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ORIGINAL ARTICLE

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Smart sensing for laboratory safety management

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ABSTRACT

The safety management of university laboratories is an important prerequisite and foundation for achieving normal education, teaching, and scientific research among teachers and students in universities. It is necessary to always keep laboratory safety management in mind. The safety management of university laboratories involves different majors and disciplines, with strong professionalism and complexity. Smart sensing is the key to achieving dynamic real-time visualization, transparency, and traceability of various experimental elements, such as hazardous reagents, experimental equipment, and experimental operators, in the safety management process of university laboratories. As an example, a smart sensing scheme for laboratory hazardous chemical reagents with capacitive liquid level has been proposed in this paper. It has combined the theoretical knowledge of smart sensing with practical safety practices, such as hazardous chemical reagents in the laboratory, to achieve the design of a complete sensing system, relying on open-source and easy-to-use software and hardware systems to assist in the rapid development and implementation of sensing system design and implementation, improve theoretical practice and application efficiency, and assist in laboratory security management practice exploration. It could lay the foundation for the integrated application of real-time dynamic traceability and visualization of laboratory safety management information in the future.

KEYWORDS

Smart sensing; Laboratory safety; Hazardous chemical reagents; Liquid level

ARTICLE HISTORY

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Introduction

The safety management of university laboratories is an important prerequisite and foundation for achieving normal education, teaching, and scientific research among teachers and students in universities [1-3]. It is necessary to always keep laboratory safety management in mind. The safety management of university laboratories involves different majors and disciplines, with strong professionalism and complexity. There are problems with the visualization, transparency, and traceability of laboratory management processes, such as incomplete coverage of management processes, difficulty in tracing the use of hazardous chemical reagents, experimental equipment, and other elements, and incorrect identification of operators. The information technology greatly simplifies the recording and tracing of personnel, reagents, and equipment information in traditional laboratory management processes, improving operational efficiency and facilitating experimental management levels [4-6].

However, the current laboratory safety management information system is more limited to static information records of laboratory chemical reagents, experimental equipment, operators, and other experimental elements in the laboratory management process, and most of them require manual input. The real-time dynamic updates and reflection process data, such as personnel changes, equipment updates, and hazardous chemical reagent usage involved in the experimental process, could not be achieved. There are numerous safety hazards in laboratory safety management, which greatly increase the visualization, transparency, and traceability in the process of laboratory safety management. Therefore, effectively integrating smart sensing technology to achieve dynamic experimental element information in the laboratory management process is an important means to achieve full management of laboratory processes, full correspondence of experimental personnel, full dynamic visualization, transparency, and traceability of various elements such as experimental chemistry and equipment, and organic integration with national safety production construction.

The research on laboratory management in international universities has been ongoing, but due to the complexity, fluidity, and process opacity of laboratory management itself, the overall level and quality of management in many laboratories are not very high. The laboratory management could generally be divided into two categories: traditional manual management and information system management.

In terms of traditional laboratory management, it still relies more on a dedicated person-responsible model. Starting from the overall function of the laboratory, it is responsible for the systematic management of fixed or experimental assets such as experimental equipment, consumables, and reagents, as well as the daily registration and management of laboratory users [7-9]. This traditional management method requires manual recording or registration by laboratory management personnel. From the perspective of management effectiveness,

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it could achieve a comprehensive management of the laboratory and achieve some detailed records. However, from the perspective of manpower and overall management efficiency, its management level is relatively backward, and more depends on the diligence of the management personnel themselves, Moreover, manual recording methods could easily lead to issues such as data loss, which is not conducive to the long-term management needs of the laboratory.

In terms of information laboratory management, due to the efficiency and level issues of traditional manual laboratory management methods, the researchers have begun to focus on replacing traditional manual management with information system laboratory management [10-14]. Information system laboratory management refers to the use of computer technology, information communication, and other technologies to achieve electronic information recording and management of the laboratory management process and to display and record traditional paper or manually recorded information through database storage and other methods. This information-based laboratory management greatly improves the efficiency and level of traditional manual management and is more conducive to long-term management and traceability of the laboratory. It also facilitates the implementation of remote management and other functions.

Current research on information laboratory management focuses more on how to achieve electronic ledger records, personnel management, and laboratory asset information management. Many of these information requires system administrators to manually input the system and manually update relevant data in real-time. Data management relies on regular updates and inputs, and more management is focused on static laboratory information, which has issues with real-time updates, and precisely because it is manually entered, there are inevitably issues such as human error and falsification. On the other hand, laboratory management more involves the management of large laboratory equipment and laboratory reagents, especially hazardous chemical reagents. The operating status, usage, and inventory of equipment are important for laboratory management, and this data management information could not be dynamically and transparently updated and traceable in existing research information management systems.

Smart sensing is the key to achieving dynamic real-time visualization, transparency, and traceability of various experimental elements, such as hazardous reagents, experimental equipment, and experimental operators in the safety management process of university laboratories. Smart sensing refers to the use of advanced smart sensing technology, combined with advanced communication methods such as wireless technology, to achieve real-time sensor information of objective parameters such as physical quantities, chemical quantities, and biomass during human activities [15-20]. It has the characteristics of automation, intelligence, and visualization.

Therefore, it is more important and practical to achieve real-time dynamic updates, automatic storage, and more transparent and visualized management of various laboratory elements in the laboratory management process, especially in universities. This will also become an advanced technology in the future laboratory management process that integrates visualization, intelligent perception, and other advanced technologies to achieve automation, intelligence, and transparency visualization and its management are important development trends that could be traced.

As discussed above, as an example, the smart sensing scheme for laboratory hazardous chemical reagents with capacitive liquid level has been proposed in this paper. The paper includes the scheme background, implementation conditions, the system design and implementation process, and the experimental principles of the scheme.

Scheme Background

The smart sensing system fully utilizes sensors, analog and digital electronics, as well as microcontroller technology to solve the real-time dynamic update, automatic storage, and more transparent and visual management of various laboratory elements in the management process of real laboratories, especially university laboratories, in addition to basic static information. The system needs to use commonly used sensor detection, analogy-digital conversion and other signal conditioning, microcontroller signal processing technical methods of wireless transmission and display. It involves various aspects such as electronic system software and hardware design, system integration, and testing basic concepts and technologies. The system utilizes simple and easy-to-use Arduino open-source software and hardware, based on capacitive liquid level sensors, to design and implement a capacitive liquid level smart sensing system for laboratory hazardous chemical reagents.

Implementation Conditions

The implementation requires experimental resources, including:

1) Capacitive liquid level sensor module.
2) Arduino Bluetooth main control module.
3) Arduino integrated development environment.
4) Arduino Bluetooth demonstration mobile application.
5) Connect cables.
6) Chemical reagent bottles for liquid-level detection experiments.

System Design and Implementation Process

This solution process is a relatively complete engineering testing case, using Arduino open-source software and hardware to design and implement a capacitive liquid-level continuous sensing detection system, which specifically includes:

1. Connecting a capacitive liquid level sensor module with a capacitive analog-to-digital conversion chip as the signal acquisition and conversion input.
2. Connecting the Arduino Bluetooth main control module to the capacitive liquid level sensor module through the I2C bus for data acquisition and processing of liquid level sensing signals.
3. Writing programs for capacitive liquid level sensing data collection and Bluetooth wireless transmission through the Arduino IDE integrated development environment, and downloading them to the Bluetooth main control module for debugging.
4. Installing the Arduino Bluetooth demonstration mobile

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app onto the phone and connecting it to the Bluetooth main control module.

5. After completing hardware design, testing, and softwaredebugging, conduct overall functional testing of the detection system.
6. Placing the sensor outside the actual water cylinder or cup container, calibrate the initial and final liquid level positions of the capacitive liquid level sensor, and compare them with the actual liquid level situation to complete the measurement and error analysis of the liquid level.

Experimental Principle

Overall system architecture

The overall diagram of the liquid-level sensing system is shown in Figure 1. The overall system includes liquid-level sensor modules, sensing signal conditioning, processing, wireless transmission, and data display modules. Each module is connected and communicates with each other, ultimately completing the collection, conditioning, processing, transmission, and display of capacitive liquid level sensor data information.

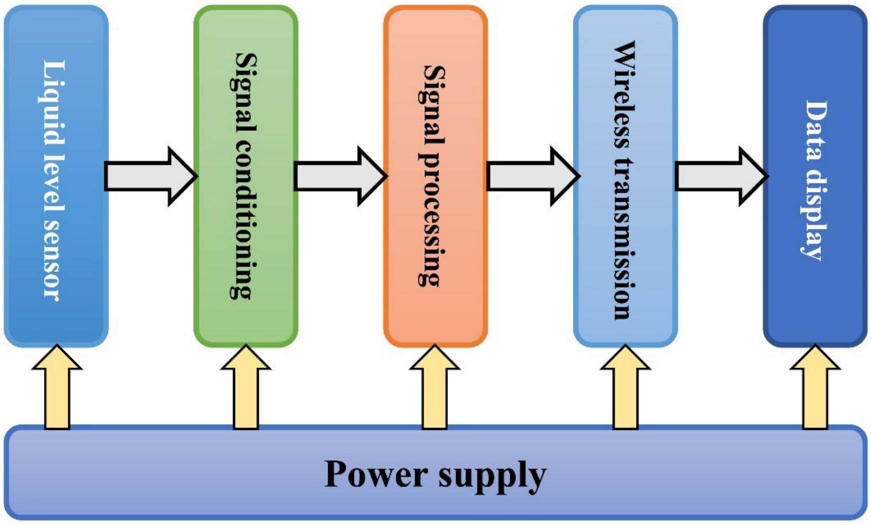

Figure 1. System architecture.

Principle of liquid level sensor

The liquid level sensor module is based on the principle of capacitive sensing measurement, and the sensor uses a TM601AWLCOR multi-channel capacitive sensing chip, which can serve as a controller for continuous liquid level detection. Calculate the corresponding liquid level height by detecting the changes in sampling values of different channels when the liquid level is at different heights.

The liquid-level sensor module needs to be tightly attached to the outer wall of the non-conductive container. When the liquid passes through the capacitor plate, it will cause a change in the dielectric constant of the capacitor, causing a change in the capacitance and detecting the position of the liquid. The capacitance (C) detection is shown in the following formula.

$$C = \frac{\varepsilon_0 \varepsilon A}{\sigma}$$

where A is the area (m²), $\varepsilon_0 = 8.85\times10^{-12}$ (F/m) is the vacuum dielectric constant, ε is the dielectric constant of the medium between the electrodes, when the medium is air $\varepsilon = 1$, σ is the distance between two plates (m).

The physical implementation and hardware circuits of the sensor module are shown in Figures 2 and 3.

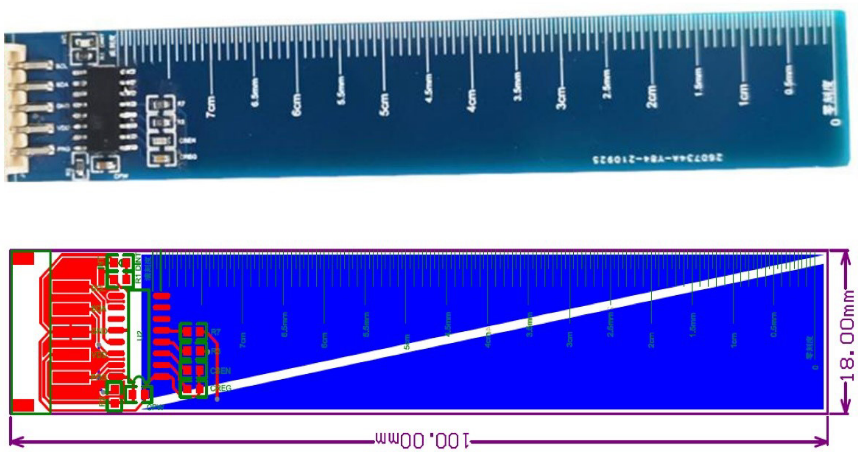

Figure 2. Physical implementation of the liquid-level sensor.

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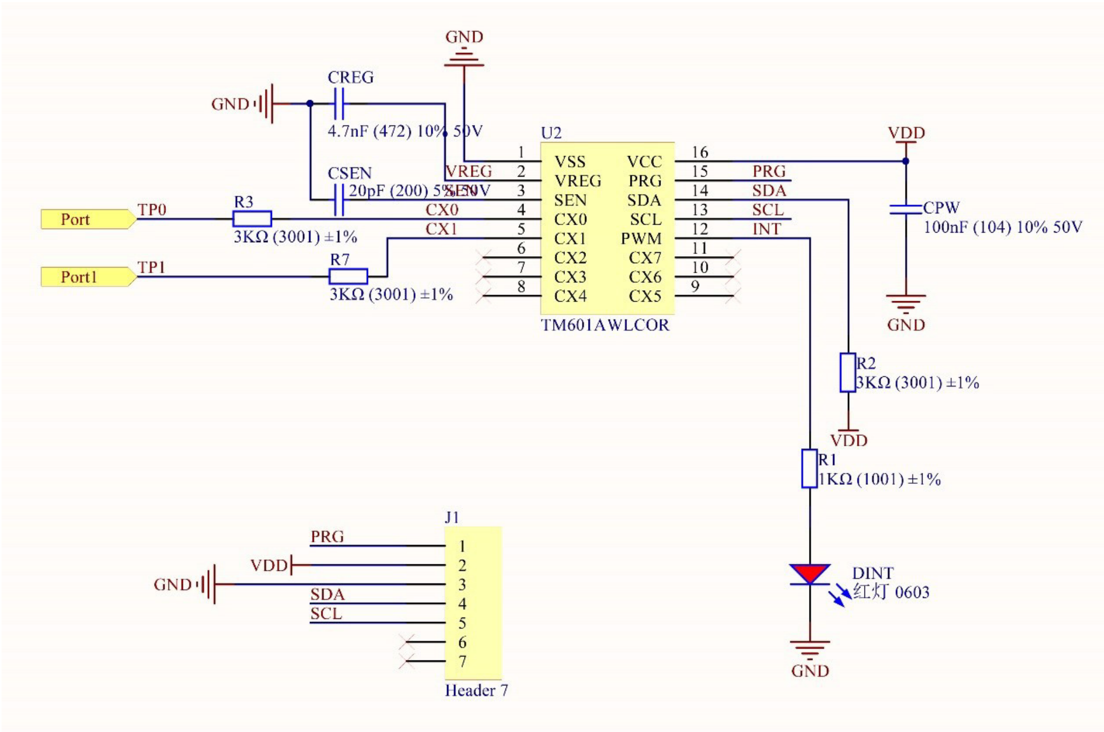

Figure 3. Hardware circuits of the sensor module.

Liquid level sensing

The liquid level sensor needs to be calibrated before use, and the calibration is carried out through a specific calibration board (as shown in Figures 4 and 5). The sensor calibration is carried out as follows.

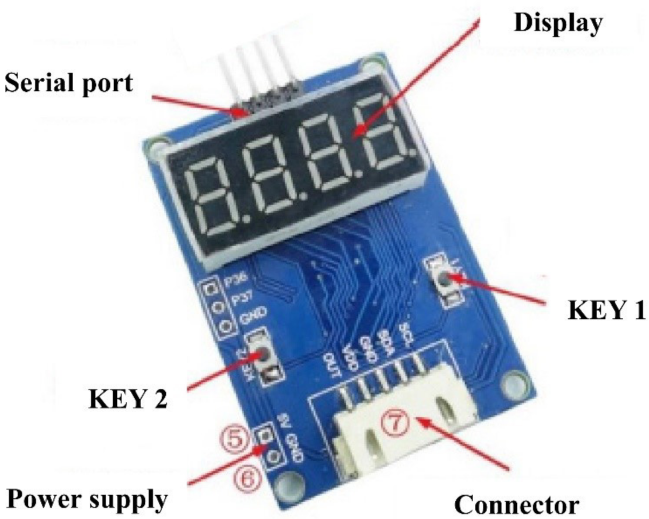

Figure 4. Calibration board.

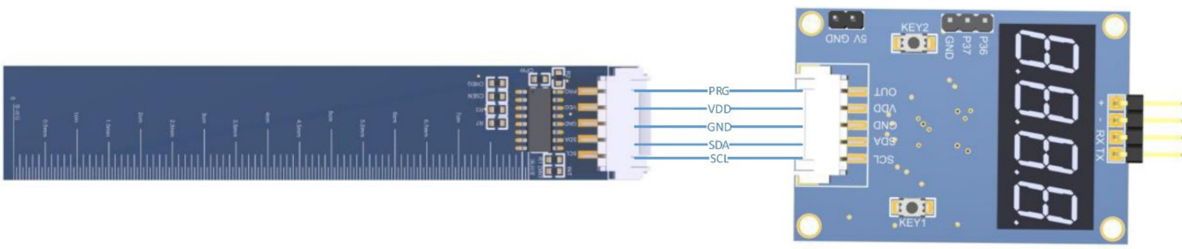

Figure 5. Calibration of the liquid level sensor.

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1. Firstly, the sensor module is tightly attached to the outer surface of the tested container or chemical reagent bottle.
2. Connecting the calibration board to the sensor module. Empty the water in the container and press the KEY1 button once to set and record the empty water status. At this time, the control board reads the threshold and writes it into the chip. At the same time, perform liquid-level detection calculations according to the new threshold. After pressing the button, the digital tube displays the number 1. If the above operation is successful, the digital tube will flash 3 times, and if the operation fails, the digital tube will flash 6 times.
3. Adding a small amount of water, raise the liquid level to the 0 mark, and continuously press the KEY2 button twice. At this time, the control board reads the threshold and writes it into the chip. At the same time, the liquid level is detected and calculated according to the new threshold. After pressing the button, the digital tube displays the number 2. If the above operation is successful, the digital tube will flash 3 times, and if it fails, the digital tube will flash 6 times.
4. Adding water, raise the liquid level to the full scale, and continuously press the KEY1 button 3 times. At this time, the control board reads the threshold and writes it into the chip. At the same time, press the new threshold for liquid level detection and calculation. After pressing the button, the digital tube displays the number 3. If the above operation is successful, the digital tube will flash 3 times, and if the operation fails, the digital tube will flash 6 times.

After calibration, the liquid level sensor is connected to the Arduino main control microcontroller (MCU) for data collection and transmission. The sensor module communicates with the microcontroller through the inter-integrated circuit (I2C) bus (as shown in Figures 6 and 7). During the period when SCL is high, SDA must maintain a stable level. The high and low-level changes of SDA can only occur during the low-level period of SCL. The sensing data consists of 8 bits of data and 1 response signal. The specific programming can refer to the Arduino IDE open-source software and programming implementation to complete the design and implementation of the detection system. The programming interface is shown in Figure 8.

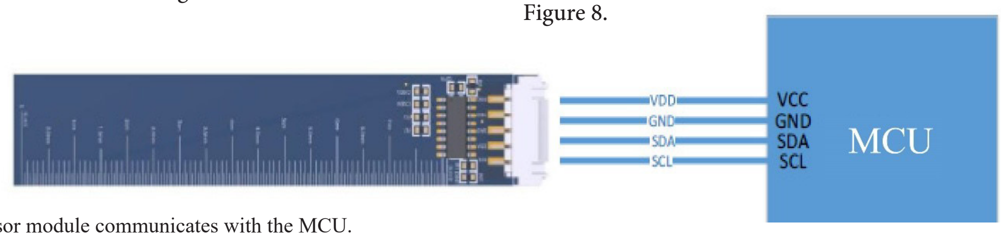

Figure 6. Sensor module communicates with the MCU.

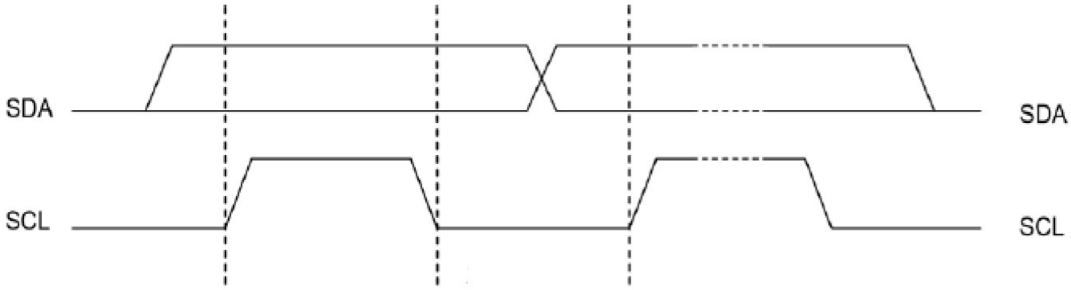

Figure 7. I2C timing diagram.

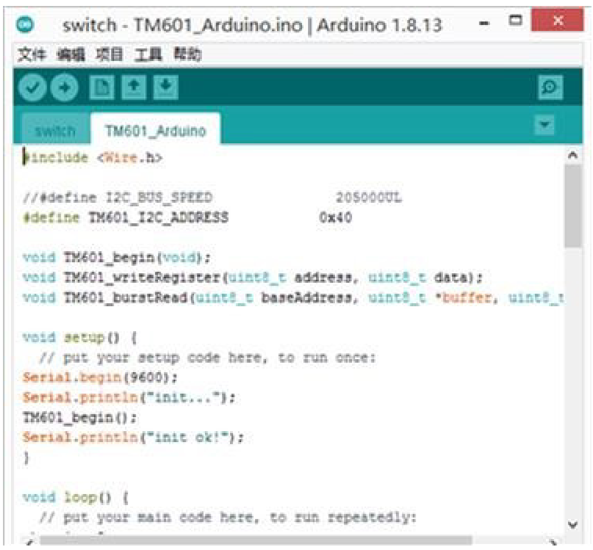

Figure 8. Arduino programming interface.

Conclusion

This paper has proposed a smart sensing scheme for laboratory hazardous chemical reagents with capacitive liquid level as an example of laboratory management. The scheme has the features and innovations below.

1. Combining the theoretical knowledge of smart sensing with practical safety practices, such as hazardous chemical reagents in the laboratory, to achieve the design of a complete sensing system.
2. Relying on open-source and easy-to-use software and hardware systems, assisting in rapid development and implementation of sensing system design and implementation, improving theoretical practice and application efficiency, and assisting in laboratory security management practice exploration.
3. To present the integration process of the sensing system in an intuitive and immersive visual manner, laying the foundation for the integrated application of real-time dynamic traceability and visualization of laboratory safety management information in the future.

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The smart sensing system has combined the theoretical knowledge of smart sensing with practical safety practices, such as hazardous chemical reagents in the laboratory to achieve the design of a complete sensing system, relying on open-source and easy-to-use software and hardware systems to assist in rapid development and implementation of sensing system design and implementation, improve theoretical practice and application efficiency, and assist in laboratory security management practice exploration. It could lay the foundation for the integrated application of real-time dynamic traceability and visualization of laboratory safety management information in the future.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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