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IoT based Water Quality Monitoring System and Evaluation

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***Abstract*— An extreme pH level of the swimming pool water can cause a serious reaction to eye and skin of the users. The existing method for monitoring the water pH level at Seberang Jaya Public Swimming Pool is not efficient enough to monitor the quality of the water as all the processes need to be executed manually. This paper discusses the proposed Smart Water Quality Monitoring System (SWQMS) design, and the evaluation of factors influencing pH value and temperature of swimming pool using DOE and ANOVA statistical tools. The experimental findings reveal that time of day, pool volume and their interaction factors do not influence the pH value however time of day does have an effect on the water temperature of the swimming pool.**

***Keywords*— Water quality monitoring, wireless sensor network, pH, IoT, DOE**

I. INTRODUCTION

Nowadays, IoT technology is used as the communication medium for various monitoring applications [1]. The IoT comprises a network of electronic physical devices that are interconnected, exchange data and interacts with each other beyond machine-to-machine (M2M) communication via the Internet. This ingenious evolution has attracted the interest and attention of many industries to be part of the IoT such as information, transportation, agricultural, healthcare and manufacturing industries. In industry application, smart devices play a vital role in maintaining, tracking and improving productivity which effectively reduces the production costs [1]. Besides that, the real-time measurements and reporting systems are important for the implementation of flexible work strategies as they provide timely information for the decision process for the user to response accordingly to the current situation [2].

Remote monitoring of water quality is necessary to identify any changes in water quality parameters in real time [3]. The main process involved in conventional monitoring water quality are collection, measurement and analysis of water samples [4]. Water is not only used for domestic purposes, but also for agriculture as well as aquatic sports such as swimming and water polo, which involve the consistency of good water. This study focused on monitoring water quality at the recreational pool. Because of the possibility of exposure to body orifices during swimming, the quality of swimming pool water must be as good as drinking water. The quality of a swimming pool very much depends on how well the chemical properties can be monitored and corrected. There are also evaluations to be carried out in tracking the condition of a swimming pool to keep it in a healthy state. The evaluations are based on two parameters: chlorine and pH level [5]. pH level is used to determine the quality of the pool water based on the amount of chlorine. pH is one of the parameter that should be monitored most frequently in all pool types [6].

The pH, also known as "pondus hydrogenii" is to show how acidic or basic water-based solution is with the purpose of displaying the very low concentrations of hydrogen ions [7]. A pH below 7.0 is consired acidic, 7.0 is neutral, while a pH above 7.0 up to 14.0 are considered bases. Water maintenance and pH control are important processes because if there are any small changes in the pH value on the water it will affect the quality of the water [8]. In the conventional method, litmus paper is used to measure the pH level by dipping into the sample of swimming pool water. pH level will be known by comparing the colour changes of the litmus paper with the pH colour chart [9]. According to World Health Organization (WHO) , safe pH level for swimming pool are between 7.20 and 7.80 [6]. The waters with alkaline and acidic can cause eye irritation for the user [10]. The user will get the dermatitis, eye irritation, gastrointestinal illness and mucosa irritation if they swim in the water with pH values equal or lower than 4.00 and above 11.00. Furthermore, the mechanical parts (metal) of the pool can be corroded if the pH value of pool water are acidic for a long times [6].

Gouws and Nieuwoudt developed a water monitoring device based on a pH sensor and an Oxidation-Reduction Potential (ORP) sensor to assess swimming pool water quality status [5]. The system does not provide data logger to record the collected data for later analysis. Furthermore, such design that uses two sensor types is considered redundant as a pH sensor alone can yield results to evaluate the quality of water accuracy, in addition to the cost of the ORP sensor. Besides, the system developed by Das and Jain [3], used LoRa module for collecting and sending to the microcontroller, and additional Wi-Fi module was embedded for internet connection. Such design needs a

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many components to make a complete system which makes it complicated as well as costly to develop.

Therefore, in this paper, the water monitoring system is developed based on IoT technology for real-time monitoring. The paper is organized as follows, Section II deals with the proposed method, Section III describes the operation of the system, Section IV addresses the DOE assessment. The study findings are addressed in Section V, and the conclusions are provided in Section IV.

II. SMART WATER QUALITY MONITORING SYSTEM

In the conventional method, the maintenance staffs of the aquatic centre monitor the pH value of the swimming pools manually. In the system implementation, the staff will be able to monitor the pH value in real-time using their mobile phone or personal computer. Hence, prompt action can be taken in order to ensure the swimming pool is safe to be used all the time. To regulate the pH level of the water pool, water pump 1 and pump 2 are embedded into the system for pumping acidic and alkaline solution respectively Furthermore, the proposed system enables the operation management to trace the data and do analysis for all the problem occurred so that the same problems will not occur in the future. The following are the main components used in the SWQMS. The conceptual overview of the system is illustrated in Fig. 1.

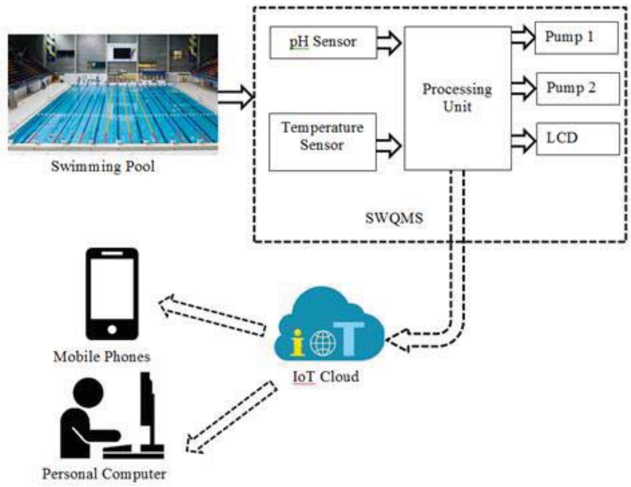

Fig. 1. Conceptual Overview of the SWQMS System

A. NodeMCU

NodeMCU V3 is a small size processing unit and inbuilt ESP8266. With an advanced API, NodeMCU provides advanced hardware IO APIs which accelerate the configuration and manipulation of the hardware. The built-in Wi-Fi module, ESP8266, is integrated on-board. This is an advantage for the system because no other external Wi-Fi module is needed for an internet connection.

B. pH Sensor

The selected analog pH sensor has built-in LEDs to indicate its power status, the BNC connector, and the interface of the pH2.0 sensor for communication with processing unit.

C. Temperature Sensor

The temperature sensor selected for this project is DS18B20. It is a digital thermometer that provides 9-bit to 12-bit Celsius temperature measurements. This sensor only needs one wire which be the main data line for transmitting temperature reading from the sensor to the processing unit. One sensor contains 64-bit of serial code which makes an advantage for the user to use multiple DS18B20 on the same 1 data wire.

D. IoT Platform

Monitoring data is uploaded into the IoT cloud via Ubidots apps. Generally, the data from the sensor is converted into information that matters for machine-to-machine interactions. Ubidots processes the data and shows the data on the dashboard where the user can access the data using their mobile phone or their personal computer. Fig. 2 shows that the interface from the Ubidots website dashboard, which is similar to mobile app. The real-time data collected from sensors can be viewed and monitored from this dashboard. The data is presented in graphical charts to ease the analysis to the user.

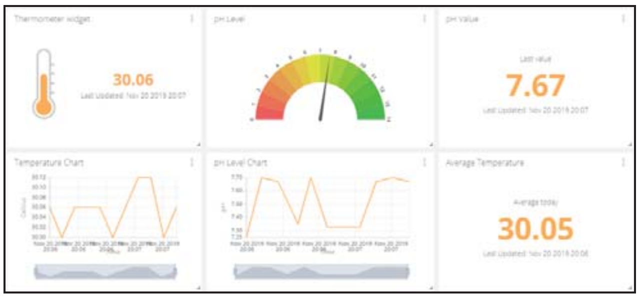

Fig. 2. Ubidots Website Dashboard

III. SYSTEM OPERATION

Fig. 3 shows the operation flowchart of the developed system. The sensors provide data to the processing unit every five minutes. There are three conditions for the pH level which is a normal condition, acidic condition, and alkaline condition. For condition one which is a normal condition, the pH value that needs to meet this condition is between 7.20 and 7.80. The second condition which is acidic, the pH value is below 7.20 and lastly is the third condition which is the pH value is higher than 7.80 indicating alkaline water. The user also will get a notification via Telegram apps every time there is a changes to the pH level as shown in the flowchart. For the second and third condition which is too acidic and too alkaline, the system will trigger pump for pumping solution to stabilize the pH value until the pH change to normal level. User can access SWQMS Tracking System to monitor the current condition of the swimming pools and take necessary action. The system continuously monitor the temperature and pH value of the swimming pool water in real-time.

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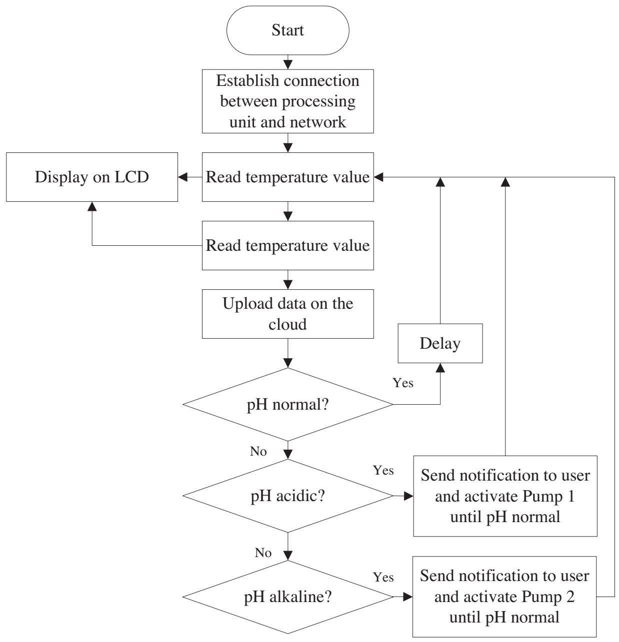

Fig. 3. System Flowchart

IV. Investigation on Significant Factors Affecting pH and Temperature

This section is focusing on finding significant factors that influencing the pH value and temperature based on Design of Experiment (DOE) approach. DOE is considered as an effective tool to perform robust experiment and identify influential factors to the pH level. The factors that were investigated in this experiments are tabulated in Table I. There are three levels for each of the factors and all of the data are replicated two times to increase the chances of detecting significant effects from the identified factors.

TABLE I. Factors and Levels of DOE

Factors	Level 1	Level 2	Level 3
Time of day	Morning	Afternoon	Evening
Pool volume (m^3)	300	400	2250

A table for the factorial design calculation is generated as shown in Table II. The response variable of the experiment is the pH value and the temperature that was carried out at the Seberang Jaya Swimming Pool. All the data are collected following the run order to get accurate data from the swimming pool.

TABLE II. Factorial Design Table

Std Order	Run Order	Time of day	Pool Volume	pH	Temperature
8	1	Evening	400	7.21	30.30
16	2	Evening	2250	7.16	30.63
11	3	Morning	400	7.15	30.48
10	4	Morning	2250	7.11	30.03
2	5	Morning	400	7.15	30.48
13	6	Afternoon	2250	7.21	30.73
1	7	Morning	2250	7.14	30.63
6	8	Afternoon	300	7.23	30.91
9	9	Evening	300	7.19	30.83
7	10	Evening	2250	7.25	30.10
3	11	Morning	300	7.19	30.41
12	12	Morning	300	7.18	30.16
18	13	Evening	300	7.14	30.56
15	14	Afternoon	300	7.16	30.69
4	15	Afternoon	2250	7.21	30.59
5	16	Afternoon	400	7.22	30.88
14	17	Afternoon	400	7.18	30.66
17	18	Evening	400	7.27	30.24

V. Results and Discussion

The data of the pH value and temperature were analysed using the Minitab 16 software and two-way ANOVA are chosen to run the statistical analysis.

A. Two-Way ANOVA of pH Value

Table III shows that the calculated P-value for the time of day is higher than the significance value which is 0.057, thus there is insufficient evidence to reject the null hypothesis H_{0T}. It can be concluded that the time of day did not affect the reading of pH value.

TABLE III. Two-Way ANOVA of pH Value

Source	DF	Seq SS	SS	MS	F	P
Time of day	2	0.009678	0.009678	0.00489	4.01	0.057
Pool volume	2	0.001011	0.001011	0.000506	0.42	0.67
Interaction	4	0.008489	0.008489	0.002122	1.76	0.221
Error	9	0.010850	0.010850	0.001206		
Total	17	0.030028				

- Null Hypothesis, H_{0T}: Time of day is not a significant factor
- Alternative Hypothesis, H_{1T}: Time of day is a significant factor
- Null Hypothesis, H_{0V}: Pool volume is not a significant factor
- Alternative Hypothesis, H_{1V}: Pool volume is a significant factor
- Null Hypothesis, H_{0VT}: Interaction is not a significant factor
- Alternative Hypothesis, H_{1VT}: Interaction is a significant factor

The P-value for both pool volume and interaction are 0.67 and 0.221, respectively. Both value are higher than 0.05 which make each null hypothesis, H_{0V} and H_{0VT} are fail to reject. Therefore, both the pool volume and time of day as their interaction factors do not effect the pH value.

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Fig. 4 shows the main effects plot for the pH. There is a steeper slope between the morning and afternoon which shows that time of day influences that changes to the pH value. On the transition between afternoon and evening, there is an only a small deflection from the horizontal showing that it just gives a small impact to the pH value. For the pool volume, there are steeper slope between the 300 and 400 also from the 400 to the 2250 volume. This slope shows that there is an effect between the pool volume to the pH value, but not really significant.

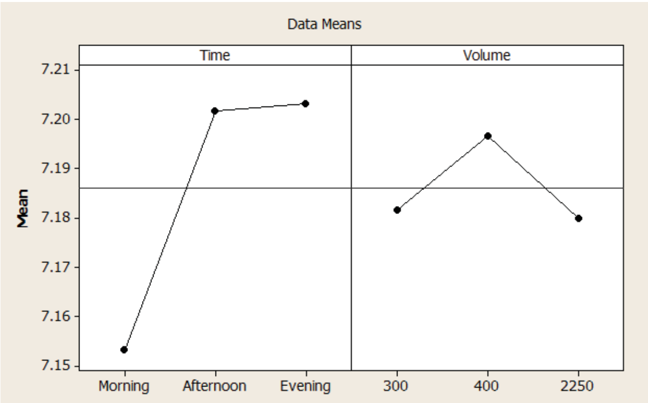

Fig. 4. Main Effects Plots for pH

B. *Two-Way ANOVA of Temperature*

From Table IV, the calculated P-value for the time of day is 0.038 which is lower than 0.05, thus there is sufficient evidence to reject the null hypothesis H_{0T}. Therefore, the time of day does affect the reading of pH value.

TABLE IV. TWO-WAY ANOVA OF TEMPERATURE

Source	DF	Seq SS	SS	MS	F	P
Time of day	2	0.47854	0.47854	0.23927	4.81	0.038
Pool volume	2	0.06121	0.06121	0.03061	0.61	0.562
Interaction	4	0.20126	0.20126	0.05031	1.01	0.451
Error	9	0.44815	0.44815	0.04979		
Total	17	1.18916				

- Null Hypothesis, H_{0T}: Time of day is not a significant factor
- Alternative Hypothesis, H_{1T}: Time of day is a significant factor
- Null Hypothesis, H_{0V}: Pool volume is not a significant factor
- Alternative Hypothesis, H_{1V}: Pool volume is a significant factor
- Null Hypothesis, H_{0VT}: Interaction is not a significant factor
- Alternative Hypothesis, H_{1VT}: Interaction is a significant factor

The P-value for pool volume is 0.562 which makes its null hypothesis H_{0V} is fail to reject. For interaction, the P-value is 0.451 which is higher than 0.05 and the null hypothesis H_{0VT} is also fail to reject. Thus, both the pool volume and interaction did not effect the temperature.

Fig. 5 shows the main effects plot for the temperature. There is a steeper slope between the morning and afternoon and between afternoon and evening. This shape of slope shows that the time of day does give significant impact to the temperature. For the pool volume, there are steeper slope between the 300 and 400 also from the 400 to the 2250 volume. This slope shows that there is an effect between the pool volume to the temperature, but not really significant.

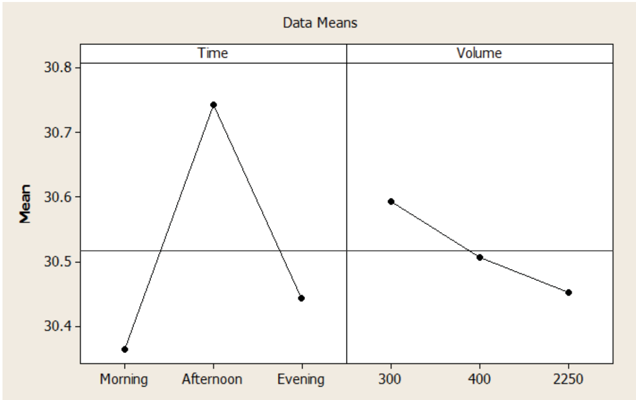

Fig. 5. Main Effects Plot for Temperature

VI. CONCLUSION

It has clearly observed that the system is capable to automatically updates the current status of water quality of the pool via IoT platform and make an adjustment to the pH level. This SWQMS system also capable to provide real-time monitoring and requires less operational maintenance. Based on the statistical analysis that was conducted, the time of day, pool volume and the interaction factors do not influence the reading of pH value. While for the temperature, the time of day factor does influence the temperature condition.

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