safety of environment. Unlike the traditional RFID inventory control system, even the little quantity change in the chemical container can be detected and recorded to enhance the inventory control with the innovation of this system. This automatic system can be deployed and transmit data wirelessly in laboratories to minimize the cost and complexity of implementation. It also can communicate with the remote GHS-based management server via internet such that administration can oversee the status quo of inventory of all chemicals in the laboratories with this system installed. The implementation of this system has shown its effectiveness to improve the safety and accuracy of inventory control of the toxic chemicals on campus.**

Keywords — RFID, wireless sensing, security and monitoring system

I. INTRODUCTION

The usage of chemicals is diversified and popular in all fields of industry. It is not a surprise that accidents about mishandling of chemicals happen frequently which usually cause loss of lives and health of labors. From governments to the laboratories, the safety of hazardous chemicals is always a first-priority issue in the management system.

Originally proposed by the United Nations Conference on Environment and Development (UNCED) and Inter-governmental Forum on Chemical Safety (IFCS) in the year of 1992, the Globally Harmonized System (GHS) of Classification and Labeling of Chemicals is supported by the International Labor Organization and Economic Co-operation and Development (OECD) to set a global standard for classification and labeling information of chemicals around the world [1]. Currently, different countries have various classifications and labeling systems of hazardous chemicals which will be a potential safety issue if these chemicals are transported to other countries without correct re-labeling [2]. If not handled properly, the transportation could delay the transactions and activities of the chemical and cause the loss of time and resources of the economy [3].

The GHS system is not only aiming at harmonization of classifications and labeling across the borders, but also designed to provide thorough information of the hazardous chemicals to assure the safety at the stages of transportation, handling, storage, disposal and etc. As there are thousands of hazardous chemicals and wastes, a computerized platform is a necessity to adopt the GHS system. A GHS-based intelligent management system of hazardous chemicals has been developed and deployed on the author's campus which can administrate import and export of these chemical, track education training records, update the inventory, monitor the laboratory safety, and provide emergency response information [4].

In most of the chemical laboratories, traditional book-keeping is common for monitoring the usage of toxic chemicals for its simplicity. To avoid ignorant or unlearned behaviors and to facilitate the operations, some electronic devices are integrated to minimize human mistakes. For example, a Laboratory Information System for Chemicals (LISC) system is implemented using an electronic scale and the bar-code reader to assist the operator input the data with minimum efforts and mistakes. In spite of computerized processes and the efficiency improved by the electronic devices, the LISC system still needs human interactions to collect information of the monitored chemicals. To automate the procedures, an intelligent device which can actively measure and collect the usage of hazardous chemicals is needed in the management system.

Although the currently deployed management system is capable of handling complicate information of these specific hazardous chemicals, it relies heavily on the operators' data entries and working patterns to keep the management system up-to-date. Once any of the operators breaks the information loops by ignorance or misconduct, the system functions and efficiency will be damaged or broken down. Even well-disciplined operators may be negligent to keep all the records promptly and correctly, not to mention the naïve trainees in the laboratories. To assure the thoroughness of information paths, an automatic management device of hazardous chemicals must be incorporated in the system as shown in the Figure 1. The need of automation motivated this study to develop an automatically monitoring and measuring device to improve the current deployed system.

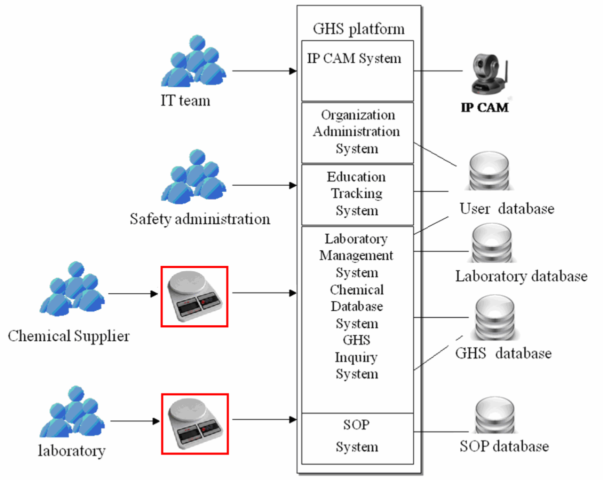

Fig. 1 Automatic devices, shown in red blocks, proposed to be integrated in the current deployed GHS-based chemicals management system

The radio frequency identification (RFID) [5] and wireless sensing technologies have emerged in the recent years, and various applications have been developed to utilize the advantages of these new technologies. With enough radio-frequency bandwidths defined and released, as well as the diversified data communication protocols developed, the wireless sensing has become an applicable technology. Different protocols have occupied different bandwidths and developed specific architectures of data communication. For examples, IEEE802.11x has taken the 2.4GHz for Wireless Ethernet and been adopted for internet communication [6], IEEE802.15.4 has been defined for the Zigbee which is a short range, low power and low data rate data communication protocol at different frequency in different countries [7], the popular GSM/CDMA mobile phone networks can also be adopted for long range data communication [8], etc. All these development of wireless communication protocols have provided platforms of wireless sensing to transmit signals of specific sensors to the master devices in which all the collected data can be processed in large scale at higher efficiency. These wireless technologies have minimized the capital of the wiring at the working sites and simplify the installation of sensing network. Since the wireless radio frequency electromagnetic wave is a format of energy transmitted among devices, standards are also defined to assure the health and safety of human and devices exposed at the working sites, such as the industrial, scientific and medical (ISM) radio bands [9].

The most important information for the hazardous chemicals management system is the transportation and usage of these chemicals, including the type, import, export, time and amount of consumption, storage of the monitored chemicals. Basically these can all be related to the inventory records of the chemicals. The RFID technology has been widely accepted in the industry for logistics to reduce the human interference and automate the processes [10-11]. The concept of RFID technology is to use a tag reader actively transmit radio wave at a specific frequency. And this specific radio wave can be absorbed by the specially designed antenna on the tag to energize the circuit on the tag and transmit data on the tag back to the reader. In this structure, the tag is a passive device which can only provide information when a tag reader approaches and provides energy at a designed frequency. In most RFID application, the tags contain only limited permanent information of the items attached, such as identification (numbers), and others. However, once the identification is detected, it can be sent to the central devices and retrieve more related information from servers. In more advanced applications, the information on the tag can be renewed to keep some information updated. The RFID applications are not limited to the industrial logistics but can also be found in the consumer business, such as the prepaid transportation tickets and electronic wallets.

Although the RFID system has improved the convenience and efficiency of the inventory control system, and indeed automated the processes, the information in the tag is adhesive to the containers of monitored items. Thus most applications of the RFID are developed to monitor the inventory in the units of the containers, such as box, bottle, barrel, etc. Controlling the inventory by the abovementioned units might be acceptable in the mass-production industry, but it would be a severe problem in some other businesses which consume some expensive, precious or hazardous materials in little amount, for example, the chemical laboratories. If applied, the RFID tag can only provide the existence of the container but not the actual amount inside the container. This shortage has kept the RFID technology from the inventory control of the liquid, powder, or small pieces sold in volume. The typical operations of chemical laboratories can be categorized in these RFID non-applicable fields, in which chemicals are taken in the amount of gram, milligram, milliliter or even less. Moreover, the hazardous waste in the chemical laboratories, if need to be monitored, increases little by little, which could also cause lethal damage to the environment and human lives if disposed or exposed improperly. Even though regulations in different countries have forced the administration of chemical laboratories to maintain proper inventory records, the effectiveness heavily depends on the operators' disciplines and morality to assure the effectiveness and safety. Herein, an automatic inventory control system is needed to monitor the hazardous chemicals in the laboratories and assure the safety of the environment.

This study is initiated by the needs of this automatic inventory monitoring system of the hazardous chemicals with minimum human interactions while maintaining the most accurate and updated information of the transportation, usage and storage of the chemicals. The system is designed to integrate the existing GHS-based management system as the central information server, and the modern RFID security monitoring and the wireless sensing technology to collect the inventory of the chemicals. The developed system would provide an around-the-clock automatic monitoring system for the inventory control of hazardous chemicals. Details are introduced in the following sections.

II. THE AUTOMATIC RFID AND WIRELESS CHEMICAL INVENTORY CONTROL SYSTEM

As briefed in the abovementioned sections, the existing GHS-based chemical management system has provided a well-implemented software system to administrate the hazardous chemicals and waste in an organization. However, the effectiveness of this system is weighted heavily on the operation of the SOP subsystem which relies on the worker's input of hazardous chemicals usage to the system [4]. In the event of ignorance, accident or misdemeanor, the system may be kept from the facts and the administrations are blinded to make correct decisions.

To eliminate the improper events of workers and shorten the response time of accidents, automatic sensing devices are therefore needed to improve the accuracy of inventory control of toxic chemicals. To better the monitoring of toxic chemicals, the devices should be designed to work around the clock to assure the safety of the chemicals. Considering the different storage requirements of chemicals and waste in a laboratory, the wireless sensing technique is chosen to facilitate the implementation of the automatic sensing device. However, wired option should also be reserved for chemicals stored in the refrigerators or special containers.

The most important issues of all inventory control systems are identification and usage. Other than the human operations, the best candidates are RFID and Image Recognition technologies. Image recognition was originally designed to utilize the IP cameras installed in the first phase of this GHS-based system, but soon it was found infeasible to identify the chemicals among other similar items [12]. Because the resolutions of image taken by the IP camera, it cannot provide enough details for image recognition. Even with the help of the pitch-zoom-tilt (PZT) camera, it is still rendered impossible to identify the labels or bar codes on the chemical bottles, not to mention the tiny alphabets on the label. This approach also requires all the bottles positioned with proper orientation to enhance the image. Otherwise, the captured image could be redeemed useless. This neatness is not easy to maintain without harsh training. To make it worse is that the labels have to be aligned with the camera line-of-sight to obtain the whole image which still comes with distortion because of the shape of the bottle. Even if all the physical problems can be overcome, the accuracy of image recognition may come with a tolerance.

On the other hand, the RFID can distinguish items accurately within an adjustable distance. The RFID tag reader is available for commercial application and the range can be adjusted from tenths of inch to yards. However, if the range is large, multiple tags can be accessed from one reader. For the inventory control of toxic chemicals, the RFID technology can only identify the existence of an item, a container in this study, but not the content of it. Considering the little consumption rate of the toxic chemicals, using only RFID does not meets the needs. An auxiliary tool must to accommodate the identification with measurement of contents. Therefore, the concept of combining the RFID, weight-measurement, and wireless sensing technologies emerges to provide the identification and weight for each chemical. The proposed design is to integrate a RFID reader, a load cell for weight measurement with the wireless communication into one device as shown in Figure 2. This device not only can display the identification and weight of the chemical container on the device, but also can upload the information to the laboratory computer or the remote administration server, such as the existing GHS-based intelligent management system via internet.

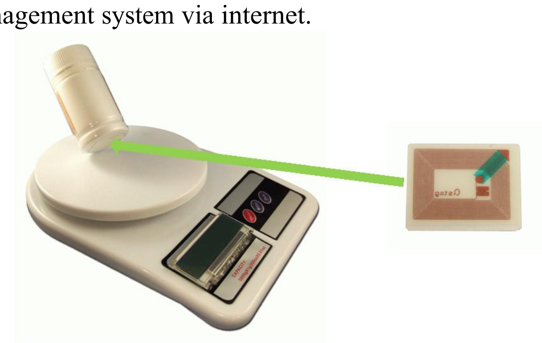

Fig. 2 Proposed RFID and wireless sensing system device

The proposed device can be designed to passively answer the polling from the management server or to actively update the information whenever changes. If works actively, the device can update information instantly when the container is removed from the device or when the content is changed unreasonably. Otherwise, if works passively, the periodic polling of all-of-same-kind devices in a laboratory should be done within minutes to keep all the inventory data as most recent as possible. The proposed system architecture is shown in Figure 3.

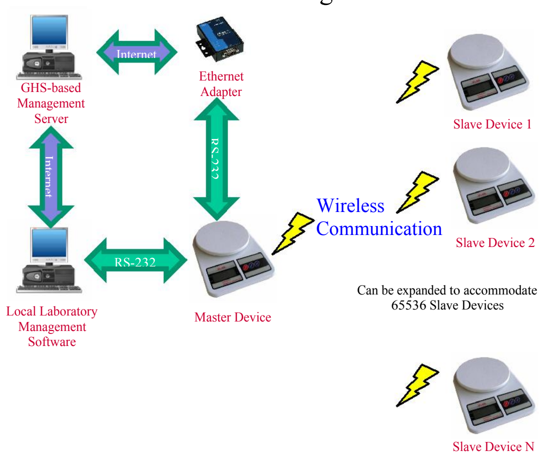

Fig. 3 The automatic RFID and wireless sensing system hardware structure

III. DESIGN OF THE AUTOMATIC RFID AND WIRELESS SENSING DEVICES

To realize the concept discussed, the design of this sensing device must consider the industrial standards for radio frequency as well as the requirements of the GHS-based intelligent management system.

At the system level, a master device is designed as an interface or bridge between the laboratory computer /administration server and all the slave sensing devices. With the wireless communication protocol, the master device can collect information from all slave devices located at different sites in a laboratory. Each slave device has equipped an ISO15693 standard RFID reader, a load cell with measuring range of 500 grams or 5 Kilograms for monitoring chemicals or waste respectively, a temperature sensor, a LCD display, LEDs, a buzzer, a ISM standard wireless communication module, and an ARM-7 processor to handle all the required operations in the slave device. The structure and prototype of the slave device is shown in Figure 4 and 5. With the above modules, the slave device can obtain the identifications, weight, and surrounding temperature of the chemicals and waste. The workflow of a slave device is shown in Figure 6. The collected information can be displayed locally on the LCD display and/or transmitted to the master device wirelessly. Sound or light warning can be asserted by the buzzer or LEDs locally to alert the worker for possible mistakes or misconducts.

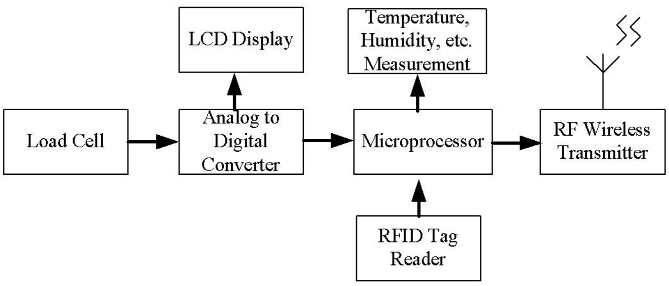

Fig. 4 Functional blocks in the slave device

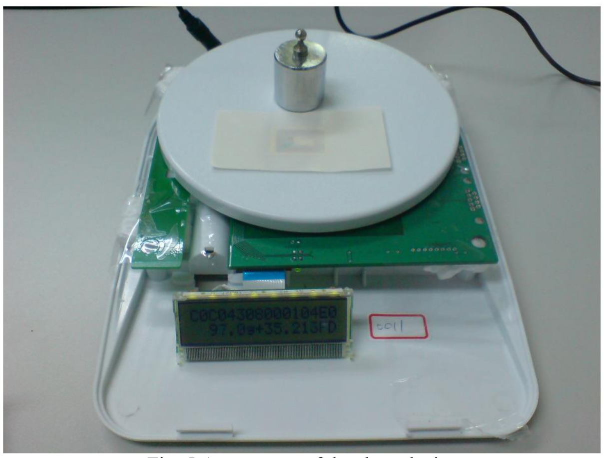
Fig. 5 A prototype of the slave device

At another end, in addition to all the capability of the slave device, the master device is equipped with communication modules as a bridge between server and slave devices. Moreover, the master device can also serve as a registration or checking station when items are imported or disposed. Depending on the machine connected, the master device can equipped with Ethernet, UART, or CAN bus module for communication. With the Ethernet, or CAN bus communication protocols, the master device can communicate with thousands of slave devices in the systems and thus provides the management system access to monitor numerous hazardous chemicals in the laboratory on site or remotely via internet. With proper setting of these devices, the system can also serve as a security system of hazardous chemicals for better safety assurance of the organization. Implementation of a master device connected to a laboratory computer is shown in Figure 7. And testing information displayed on the screen is shown in Figure 8. The workflow of the master device is shown in Figure 9.

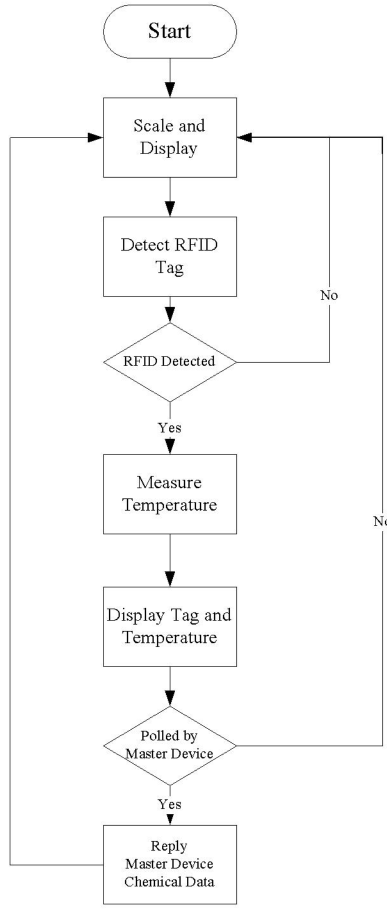

Fig. 6 Work flow of the slave device

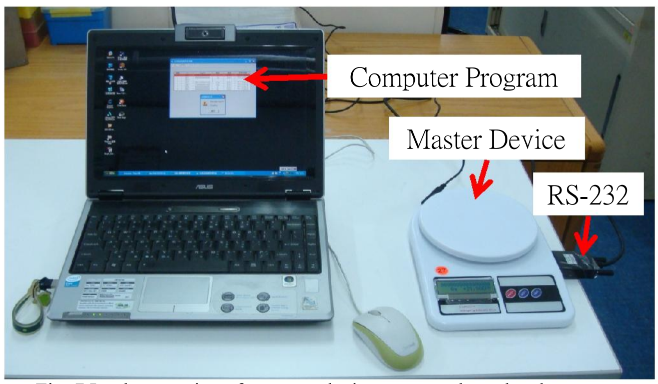

Fig. 7 Implementation of a master device connected to a local computer

With aid of the automatic devices, the operations of SOP subsystem can be dramatically simplified. Without proper user log-in approved by the system, any movement or change of monitored chemicals will be recorded and alarmed to the management right away. Report should be filed and reviewed to correct this misbehavior. In case of any warning caused by accidents or misdemeanors, the system can respond right away to prevent or lessen the possible damages and can also provide the handling information of related chemicals automatically on the intelligent e-platform. With authorized log-in, the worker does not have to enter the usage of the chemicals individually since the system can automatically identify all the chemicals taken from their storage spots. At the worker's log-off, the intelligent system will summarize all the properly restored chemicals for worker's verification.

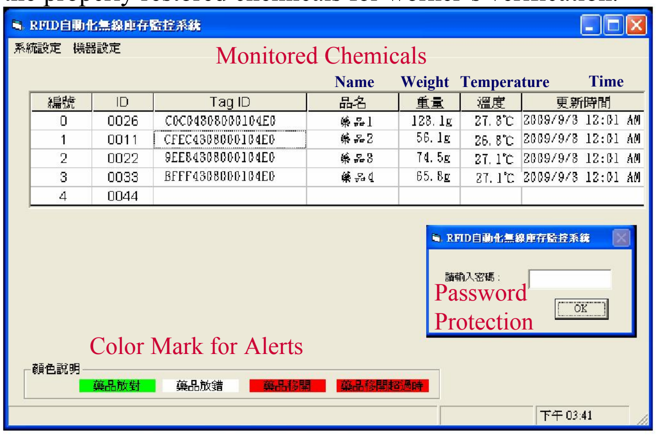

Fig. 8 Information collected and displayed on a local computer

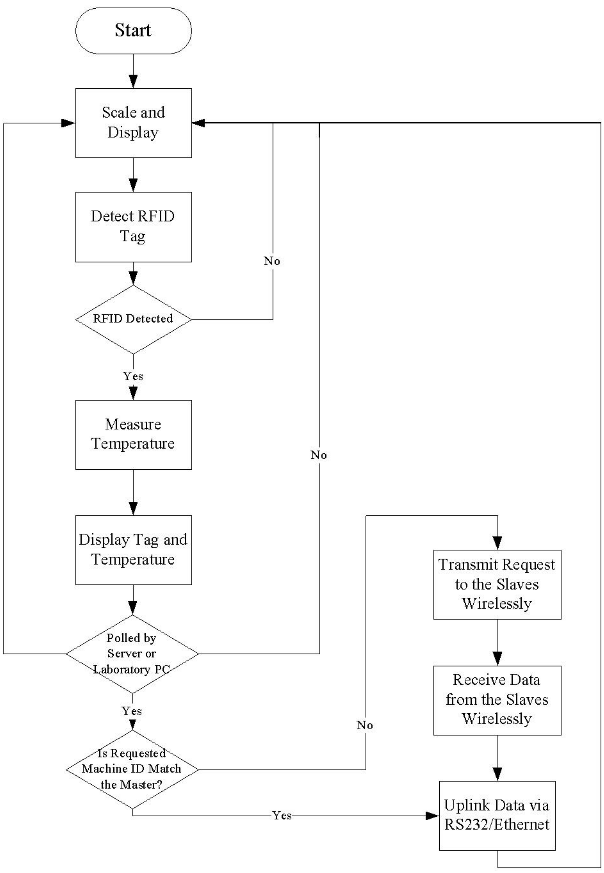

Fig. 9 Workflow of the master device

The system can also warn the worker for missing chemicals, if any, to search and secure the missing ones. Inappropriate log-off will be identified by the system and correcting action should be filed and reviewed by the administration. Changes of the toxic waste are also monitored and can be analyzed with respect to the usage of chemicals. Therefore, unreasonable disposal of the toxic waste can also be identified to protect the organization from workers' ignorance or misconduct of illegal disposals.

IV. IMPLEMENTATION

When the developed system is deployed in the laboratories on campus, for the different needs of operations, the system is programmed in two modes,

A. Single Device, i.e. One Master device only, and

B. Multiple Devices, i.e. Master & Multiple Slaves.

For laboratories which do not have hazardous chemicals, only one Master device is installed so that operators can renew the inventory of chemicals at a required period. To update the information, operators simply open the computer program and put the container of chemicals on the platform of the device, as shown in Figure 10, the weight, RFID tag and other information will be sent to the server automatically when the device beeps. Once this easy procedure is repeated for all chemicals in the laboratory, the server will received all the most up-to-date inventory records.

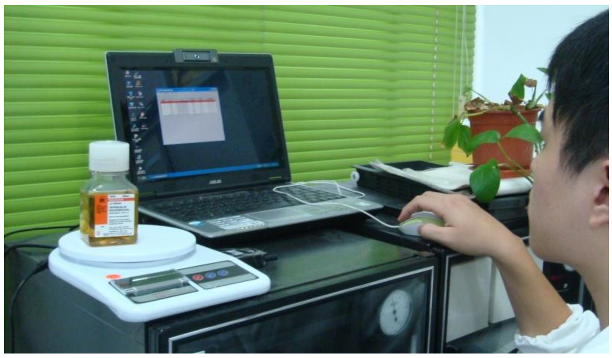

Fig. 10 Operation of the single master device mode

For those laboratories which have toxic or hazardous chemicals need to be monitored all the time, the multiple device system is implemented to assure the safety around the clock. Each subsystem in a laboratory consists of one master device and 4 slave ones, as shown in Figure 11. To accommodate the future expansion, the database and wireless protocol are designed to take up to 65536 slave machines. Each slave device is also designated a machine ID so that the management system can track its location. The system can read the RFID tag number without interference to neighboring devices, measure the temperature, and sense the current weight of the chemical within the designed range with resolution of 0.1 gram. The wireless communication has been tested for its durability and stability, which is capable of delivering data within 50 meters for weeks without interruption. The scanning time for 1000 slave devices is less than 200 seconds. The measurement data can also be displayed on the slave's LCD, where the upper row is the unique RFID tag number with the weight and temperature displayed in the lower row.

Because the slave devices are designed to be distributed arbitrarily in the laboratory, to avoid the nuisance from the radio wave of other slave devices, the power rate and range of the RFID readers are adjusted to detect tags within a few centimeters. As the result, there is no interference observed when devices are implemented side-by-side. Although water or liquid has been known to be a factor for RFID tag reading, the tests in this study show that the applied RFID reader can successfully identify the tag, which is located at the bottom of containers.

Fig. 11 Implementation of the multiple device system in the storage cabinet

With a master device connected to a laboratory computer or an Ethernet adaptor, the polling request can be sent via the master device wirelessly to the slave ones. To communicate with the server of administration office at a remote site via Internet, the master device has equipped with an extra RS-232 port, such that it can be connected to the Ethernet adapter. The slave devices will respond with the monitored chemicals information and collected by the master device wirelessly, which will be processed and shown on the local computer periodically to update the most recent status of monitored hazardous chemicals and waste. The program interface can display information of those monitored chemicals for local laboratory review. The administration office can inquiry any chemical in any laboratory at any time and obtain instant response in real-time. The administrator can check the history of chemicals inventory from anywhere via a Web-based interface as shown in Figure 12.

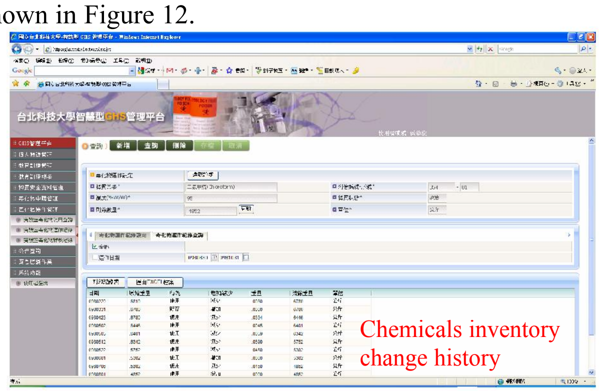

Fig. 12 Web-based interface for chemicals inventory review

In addition, the temperature sensor integrated can be used to monitor the storage condition of the chemicals as well as the potential fire accident. Various sensors can also be attached to the device upon request to monitor the environmental factors, such as humidity, light, etc. The device can even be connected to the security sensors, such as proximity or infrared sensors to alarm the management system if no authorized activities on the critical chemicals take place. All these information can be transmitted to the server for monitoring and recording wirelessly and via internet.

V. CONCLUSIONS

The developed intelligent wireless chemical inventory control system using RFID and wireless sensing technologies has automated the inventory identification and measuring processes. With this automatic system, not only the usage of all the hazardous chemicals can be recorded without human input, but also the security of them is monitored all the time. The developed system has eliminated the human operations in the inventory system and can measure the varying quantities of the chemicals in the container. This system also provides the administration a real-time accessibility to the inventory control so that the safety and environment protection of the operating sites can be assured. The wireless networking also simplifies complicate implementation and provides flexibility of chemical storages.

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