Automatic water quality arsenic element detection device based on internet of things

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Abstract. Arsenic contamination in groundwater is an outcome of anthropogenic or natural sources. The determination of arsenic in water is of crucial importance. Therefore, a portable and integrated device is designed for arsenic detection. Based on ESP32-cam, the reaction is proceeded in automation, accompanying colorimetric detection of copper sheet. Therefore, information concerning the concentration of arsenic will be received by people through the Internet.

1. Introduction
Reported by the website of the World Health Organization (WHO), “Long term exposure to inorganic arsenic, mainly through drinking-water and food, can lead to chronic arsenic poisoning. Skin lesions and skin cancer are the most characteristic effects.” It is indicated that exposure to arsenic is linked to a negative influence on people’s health. As the intake of arsenic compounds by people mainly through anthropogenic usage of water in irrigation, food preparation, and drinking, the detection of arsenic poses crucial status.

The development in the exploration of arsenic manifests in specifics methods for arsenic detection. Generation of color through the reaction of Arsine gases with mercuric bromide (KIT-1) or silver nitrates (KIT-2) is detected by paper strips, forming Low-cost Field Test Kits.

Figure 1. Low-cost Field Test Kits.

As the exploration in science proceeding, current technology, such as inductively couple plasma (ICP) MS, atomic fluorescence spectroscopy (AFS), allows the detection of arsenic below 10 ppb. Less time-consuming, cheaper, and simpler methods are being researched. A special biosensor
composed of AuNPs, controlled by a cationic polymer and an Ars-3 aptamer, could conveniently distinguish arsenic.

![Figure 2. Atomic fluorescence spectroscopy (AFS).](image)

Based on the experience of former researchers, chemical indicators for arsenic concentration are formed by the reaction of arsenic compounds, stannous chloride, and acidic solution. Colorimetric detection as the direct determination of arsenic distinguishes the change in color of a copper sheet. The whole device for arsenic detection accomplishes the automation of chemical reaction and monitoring.

2. Experimental scheme

2.1. Problem restate
High-concentrated arsenic (As) mainly exists in industrial wastes and seafood, causing skin, urinary bladder, and kidney cancer. As arsenic is highly toxic in its inorganic forms, it’s a potential health threat to people. One of the effective solutions is to detect arsenic concentration in water. Detection of arsenic and its oxides in sample water based on Reinsch test. Automatic testing of arsenic is accomplished by the combination of mechanical and electronic technology. Besides, the portability of the integrated device for arsenic detection enables its feasibility even in remote regions. In conclusion, a portable and integrated apparatus for the determination of soluble arsenic and its compounds is structured.

![Figure 3. Reinsch test.](image)

2.2. System structure
Based on chemical reactions, the process for accessory operation follows in sequence. Get a water sample in the beaker and place it at the designed position. Servo 1 motivates the cart-style feeding device by rotating 90 degrees back and forth, dropping 0.5 grams of stannous chloride into the solution.
In the meantime, the peristaltic pump works to add 5 milliliters of concentrated hydrochloric acid into the sample. Relay controls heater to work until the solution reaches the state of slightly boiling. After maintaining the condition of slightly boiling for 10 minutes, servo 2 rotates the circle-shaped plate to drop two pieces of copper sheets into the solution, leaving them to react with arsenic compounds for 20 minutes while keeping the solution slightly boiling. During this period, another peristaltic pump provides water to maintain the water level as long as the level drops below a certain height. After 20 minutes’ reaction, the copper sheets are elevated out of the solution through the rotation of the steering wheel which connects with high-tube filter by nylon rope. Being photographed and monitored by the ESP32-cam, the photo is uploaded and displayed on the screen. People can distinguish the color change of copper to determine the concentration of As.

3. Physical design
Mechanical design functions mainly for reagent supply. Mechanical components in the system for raw materials are classified by their physical properties.

3.1. Cam-structured feeding device for quantitative delivery
Stannous chloride (SnCl₂), one of the reagents, is in the form of solid powder. In order to be quantitatively delivered, a square groove with a push-pull structure enables continuous and precise acquirement of SnCl₂. To prepare enough stannous chloride for multiple experiments, a sealed cube box with an openable cover is built. The whole structure is made with a tenon-and-mortise structure to enable convenient build-up.

![Figure 4. Schematic diagram of quantitative delivery device.](image)

A cam-structured feeding device allows horizontal movement of the rectangular-shaped plate with a square groove. Steering wheels and elastic rubber bands function as motivation and limitation of the plate’s movement and its range. As the servo is installed vertically, the steering wheel push the plate to move back, which is against the force of elastic rubber bands. As the plate moves to its extreme, it moves in the opposite direction following the elastic force. Besides, a cube box works as a container for stannous chloride, making multiple experiments more convenient. With an openable lid on the top of the cube box, not only can this structure facilitates the supplement of reagent, but also ensure a hermetic seal.

3.2. Spiral feeding device
Since the thickness of copper sheets is difficult to measure precisely, two pieces of copper are placed in each square groove. By the rotation of the steering wheel, each square groove is aligned with the feeding port. The rotating compartment with six square grooves is in the shape of a concentric circle, leaving space for the steering wheel to smoothly rotate. Through misplacement of grooves and fixed-angle rotation, the copper sheets could be quantitatively delivered and added.
Figure 5. Schematic diagram of rotary copper sheet delivery device

Copper is delivered by the rotation of steering wheels. The average size of copper sheets is 6.38 mm×5.70 mm, thus designing square grooves for supply and delivery with 11 mm×8 mm. The whole installation consists of three layers. The first layer is for the fixation of servo and a slot for the copper supplement. The size of the notch is 1 mm×3 mm larger than that of the second layer, for it could prevent the failure of copper supply when notches are not precisely aligned. Six square grooves are placed on the second layer, motivated by steering wheels. Considering limitations on the rotating angle of the servo, six square grooves are distributed on a semicircle with a radius of 45 millimeters, 36 degrees to each other. With a same-sized plate covering it, the copper on the second layer could be in a sealed space, avoiding oxidation. As the servo is limited to rotate at a range of 0 degrees to 180 degrees, all of the grooves are designed in a semicircle. The purpose of the final layer is to deliver two pieces of copper at a fixed point. The square slot is 36 degrees from that of the first layer, although in the same size. This deviation enables an in-time supplement of copper as soon as the copper is consumed. As a whole, three layers of circle plates are fixated by four isolation columns, controlled by the programming on the corresponding pin on a single chip microcomputer.

3.3. Swivel lifting structure
To take out copper sheets as the reaction ends, it is imperative to place the copper in a liftable device. By rotating to change the length of the nylon rope in the vertical direction, the swivel lifting structure indirectly elevates a high-tube filter containing copper. Specifically, as the steering wheel rotates, the nylon rope, which connects the servo and the filter, is pulled up, lifting the copper. Besides, to fix the high-tube filter with the servo, a concentric-shaped plate attaches nylon rope at four corners.

Figure 6. Schematic diagram of rotary rope lifting device.

3.4. Peristaltic pump
A low volume of reagent is required in the experiment, thus requiring a pump with a low flow rate. Compared with other pumps, the peristaltic pump with a slower flow rate is functional to an accurate measurement of input reagent. The peristaltic pump makes use of air pressure difference for drainage. When part of the hoses is pressed by scroll wheels, the solution is drawn into the hoses.
4. The whole frame
The physical structure of the overall structure is shown below.

5. Circuit Design and Programming
The schematic diagram of the circuit system is shown in the figure below, and the data flow direction is indicated by arrows, respectively, and the driving voltage is distinguished by different colors.

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**Figure 7.** Schematic diagram of peristaltic pump structure.

**Figure 8.** Overall structure.

**Figure 9.** Circuit diagram.
The program control flow controls each part of the device in order to complete the water quality detection experiment according to the experimental control sequence.

![Program control flow chart](image)

**Figure 10.** Program control flow chart.

6. Experiment

6.1. Experiment purpose

Verify that the device can detect arsenide and the effect of arsenide concentration.

6.2. Experimental process

First, mix 20ml distilled water with a certain amount of realgar. After that, add 5ml 37% concentrated hydrochloride acid with a 20ml solution, pouring them into a beaker.

Second, place the beaker with an asbestos net on a heater, and keep heating until the solution reaches slightly boiling.

Third, maintain the solution slightly boiling for 10 minutes, and then add two pieces of copper sheets into the solution, continuing to be slightly boiling for 20 minutes. Throughout the whole experiment, distilled water is added into the beaker as long as the liquid level drops below 20 ml.

Fourth, after 20 minutes, use a tweezer to take two coppers out of the beaker, placing it in a clean vessel. Observe the change of copper’s color, matching it to the standard color chart. Record all the data into a chart form.

Fifth, repeat the whole experiment with different concentrations of realgar or with distilled water. Record the concentration and the color change of copper. Compare data with one another.

6.3. Experimental result

The appearance of arsenic or arsenic compounds is able to change the surface color of copper sheets from red-orange to grey-black during the reaction. In an appropriate condition, the more concentrated
arsenic exists in the solution, the deeper the color of copper would be. Copper sheets do not change color or physical condition without arsenic in the solution.

Table 1. Three Scheme comparing.

| Numble | Realgar volume | Phenomenon                           |
|--------|----------------|--------------------------------------|
| 1      | 0              | No significant changes               |
| 2      | 5              | Blacken                              |
| 3      | 10             | Blacken                              |
| 4      | 15             | Blacken                              |
| 5      | 20             | Blacken                              |
| 6      | 50             | The color turns black and then part of the black solid peels off |

6.4. Experimental analysis
Under acidic conditions, displacement reaction occurs between copper and arsenic. Shown by the reaction, as compounds have been fully dissolved in acidic solution under slightly boiling conditions, reacting with copper. During the reaction, 37% of hydrochloride acid provides an acidic reacting environment, while stannous chloride serves as a catalyst, maintaining solution reducibility. After the reaction, the reacted as element adheres to the surface of copper sheets, changing the surface color from orange-red to grey-black.

7. Conclusion
The installation is for the automation of arsenic detection in water, achieved by the combination of mechanics structure, electronic circuit, chemical reactions, and programming. Divided into several devices, accessories, made by laser cutting technology, are constructed in mortise and tenon structure. The electronic circuit serves as the linkage among independent servos, pumps, and sensors, building the base for integration and automation. Two main controllers, Arduino and ESP32-Cam, transmit the programs into practical activities of devices. In the meantime, commands to devices are transformed into digital signals through programming, received by the devices. In conclusion, power motivates the devices which are in a designed structure and circuit while the motion of devices is controlled by programming.

However, some improvements could be made in the future if conditions available. Materials or devices with greater heat dissipation could be designed to replace the heater, such as semiconductors. Moreover, the structure of the device could be simplified and more integrated, facilitating portability.

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