Water Quality Testing Device by using Sensors and Image Processing Techniques

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Abstract*— Water quality testing is essential to ensure that the water is always safe to use. Most people are not aware of the water quality that is consumed and that is used. It is important to have a simple water quality testing device for people to detect the water quality easily. This is to ensure that the water is safe to consume and use. There are some powerful water quality testing device such as Rapid Adaptive Needs Assessment (RANA) Water Quality Kit and remote sensing water quality kit. These powerful water quality testing devices might be hard for average people to use and the results take some times. Hence, a simple water quality testing device is proposed, which is a water quality testing device using image processing techniques and sensors. The main components that are used to process the data are microcontroller and microcomputer. The microcontroller used is Arduino Uno, and the microcomputer used is Raspberry Pi Zero. The proposed water quality testing device has 2 mode, which are instant mode and continuous mode. Instant mode takes an image of test strip, and the microcomputer will run it through some image processing methods, such as colour conversion and perspective transform. Then, the test strip data is compared with the colour chart to obtain the water quality information. The water quality information is then saved to the device and a cloud database. For continuous mode, the water quality data is obtain from the sensors, and process in a microcontroller, then send to the microcomputer. The microcomputer is connected to a display, and the display are able to show the water quality information. The instant mode of the device is tested with 4 types of water, and the continuous mode is tested with 2 types of water. From the results, it is shown that both mode has successfully obtained the water quality information and the information is satisfactory. Other than that, it is shown that the instant mode data has successfully been saved into the device and cloud database, which is Google Sheet.

Keywords—Water Quality, Water Quality Testing Device, Image Processing, Perspective Transform, Colour Space Conversion, Sensors, Cloud Database

I. Introduction

A. Problem Statement

In most rural areas, the water quality is bad due to poor regulation of agriculture waste. The use of water and consumption of water with bad water quality can cause some serious issues. For example, consumption of contaminated water can cause disease such as diarrhoea and dysentery. Another example is that usage of hard water can cause dry skin on human.

B. Research Questions

What are the existing portable water quality testing kits or devices? What are the image processing methods can be used to determine the water quality?

C. Objectives

The objective of this project is to identify if the water quality is safe for usage and consumption. Other than that, it is to design a portable water quality testing device that is easy-to-use and reliable. Besides, the data of the water quality testing device can be stored in a cloud database.

II. Literature Review

A. Existing portable water quality testing device

1) Rapid Adaptive Needs Assessment water quality kit

RANA water quality kit is developed with the purpose of measure the water quality during the first 3 days after a natural disaster happened [1] It is developed by the Department of Defence (DoD) in the United States in 2011.

The kit is able to measure the temperature, turbidity, pH, dissolved oxygen and conductivity of water by deploy the kit on the water. Those water quality parameters are measured by using corresponding probes, and the probes might need calibration. The kit will record the water quality data to the built-in data logger for every 2 hours. The kit then uses a handheld device, such as smartphone, to send the data to a database by using Pre-positioned Expeditionary Assistance Kit (PEAK) telecommunication network.

RANA kit has a similar design to a water quality kit design by Cheny and others in 2005 [2]. The 2005 water quality kit designed by Cheny and others also uses probes and a handheld device, which is pocket personal computer (PC), to send the data. Even though both kit uses wireless technology to transmit data, the RANA kit is much better than the 2005 water quality testing kit because it uses telecommunication network, which can transmit data as long as the kit is within the network coverage instead of Bluetooth, which has short transmission distance.

2) Low Cost Water Quality Testing Device

This low cost water quality testing device is developed by Indu and Choondal in 2016 [3]. The purpose of this device is to raise the awareness and interest about water quality in general society, as the device is low cost.

The device can detect the pH, conductivity and temperature of water through corresponding probes. The analog values then go through an analog to digital converter (ADC), and then to the microcontroller. The microcontroller is connected to a screen, so the data will show on the screen.

Unlike the RANA kit, this lost cost device has no data logger, so the data shown on the screen is not saved anywhere. Other than that, the low cost device has no communication system, which means it is a stand-alone device and the water quality data cannot be export.

3) Remote Sensing Water Quality Kit

Remote sensing water quality kit is developed by Siam and others in 2019 [4]. This remote sensing kit is designed to be place inside the water reservoir of household. It is anticipated as an important part of futuristic smart city concept, as this device if an Internet of Things (IoT) device.

The remote sensing kit has a similar design with the previous low cost water quality device, as it uses several water quality sensors, such as pH, turbidity, conductivity and temperature. The sensors are connected to a multiplexer, and then connect to a microcontroller. The microcontroller then connect with a wireless fidelity (WiFi) module to send the water quality data to the cloud. User are able to view the data through website.

The reason that this remote sensing kit is anticipated as an important part in the smart city concept is it has the potential to grow into a reliable and efficient network, like the wireless network system proposed in 2017 by Nguyen and Phung [5]. In fact, a similar version of the system, which is an IoT based water quality monitoring system, is proposed by Jerom and Manimegalai in 2020 [6].

B. *Communication Protocols*

1) *Serial Peripheral Interface*

For Serial Peripheral Interface (SPI), there are 4 important communication pins, which are the serial clock (SCLK), master out slave in (MOSI), master in slave out (MISO) and slave select (SS). The biggest advantage of SPI is a master device can communicate with several slave devices [7].

One of the sample SPI is sample single master with several slaves. The SCLK and the MOSI signal is coming out from the master device to the slave devices. Other than that, the SS signal is also coming out from the master device to the slave devices, and it is used to choose the slave which the master wishes to communicate with. Meanwhile, the MISO signal is coming out from the slave devices to the master device. All the pins in SPI is unidirectional.

2) *Universal Asynchronous Receiver/Transmitter*

For Universal Asynchronous Receiver/Transmitter (UART), there are 2 communication pins, which are the Transmitter (TX) and Receiver (RX) [8]. The TX and RX are asynchronous. The TX and RX work at the same baud rate, where baud rate is the data transfer speed [9]. The baud rate of UART can be set, and the unit is bits per second.

There are 3 types of mode for UART, which are simplex, half-duplex and full-duplex. In simplex mode, only one pin is working. For half-duplex, either the TX pin or RX pin is working at a time. For full-duplex, both the TX and RX pin are working at the same time.UART are able to transmit and receive 8-bit of data, but the data is transmit and receive bit by bit serially [10].

C. *Image perspective techniques*

1) *Perspective Transform*

Perspective transform is an image processing technique that can transform an image from a 3 dimensional (3D) perspective into a good 2 dimensional (2D) perspective image. In other words, it can change the viewpoint of an image [11]. This technique is used in different fields, such as estimation of number of people in crowded scenes and road traffic sign detection [12] [13].

In order to apply perspective transform, 4 points need to be identified. These 4 points indicates the corner of an image. Other than that, the width and height of result image need to be identified too. Besides, a 3×3 transformation matrix is needed to convert the original 3D image into 2D image. The perspective transform equation are shown as below:

$$\begin{bmatrix} t_i x'_i \\ t_i y'_i \\ t_i \end{bmatrix} = map\ matrix \cdot \begin{bmatrix} x_i \\ y_i \\ 1 \end{bmatrix} \quad (1)$$

$$dst(i) = \left(x'_i, y'_i\right), src(i) = (x_i, y_i), i = 0,1,2,3 \quad (2)$$

The transformation matrix can be calculated by using the original points and the destination points. This technique can straighten a slanted and distorted image.

2) *Colour space conversion*

Colour space conversion is extremely useful when dealing with image in computer. This is because by converting the colour space from one to another, the raw meaningless data can be transform into useful data. Other than that, by changing the colour space, the image can be process easier [14].

a) Red, Green, Blue (RGB) to CIELAB

The CIELAB has 3 channels, which is the L* representing perceptual lightness, and a*b* representing the human perception of colours. According to Tseng and Lee, by converting RGB colour space into CIELAB colour space, it is easier for them to perform low light image enhancement.

Besides that, it is found out that the CIELAB colour space is good for colour analysis, such as colour acceptability decision making [15]. It is normally used in colour inspection of flat objects, such as cards and papers.

In order to perform change the image from RGB to CIELAB, the RGB is first convert to the CIEXYZ, then from the CIEXYZ to CIELAB. Fig.1. show the details calculation steps of RGB to CIELAB conversion.

b) RGB to Grayscale

RGB to Grayscale is another type of colour space conversion, where the 3 channel RGB colour are transform into 1 grayscale channel. By doing this conversion, the colour data of the image is abandoned, and in exchange, the size of the image has become smaller and the image process speed on the grayscale image is faster [16].

There are several ways to convert RGB to Grayscale, as each algorithms has its own advantage and disadvantage [17].

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \leftarrow \begin{bmatrix} 0.412453 & 0.357580 & 0.180423 \\ 0.212671 & 0.715160 & 0.072169 \\ 0.019334 & 0.119193 & 0.950227 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$X \leftarrow X/X_n, \text{where} X_n = 0.950456$$

$$Z \leftarrow Z/Z_n, \text{where} Z_n = 1.088754$$

$$L \leftarrow \begin{cases} 116 * Y^{1/3} - 16 & \text{for } Y > 0.008856 \\ 903.3 * Y & \text{for } Y \leq 0.008856 \end{cases}$$

$$a \leftarrow 500(f(X) - f(Y)) + delta$$

$$b \leftarrow 200(f(Y) - f(Z)) + delta$$

$$f(t) = \begin{cases} t^{1/3} & \text{for } t > 0.008856 \\ 7.787t + 16/116 & \text{for } t \leq 0.008856 \end{cases}$$

$$delta = \begin{cases} 128 & \text{for 8-bit images} \\ 0 & \text{for floating-point images} \end{cases}$$

Fig. 1. Details calculation for RGB to CIELAB conversion

Table I show the different equations for RGB to grayscale conversion and table II show the advantages and disadvantages of it.

3) Colour difference

Colour difference is a metric to identify the difference between 2 colours. CIE has created several standardized methods to identify the colour difference, and it is called delta-E [18].

Table III shows the colour difference equations. By looking at the equations, it is found that as the time passed, the equations are getting more complex, which means that it requires more computational power and the calculation process speed will be slower down. In exchange, a more precise and accurate colour difference can be known.

Do note that from 1994 onwards, the colour space that used to calculate the colour difference changed from L*a*b* to L*C*H*, which L*C*H* colour space represent lightness, chroma and hue.

TABLE I: EQUATIONS FOR RGB TO GRAYSCALE

Name	Equation
Intensity	$\mathcal{G}_{Intensity} \leftarrow \frac{1}{3}(R+G+B).$
Luminance	$\mathcal{G}_{Luminance} \leftarrow 0.3R+0.59G+0.11B.$
Lightness	$\mathcal{G}_{Lightness} \leftarrow \frac{1}{100}(116f(Y)-16),$ $Y=0.2126R+0.7152G+0.0722B.$ $f(t)=\begin{cases} t^{1/3} & \text{if } t>(6/29)^3 \\ \frac{1}{3}\left(\frac{29}{6}\right)^2 t+\frac{4}{29} & \text{otherwise.} \end{cases}$
Value	$G_{Value}=\max(R,G,B).$
Luster	$\mathcal{G}_{Luster} \leftarrow \frac{1}{2}(\max(R,G,B)+\min(R,G,B)).$

TABLE II: ADVANTAGES AND DISADVANTAGES OF EQUATIONS

Name	Advantages	Disadvantages
Intensity	Easy to calculate, require minimum computational power, and fast in operation.	It assume all the RGB channels have the same weight, which is not human friendly, because human perceive colours differently.
Luminance	Balanced weight among RGB, closer to human perception on brightness.	-
Lightness	Closer to human perception of colour.	-
Value	Provide absolute brightness information which can keep some feature of the original image.	Slow in speed, as it needs to compare all the values within the channel, and also might affected by the brightness easily.
Luster	Less sensitive to brightness change.	Slow in speed, as it needs to compare all the values within the channel

TABLE III: EQUATIONS FOR COLOR DIFFERENCE

Name	Equation
CIE76	$\Delta E^*_{ab}=\sqrt{\Delta L^{*2}+\Delta a^{*2}+\Delta b^{*2}}$
CIE94	$\Delta E^*_{94}=\sqrt{(\frac{\Delta L^*}{K_L S_L})^2+(\frac{\Delta C^*}{K_C S_C})^2+(\frac{\Delta H^*}{K_H S_H})^2}$
CIEDE2000	$\Delta E^*_{00}=\sqrt{(\frac{\Delta L'}{K_L S_L})^2+(\frac{\Delta C'}{K_C S_C})^2+(\frac{\Delta H'}{K_H S_H})^2+R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)}$

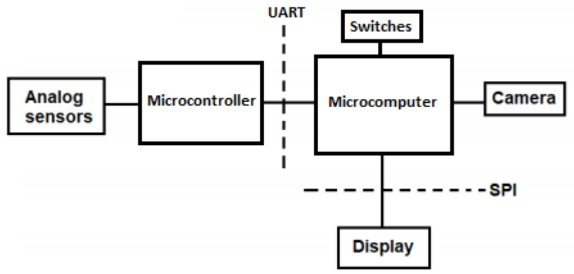


Fig. 2. Block diagram of the water quality testing device

III. METHODOLOGY

A. Overview

The water quality testing device has a display which will show a main menu, and there will be 3 buttons, which is up, down and enter to control the main menu. By using this main menu, user can easily navigate to the functions of the water quality testing device

There will be 2 modes for this water quality testing device, which is instant data acquisition and continuous data acquisition. The instant data acquisition is using image processing technique to get the data, while the continuous data acquisition is using sensors to get the data.

The instant data acquisition process is the camera will capture the image of the test strip and send it to the microcomputer. The image will then process by the microcomputer by using image processing techniques, and the useful information will be obtained. Then, the information will be saved in the microcomputer and a cloud database, as well as shown on the display.

The continuous data acquisition is the analog sensors will get the data of the water and send it to the microcontroller. The microcontroller with then process the analog data and transform it into useful information. The information will then be shown on the display.

The microcontroller used in this project is Arduino Uno. The analog sensors are pH sensor and TDS sensor. The microcomputer and camera used is Raspberry Pi Zero with camera module. The display is 1.3” IPS LCD Module. The test strip used is VANSFUL 14 in 1 test strip.

Fig. 3. shows the water quality testing device prototype. Table IV show the pin connections of the water quality testing device.

B. Instant Data Acquisition Process

The data of the VANSFUL 14 in 1 colour chart are extract manually and saved into a json file. The json file contains the first 9 set of data of the colour chart, as only the first 9 set of data is relevant. The first 9 set of data are free chlorine, pH, total alkalinity, hardness, iron, copper, lead, nitrate and nitrite. The json file has the exact numerical value and the RGB value of each set.

First, the test strip is place in front of a very dark background, and the camera will capture the image of the test strip. The image capture will be send to the Raspberry Pi Zero, and the image processing techniques are coded in Python. After that, the image will go through RGB to grayscale colour conversion and perspective transform. This is to get the exact test strip image, and ignore the background.

The RGB to grayscale algorithm used by the Python program is Luminance algorithm. This is because the Luminance algorithm has balanced weight on RGB colour, and it is close to how human perceive brightness. Other than that, it can operates fast and require less computational power.

The colours on the test strip are separated, and go through RGB to CIELAB colour conversion. After that, it will be compare to the corresponding colour chart data, which the colour chart data is converted from RGB to CIELAB too. By finding the CIE74 distance between the test strip colour data with its corresponding colour data in the colour chart, the delta-E is obtained. Based on this delta-E, the colour chart data with smallest delta-E will be saved, and then if the delta-E is more than 10, the value will be NIL, as the difference is big.

Based on the value obtained, a simple harmfulness algorithm is used to determine if the water quality is safe. If all the value are within the safe range, the water quality will be identify as 'safe'. If some of the values are within the harm range, and it is less than 30% of all the values, the water quality will be identify as 'careful', as it requires user to pay more attention to it. If more than 30% of the values are within the harmful range, the water will be identify as 'harmful'.

After that, the results will be save into a json file. The json file contains the date, time, geo-location, all the delta-E, the RGB values, and the exact values. Besides, the results can be seen on the LCD display. On the other hand, the date, time, geo-location, all the RGB values and the exact values will be saved into a cloud database, which is Google Sheet.

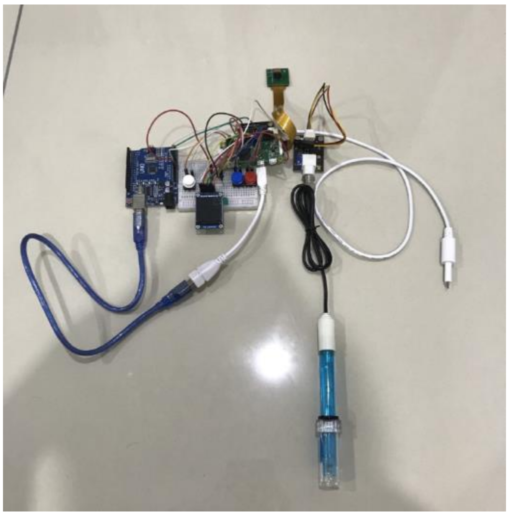


Fig. 3. Prototype of the water quality testing device

TABLE IV: PIN CONNECTIONS

Pin		Pin
Arduino Uno 5V	connected to	pH sensor Vcc
Arduino Uno 5V		TDS sensor Vcc
Arduino Uno GND		pH sensor GND
Arduino Uno GND		TDS sensor GND
Arduino Uno A0		pH sensor analog
Arduino Uno A1		TDS sensor analog
Arduino Uno USB		Raspberry Pi Zero USB
Raspberry Pi Zero 3V3		LCD Module Vcc
Raspberry Pi Zero GND		LCD Module GND
Raspberry Pi Zero SCLK		LCD Module SCL
Raspberry Pi Zero MOSI		LCD Module SDA (MOSI)
Raspberry Pi Zero GPIO24		LCD Module RES
Raspberry Pi Zero GPIO22		LCD Module DC
Raspberry Pi Zero GND		Up button terminal B
Raspberry Pi Zero GND		Down button terminal B
Raspberry Pi Zero GND		Enter button terminal B
Raspberry Pi Zero GPIO16		Up button terminal A
Raspberry Pi Zero GPIO26		Down button terminal A
Raspberry Pi Zero GPIO2		Enter button terminal A

C. *Continuous Data Acquisition Process*

For continuous data acquisition, the pH sensor and the TDS sensor are being placed into water. The sensors will send the analog data to the Arduino Uno, and the program in the Arduino Uno will process those analog data into valuable information. Those information will be constantly updated as the sensors keep updating the analog data.

The Arduino Uno will first sample some analog values, and then get the averaged value. The reason of it is to prevent the sensors to be too sensitive to the analog data. For pH, the Arduino Uno will change convert the analog value to millivolts, then convert the millivolts into pH value. For TDS, the Arduino Uno will use a predefined library to convert the analog value to ppm. The pH value and ppm are valuable information.

The Arduino Uno will then package the information into 1 byte, and send it to the Raspberry Pi once every second. Based on the value obtained, a simple harmfulness algorithm is used to determine if the water quality is safe. If the pH value and the TDS value is within the safe range, the water will be identify as 'safe'. If one of it is not within the safe range, the water will be identify as 'careful'. If both the pH value and TDS value is not within the safe range, the water will be identify as 'harmful'. The safe drinking water pH value range within 6.5 and 8.5. The safe drinking water TDS value is lesser than 500 ppm.

At last, the Raspberry Pi will then show those information on the LCD display.

TABLE V: EXPERIMENTAL TEST STRIPS

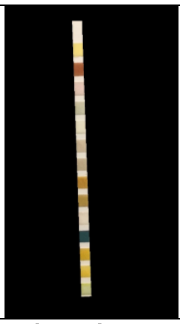
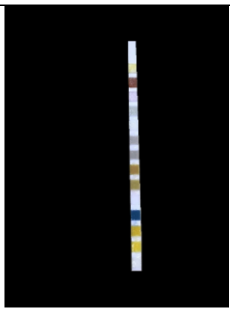
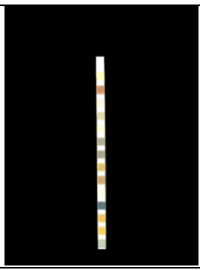
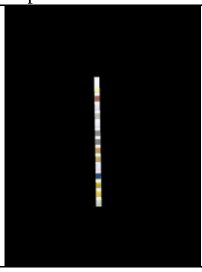
Types of water	Filtered water	Lab solution
Test strip		
Types of water	Carbonated water	Tap water
Test strip		

TABLE VI: LCD OUTPUTS OF INSTANT DATA ACQUISITION

Types of water	Filtered water	Lab solution
LCD output		
Types of water	Carbonated water	Tap water
LCD output		

TABLE VII: LCD OUTPUTS OF CONTINUOUS DATA ACQUISITION

Types of water	Carbonated drink	Filtered water
LCD output		

TABLE VIII: INSTANT DATA ACQUISITION RESULTS

Types of water	Filtered water	Lab solution	Carbonated water	Tap water
Water quality	Safe	Careful	Sage	Careful

TABLE IX: CONTINUOUS DATA ACQUISITION RESULTS

Types of water	Carbonated drink	Filtered water
Water quality	Harmful	Careful

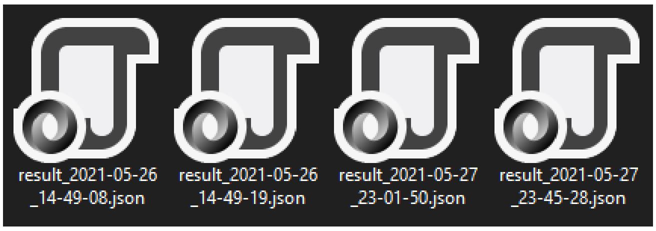


Fig. 4. Previous instant data in device

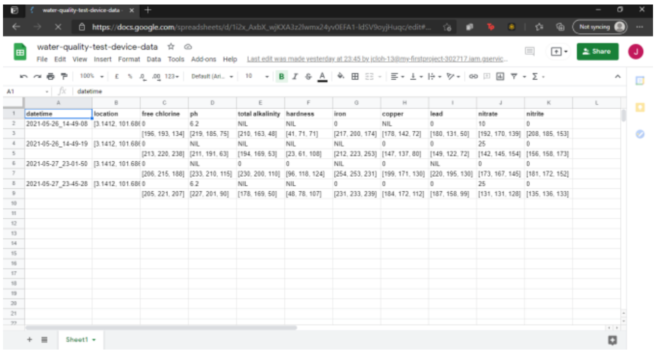


Fig. 5. Previous instant data in cloud database

D. *Experiment*

1) *Instant data acquisition*

The water quality testing device is tested with 4 types of water. The types are filtered water, lab solution, carbonated water, and tap water. Table V shows all the test strips that are used for the experiment.

2) *Continuous data acquisition*

The water quality testing device is tested with 2 types of water, which are carbonated drink and filtered water.

IV. RESULTS

A. *Instant data acquisition*

Table VI shows the LCD outputs of all the 4 types of the water on instant data acquisition testing. Fig. 4. and Fig. 5. Shows the data in device and cloud database.

B. *Continuous data acquisition*

Table VII shows the LCD outputs of all the 2 types of the water on continuous data acquisition testing.\

V. DISCUSSIONS

A. *Instant data acquisition*

Table VIII shows the comparison between the results of instant data acquisition. By looking at the comparison, it is found out that the output is quite satisfactory, as the lab solution and tap water are marked ‘careful’, which means the user might need to pay more attention to the water. Other than that, the filtered water and carbonated water are marked as ‘safe’ by the water quality testing device, which means the user can consume the water and use the water safely.

Even though the results are quite satisfactory, but it can be improved. For example, the carbonated water has a pH level of 6.2, meanwhile normal carbonated water has pH level of 4.5. The performance can be improved by using more complex image processing methods, such as instead of using Luminance algorithm to convert image to grayscale, use Lightness algorithm, as Lightness algorithm have better imitation of how human perceive colours. However, with better and more complex algorithm, it will consume more computational power and might be more expensive in terms of time and money.

B. *Continuous data acquisition*

Table IX shows the comparison between the results of continuous data acquisition. By looking at the comparison, it is found out that the water quality of continuous data acquisition method are tend to be more cautious compared to instant data acquisition. The quality of carbonated drink is identify as ‘harmful’, and the quality of filtered water is identify as ‘careful’. This might due to the fact that there are only 2 sensors to determine the overall harmfulness of the water, and it might also due to the strict safe water range.

In order to improve the performance, more sensors can be added to the Arduino Uno. Other than that, better heuristic function can determined to better define the water quality information.

VI. CONCLUSION

In conclusion, the overall design of the water quality testing device is sufficient for home usage, especially in rural area where the water quality is often bad. The speed of the water quality testing device is fast as for instant mode, the water quality information can be obtained within a short time, instead of the traditional method that requires days to weeks. For continuous mode, the water quality information is updated per every second. The results of the water quality testing device is consider good, as it did not have any bad classification, such as when the water quality is bad and the device identify it as safe. However, the water quality testing device can be improved. The improvement can focus on the accuracy and the precision of the device, by implementing a better image processing methods for instant mode, and sample more data as well as increase the speed of data collecting for continuous mode.

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