ICIC Express Letters
Part B: Applications
Volume **13**, Number **6**, June **2022**

ICIC International ©2022 ISSN 2185-2766
pp. **623–630**

AN EXPERIMENTAL KIT OF WATER LEVEL MEASUREMENT WITH LOW-COST CAPACITIVE SENSORS

Ratchanoo Katman[1] and Anucha Kaewpoonsuk[2,*]

[1]Program of Physics
Faculty of Science and Technology
Pibulsongkram Rajabhat University
156 Moo 5, Tambon Plaichumpol, Muang, Phitsanulok 65000, Thailand
ratchanook@psru.ac.th

[2]Department of Physics
Faculty of Science
Naresuan University
99 Moo 9, Tambon Tha Pho, Muang, Phitsanulok 65000, Thailand
*Corresponding author: anuchak@nu.ac.th

Received October 2021; accepted December 2021

Abstract. *The aim of this paper is to introduce a simple and low-cost experimental kit for students to do a learning activity in the classroom to study electronic circuits and measurement systems. The experimental kit is designed using two insulated copper wires which act as capacitive sensors for water level measurements. The capacitive sensors are connected to the 555-timer IC to obtain a rectangular output signal which its time-period is proportional to the water level. The ESP32 microcontroller board is used for time-periodic measurement and wireless transmission of data to display on a smartphone by the Blynk app. Experimental results showed that the period of the output signal is directly proportional to the capacitance of the capacitive sensor which is related to the water level. The worst-case linearity error value is about 0.19 cm for water level at the height of 1.00 cm. The learning activity designed encourages student participation in the classroom.*
Keywords: Water level measurement, Capacitive sensor, Experimental kit, Learning activity

1. **Introduction.** It is well known that digital signal processing technology has advanced greatly. Signal processing with many electronic circuits has been replaced by modern digital processors such as microcontrollers, raspberry pi, programmable logic controllers and smartphones. Electronic circuits for analog and digital signal processing are more complicated than programming methods. This makes learning about electronic circuits for many physics and engineering students tediously. However, many electronic circuits are still essential for the development of instrumentation and control systems. The 555-timer IC is an integrated circuit device whose notable applications include time delay and pulse generation. It is very useful and important that the students should know. The 555-timer IC has gained widespread popularity in the design of signal generator circuits to generate excitation signals in measurement and control systems [1-4]. In addition, connecting the sensor as part of the signal generator circuit using the 555-timer IC is another popular application method by converting the resistance or capacitance changes to the square wave of frequency which is related to the resistance or capacitance value of the sensor [5-9]. In addition, interfacing electronic circuits with a microcontroller to design an experimental kit is widely applied in teaching and learning [10-12]. In 2012, the application of insulated copper wire adapted to capacitive sensors in combination with a 555-timer IC for water level measurement was proposed [13]. It produces a rectangular signal whose period

DOI: 10.24507/icicelb.13.06.623

corresponds to the water level. Then, a period-to-DC converter circuit was used. Subsequently, the microcontroller was used for transmitting the obtained DC voltage signal to the computer for water level calculation and display. There are three major drawbacks of this system. The first is that such sensors are not suitable for continuous use. This is because it is not designed for permanent immersion. The second drawback is the use of a period-to-DC converter circuit which is a rather large and complex circuit. The last one is that Visual Basic (VB) programming for monitoring measurement results on a computer screen is not suitable for electronic beginners or students who do not have background knowledge of programming. Nowadays, the technology of microcontroller boards and smartphones has been developed greatly. Hence, the application of a microcontroller for signal periodic measurement and wireless transmission of data to a smartphone is much easier. Moreover, smartphone applications enable users to control electronic devices and monitor measurement results.

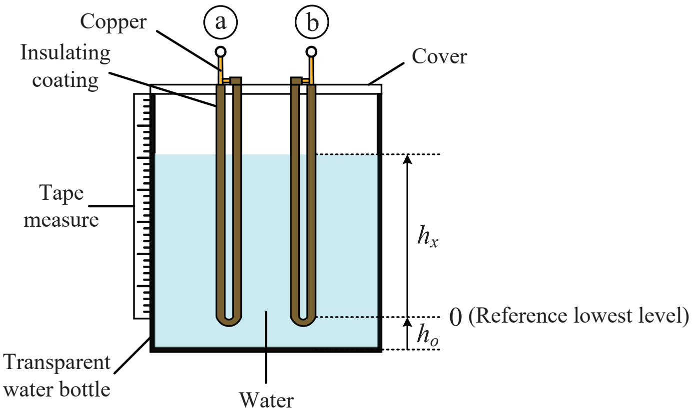
In this paper, a demonstration experiment using insulated copper wire in combination with an ESP32 microcontroller board and a smartphone for water level measurement is presented. This is to serve as a stimulus for learners' interest in seeing the benefits and importance of the knowledge of electronic circuits necessary for the development of measurement and control systems. The content is organized as follows. In Section 2, a theoretical background of the sensors and the prediction of the periodic signal produced by the 555-timer IC are explained. The apparatus and procedure for connecting the 555-timer IC to the ESP32 microcontroller board and a smartphone are explained in Section 3. The calibration procedures and test methods of the proposed experimental set are described in Section 4. The results are also discussed. In addition, the learning activity of the students in the electronic class is shown in this section. Finally, the last section is the conclusion.

2. **Principles and Methods.** Two insulated copper wires are bent into a U-shape which act as a capacitive sensor for measuring the water level height in a transparent water bottle, demonstrated in Figure 1. The two upper ends of each wire stripped the insulation to serve as electrodes a and b. The side of the transparent water bottle is attached to the water level gauge to be used for comparison with the electronic measurement results achieved from the designed experimental kit. The minimum water level height inside the transparent water bottle is defined as the reference value of the system h_o which is considered to have zero water level. The h_x and r represent the water level height to be measured and the radius of each copper wire. In Figure 1, it is assumed that the resistance of water is very low compared to the resistance of the circuit to be connected. Therefore, the equivalent circuit of the capacitive sensors can be shown in Figure 2. Here, it is seen that there are two capacitors (C_1 and C_2) connected in series. The conductive parts of the capacitive sensors are two copper wires and water in the transparent water bottle. The values of capacitive sensors can be expressed as

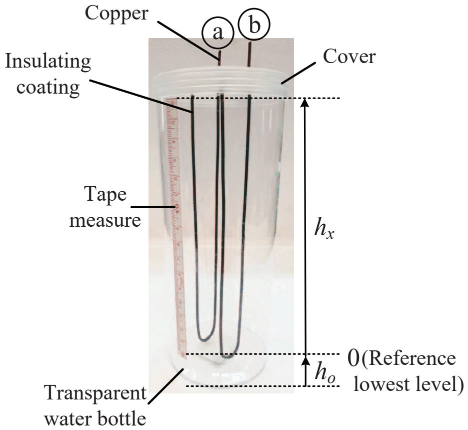
$$C_1 = C_2 = \frac{\varepsilon_r \varepsilon_o A}{d} = \frac{\varepsilon_r \varepsilon_o 2(2\pi) h_x}{\ln(r_1/r_2)} \tag{1}$$

$$C_s = \frac{C_1 C_2}{C_1 + C_2} + C_o = \frac{\varepsilon_r \varepsilon_o (2\pi) h_x}{\ln(r_1/r_2)} + C_o \tag{2}$$

where A is the area of the insulator immersed in water during the distance h_x; d is the thickness of the insulator; r_2 is the radius of the insulated copper wire; r_1 is the radius of the uninsulated copper wire; ε_o is the permittivity of free space (8.85×10^{12} F/m); ε_r is the dielectric constant of the insulator; C_o is the capacitance of the sensor when the water is at h_o level.



(a) Schematic drawing



(b) Photograph

FIGURE 1. Capacitive sensors and their installation

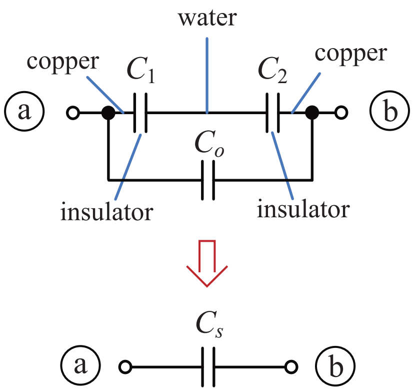


FIGURE 2. Model of the capacitive sensors

Figure 3 shows a block diagram of the proposed experimental kit. The sensor terminals a and b are connected as an integral part of a square wave signal generator. The period T of the output signal V_o obtained from the square wave signal generator is directly proportional to the water level. The period detection and calculating the frequency f of the output signal V_o are processed by the ESP32 microcontroller board. Both the period and frequency values can be used to estimate the water level to be measured. In the display section, the measured results (period T, frequency f and water level h_x) are sent to display on a smartphone via the Blynk app. From the routine circuit analysis, the period T and frequency f of the output signal V_o can be determined as

$$T = 0.693(R_1 + 2R_2)C_s \tag{3}$$

$$f = \frac{1}{T} = \frac{1.44}{(R_1 + 2R_2)C_s} \tag{4}$$

It can be seen that the period T of the output signal V_o is directly proportional to the capacitance C_s of the capacitive sensor which is related to the water level height. From Equations (3) and (4), the user can operate the sensor utilizing calibrating the measurement results with the known water level. The process of calibrating variables to synthesize equations for calculating water level height involves adjusting the water level and measuring the period T of the output signal V_o. Subsequently, Excel was used for trend analysis and equation synthesis. These equations are written back into the microcontroller for water level measurement applications.

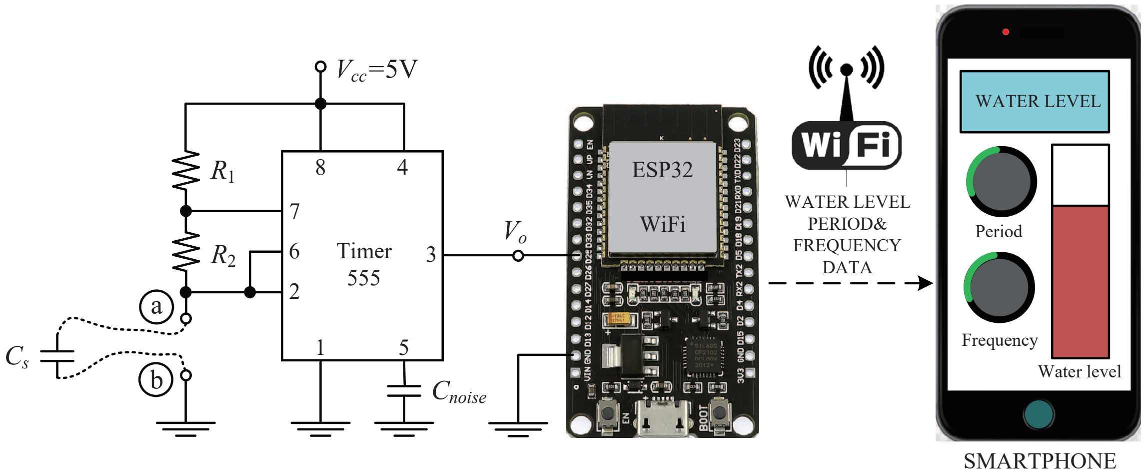
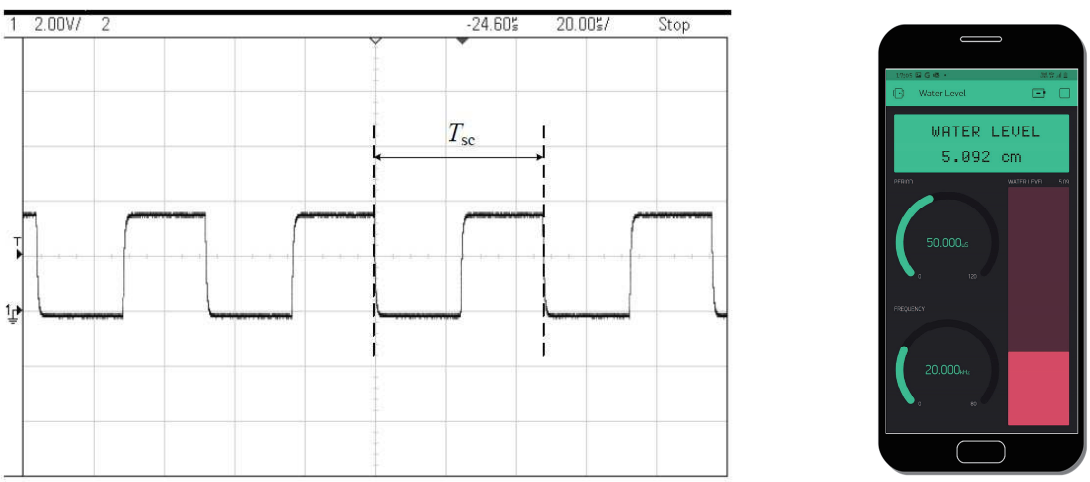


FIGURE 3. Diagram of the proposed experimental kit

3. **Experimental Setup.** To demonstrate the performances of the proposed experimental kit, the square wave signal generator is designed using the 555-timer IC. The power supply voltage V_{cc} used is set to 5 V. The resistors used in the circuit are chosen to be $R_1 = 1$ kΩ and $R_2 = 100$ kΩ. The noise suppression capacitor C_{noise} in the circuit is chosen as 0.01 µF. In Figure 3, the capacitive sensor C_s is replaced by two U-shaped insulated copper wires with a diameter of 1.00 mm and a length of 36.00 cm. The ESP32 microcontroller board is used for detecting the period T of the output signal V_o via pin D25.

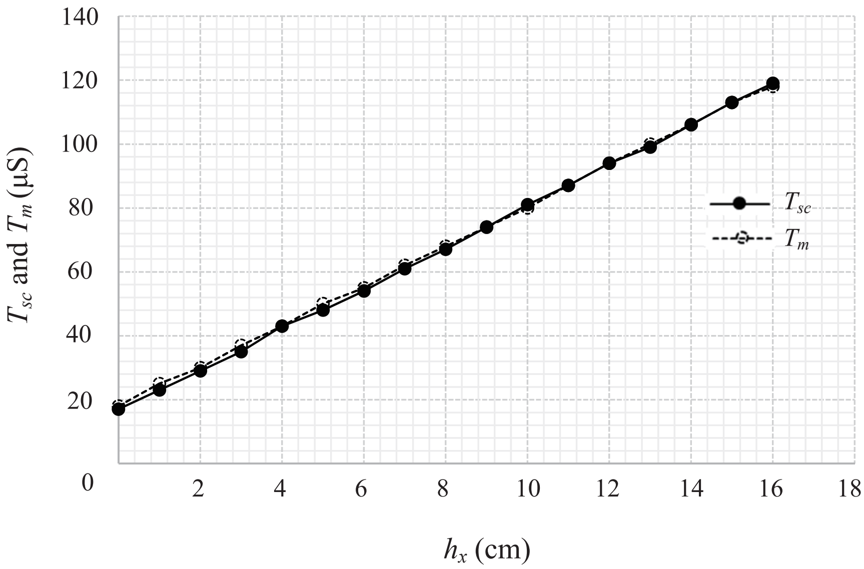
In the procedures for using and testing the functionality of the experimental kit, the water level in the transparent water bottle has been changed to various values. Then, an oscilloscope is used to examine the shape and measure the period T of the output signal V_o as demonstrated in Figure 4(a). A linear relationship between the period T and the water level h_x is used to program the microcontroller for converting the period to the unknown water level to be measured. The water level measurement project is created using the Blynk app on a smartphone to monitor the period T, the frequency f and the water level h_x processed from the ESP32 microcontroller board through the WiFi network as shown in Figure 4(b).



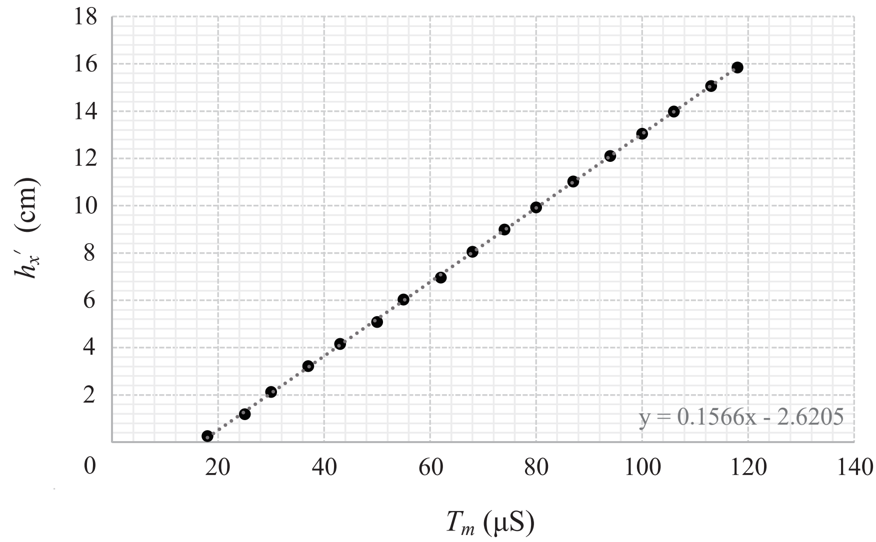
(a) The output signal V_o (b) Display screen

FIGURE 4. The measured output signal V_o when the water level $h_x = 5$ cm

4. **Results and Discussion.** Figure 4(a) shows an example of the output signal shape obtained when the water level $h_x = 5$ cm. A plot of comparison between the period T_{sc} measured by the oscilloscope and the period measured T_m by the microcontroller is shown in Figure 5(a).



(a) Plots of the periods T_{sc} and T_m against the water level h_x



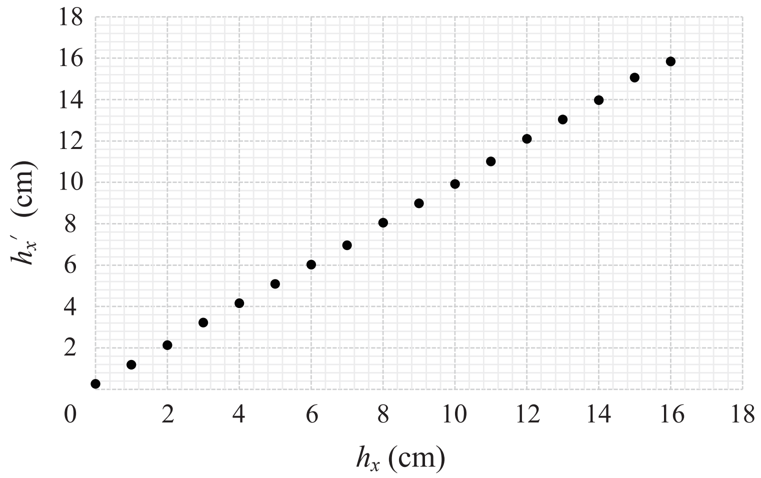
(b) Plot of the water level h'_x against the period T_m measured by the microcontroller

FIGURE 5. The relationship between the period and the water level

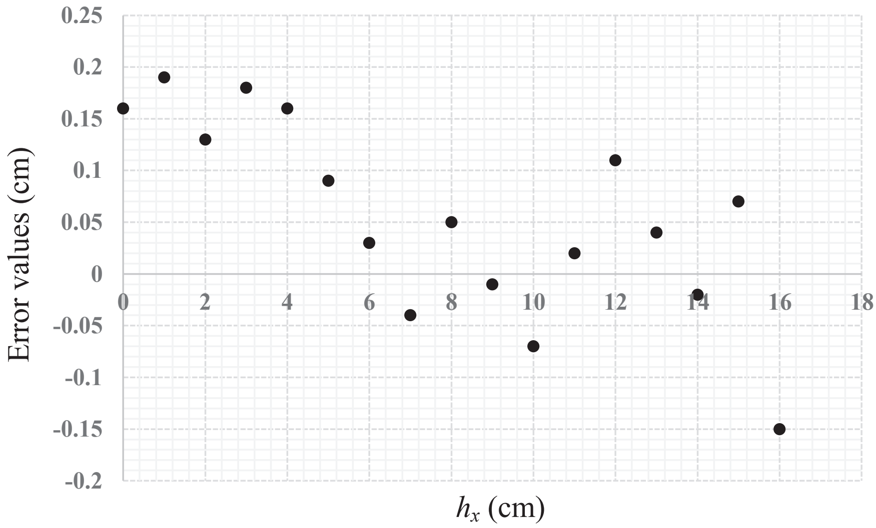
It is evident that the period T_m corresponds to the period T_{sc}. This measured result can be used to verify the validity of microcontroller-based period detection. It was also shown that the trend line of both the periods T_{sc} and T_m against the water level height h_x is approximately the straight line according to Equation (3). The R-squared values R^2 of both two graphs T_{sc} and T_m are 0.9997. It is then switched between the x and y-axis of the graph as shown in Figure 5(b) to be used for synthesizing the equation to calculate the water level h_x which can be written as

$$h_x = 0.1566T_m - 2.6205 \tag{5}$$

Figure 6(a) shows the plot of the average water level height obtained from measuring three times from 0 cm to 16 cm. The worst-case linearity error is about 0.19 cm for water level height h_x of 1.00 cm. It is clearly seen that the proposed experimental set provides adequate performance for the experimental kit.



(a) The water level h'_x compared to h_x

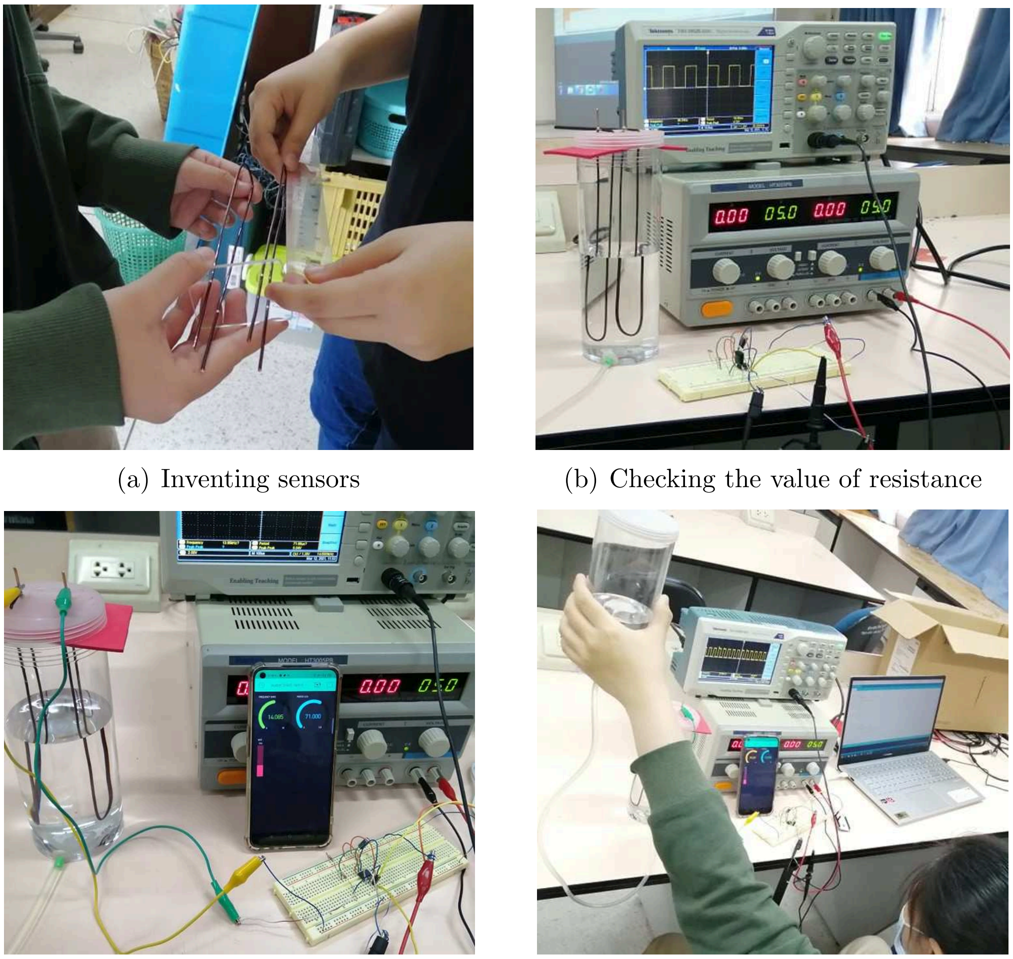


(b) Linearity error

FIGURE 6. Results of water level measurement

After testing the functionality of the proposed experimental kit and the experimental result, we have designed it as a learning activity in the electronic class. The students have to create their own sensor, calculate a suitable value of resistance used in a square wave signal generator based on the 555-timer IC for measuring the water level and design the screen on a smartphone by the Blynk app for monitoring the changing of the water level as shown in Figures 7(a)-7(d). This activity encourages student participation in the classroom.

5. **Conclusions.** We propose an experimental kit for water level measurement based on the 555-timer IC with low-cost capacitive sensors. The superiority of the primary water level measurement method [13] is using a microcontroller for the period detection instead of the period-to-DC converter circuit. The setup is easy to implement and it uses free applications on smartphones for monitoring the water level. The experimental results show that the designed experimental kit can measure the water level accurately.



(a) Inventing sensors

(b) Checking the value of resistance

(c) Displaying results on a smartphone screen

(d) Measuring the water level

Figure 7. Learning activity of the students in the electronic class

The simple experimental kit proposed in this paper can be used as an alternative tool for experimental practices. It can also be used as an example of how to integrate a smartphone with a small electronic circuit to stimulate the learner's interest. It is expected that the COVID-19 situation will remain with us for a long time. The management of teaching in the fields of electronics, measurement and control systems is necessary to rely on social distancing patterns. A low-cost experimental kit is an interesting topic for research during this time so that students can use the experimental equipment thoroughly.

REFERENCES

[1] S. M. A. Motakabber and M. I. Ibrahimy, Design and development of computer controlled active sonar system, *Tehnički Vjesnik*, vol.21, no.4, pp.751-756, 2014.

[2] P. Chetpattananondh, K. Thongpull and K. Chetpattananondh, Interdigital capacitance sensing of moisture content in rubber wood, *Computers and Electronics in Agriculture*, vol.142, pp.545-551, 2017.

[3] M. Boada, A. Lázaro, R. Villarino and D. Girbau, Battery-less moisture measurement system based on a NFC device with energy harvesting capability, *IEEE Sensors Journal*, vol.18, no.13, pp.5541-5549, 2018.

[4] A. S. Disale, D. P. Chavan, P. B. Undre, A. S. Alameen and P. W. Khirade, Measurement of soil capacitance using pulse width technique, *J. Phys.: Conf. Ser.*, vol.1644, 012044, 2020.

[5] B. Biswas, A. Dey, S. Roy and S. K. Sarkar, Fabrication of a WO3 conductometric activated thin film sensor for resistance-to-frequency conversion based sensing application, *IETE Journal of Research*, https://doi.org/10.1080/03772063.2019.1615387, 2019.

[6] Y. C. Chung, N. N. Amarnath and C. M. Furse, Capacitance and inductance sensor circuits for detecting the lengths of open- and short-circuited wires, *IEEE Trans. Instrum. Meas.*, vol.58, no.8, pp.2495-2502, 2009.

[7] B. Huang, D. C. H. Yang, A. M. Madni, L. Fellow and J. B. Vuong, Multielectrode differential capacitive sensors-model simulation with design application, *IEEE Sensors Journal*, vol.13, no.4, pp.1371-1379, 2013.

[8] V. Ogwo, K. N. Ogbu, C. C. Anyadike, O. A. Nwoke and C. C. Mbajiorgu, Development and testing of a capacitive digital soil moisture sensor with printed circuit board as a probe, *Nigerian Journal of Technology*, vol.39, no.3, pp.911-917, 2020.

[9] K. V. Santhosh, B. Joy and S. Rao, Design of an instrument for liquid level measurement and concentration analysis using multisensor data fusion, *Journal of Sensors*, https://doi.org/10.1155/2020/4259509, 2020.

[10] C. Galeriu, C. Letson and G. Esper, An arduino investigation of the RC circuit, *The Physics Teacher*, vol.53, pp.285-288, 2015.

[11] S. Kittipanyangam and K. Eguchi, The development of a fuzzy-based light absorbance measurement device for chemical education, *International Journal of Innovative Computing, Information and Control*, vol.15, no.3, pp.1115-1129, 2019.

[12] P. Ü. Yavas and M. Karadag, An electronic electroscope for determining polarity of charge, *Phys. Educ.*, vol.54, no.4, 045004, 2019.

[13] A. Kaewpoonsuk and K. Prompak, Low-cost capacitive sensor and interfacing circuit for water level monitoring, *NU Science Journal*, vol.9, no.1, pp.98-108, 2012.