

INTERNET-BASED CONDUCTIVITY MEASUREMENT SYSTEM WITH SELF-TEMPERATURE COMPENSATION

RATCHANOO KATMAN^{1,2}, APINAI RERKRATN³ AND ANUCHA KAEWPOONSUK^{1,2}

¹Department of Physics

Faculty of Science

²Research Center for Academic Excellence in Applied Physics

Naresuan University

Phitsanulok 65000, Thailand

ratchanook@psru.ac.th; anuchak@nu.ac.th

³Faculty of Engineering

King Mongkut's Institute of Technology Ladkrabang

Chalongkrung Road, Ladkrabang, Bangkok 10520, Thailand

apinai@gmail.com

Received December 2018; accepted March 2019

ABSTRACT. *An Internet-based conductivity measurement system with self-temperature compensation is presented in the paper. In order to get a simple and portable measurement system, a readout circuit in analog part is designed using only two operational amplifiers (opamps) connected with basic electronic components and energized using single supply voltage. An excitation voltage generated by the AD9833 module is applied to a conductivity sensor. The measured output DC voltages are found to be directly proportional to the conductivity of the solution. The NodeMCU ESP8266 WiFi dev board is used to determine the conductivity and measure the temperature whose effect on the conductivity is compensated. The measured results are sent to display on a smartphone by Blynk app. The conductivity measured by the proposed system is in good agreement with that due to the standard EC meter. A maximum error of measuring the conductivity at different temperatures of solution is 4.79% of full scale.*

Keywords: Conductivity measurement, Single supply, Temperature compensation, Internet-based measurement system

1. Introduction. The conductivity is one of the most useful parameters for measuring water quality. The monitoring system of quality parameters of surface waters in urban areas has been proposed. The signal conditioning circuit in which an oscillator used for generating the excitation voltage contains was designed using dual-supply opamps. The data from the sensor was displayed on LabVIEW via wireless communication [1]. Afterward, the water quality monitoring system using Internet of Things (IoT) technologies has been presented [2]. According to using a DC voltage in the conductivity sensor, a polarization effect at the conductivity cell probably exists. This may lead to error in the conductivity measurement. Additionally, the conductivity is also used to measure the amount of soluble salts in the soil [3,4]. In recent years, hydroponic crop production has increased worldwide. The conductivity is a good indicator of the amount of the nutrient solution. It affects the nutrient uptake, growth and yield of plants [5]. Then, the conductivity measurement systems have been developed successively in hydroponic systems. The automated nutrient composition control system has been presented to monitor and modify the pH and conductivity of the nutrient solution [6]. The conductivity measurement circuit using a technique of the zero and span circuit has been proposed to expand the range of the conductivity measurement in solution [7]. The circuits in the two previous

studies were designed using dual-supply opamps connected with the microcontroller and LCD. The AC source was used to generate the excitation voltage for electrodes. Recently, IoT technologies were used to develop the environment and nutrient solution monitoring system for aeroponic and hydroponic farms [8,9]. It is well known that the conductivity in nutrient solution is an important parameter for a hydroponic crop but it was not measured in the system [8]. In order to improve measuring the conductivity in the system and simplify the measurement circuit, we apply IoT technologies and single-supply opamps into our proposed circuit design.

In this paper, we present the simple system design for measuring the conductivity of solution via Internet network with self-temperature compensation. The readout circuit is implemented from basic electronic components and uses only two commercially available operational amplifiers with a single supply voltage. The conductivity sensor can be built easily using two carbon rods. It is stimulated by the sinusoidal voltage generated using the AD9833 module. The NodeMCU ESP8266 WiFi dev board acts as the processor and data transmitter to cloud. The solution temperature and the conductivity at reference temperature are displayed on a smartphone by the Blynk app. User can immediately and continuously monitor the measured results.

The rest of the paper is organized as follows. In Section 2, we propose the method of designing the Internet-based conductivity measurement system with self-temperature compensation. The details of experimental setup are described in Section 3. After that, Section 4 demonstrates the experimental results and discussion. Finally, conclusions are given in Section 5.

2. Description of the Method. The structure of the Internet-based conductivity measurement system with self-temperature compensation is shown in Figure 1. The proposed system is composed of a DS18B20 temperature sensor, a NodeMCU ESP8266 WiFi dev board, an AD9833 module, a clamper circuit with a voltage gain, a current-to-voltage converter, an absolute circuit, a clamper circuit, and a low-pass filter. Two electrodes act as a conductivity sensor for measuring the conductivity of targeted solution. The electric current flowing through the solution is investigated and converted to the voltage by the current-to-voltage converter. Output voltages are directly proportional to the conductivity of the solution. In part of the microcontroller system, the NodeMCU ESP8266 WiFi dev board is used to acquire temperatures and output voltages obtained from the readout circuit, and calculate the conductivity at a common reference temperature. After that, the measured temperature and the conductivity values are sent to the Blynk app on a smartphone.

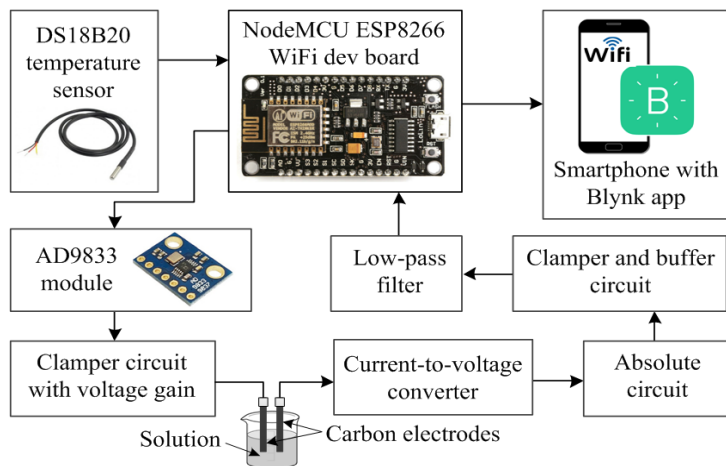


FIGURE 1. Structure of the conductivity measurement system

2.1. Readout circuit design. In Figure 1, a sinusoidal excitation voltage is generated using the AD9833 module which is controlled by the NodeMCU ESP8266 WiFi dev board in order to reduce a part of the oscillator circuit. Furthermore, we can program the AD9833 module to change the frequency and waveform of the output signal.

The produced sinusoidal excitation voltage can be stated as

$$V_{ex} = V_{DC} + A_0 \sin(\omega t) \quad (1)$$

where the V_{DC} and A_0 are values of the initial DC component and the amplitude of the sinusoidal excitation voltage V_{ex} . Because the voltage V_{ex} is a small signal which is not suitable for this designed system, we improve the voltage V_{ex} using the clamper with the voltage gain of $A_{v1} = 1 + R_2/R_1$. Its DC offset $V_{offset1}$ is adjusted until the output voltage has $V_{CC}/2$ DC component. The improved voltage V_{ex} can be rewritten as

$$V_{ex} = (V_{DC} + V_{offset1}) + \left(1 + \frac{R_2}{R_1}\right) A_0 \sin(\omega t) \quad (2)$$

or

$$V_{ex} = \left(\frac{V_{CC}}{2}\right) + A_{v1}A_0 \sin(\omega t) \quad (3)$$

The voltage V_{ex} is applied to two electrodes immersed in the solution. During this process, the conductivity of the solution is proportional to the electric current that flows between two electrodes. The electric current is investigated and converted to the voltage by the current-to-voltage converter with the non-inverting input connected to the reference voltage $V_{ref} = V_{CC}/2$. Hence, its output voltage can be written as

$$V_1 = V_{ref} - \frac{R_3}{R_{sol}} A_{v1} A_0 \sin(2\pi f_0 t) \quad (4)$$

The absolute circuit is modified as shown in Figure 2, where the inverting amplifier U3/1 with the non-inverting input connected to the $V_{ref} = V_{CC}/2$ is connected with the rectifier U4/1. The absolute circuit is used to inverse the output voltage V_1 to the full wave voltage V_2 which can be approximated as

$$V_2 \cong V_{ref} + \left| \frac{R_3}{R_{sol}} \left(\frac{R_5}{R_4}\right) A_{v1} A_0 \sin(\omega t) \right| \quad (5)$$

or

$$V_2 \cong V_{ref} + \left| \frac{R_3}{R_{sol}} A_{v2} A_{v1} A_0 \sin(\omega t) \right| \quad (6)$$

where the voltage gain A_{v2} is equal to R_5/R_4 . In order to send the voltage V_2 to the microcontroller system, its DC component is adjusted by the clamper until the output voltage has zero DC component to fix the peak of the output voltage in the operating range of microcontroller (0-5 V). Thus, the output voltage V_3 can be represented by

$$V_3 \cong \left| \frac{R_3}{R_{sol}} A_{v2} A_{v1} A_0 \sin(\omega t) \right| \quad (7)$$

After that, the voltage V_3 is sent to the buffer U2 before converted to the DC voltage by the low-pass filter. The average output DC voltage is determined by multiplying the peak of the voltage V_3 by the constant $B = 0.637$. Then, the output DC voltage V_{out} can be approximately written as

$$V_{out} \cong B \left(\frac{R_3}{R_{sol}} A_{v2} A_{v1} A_0 \right) \quad (8)$$

The conductance G is defined as the reciprocal of the solution resistance R_{sol} . We can calculate the conductivity σ of solution by the formula $\sigma = GK$, where the K is a cell

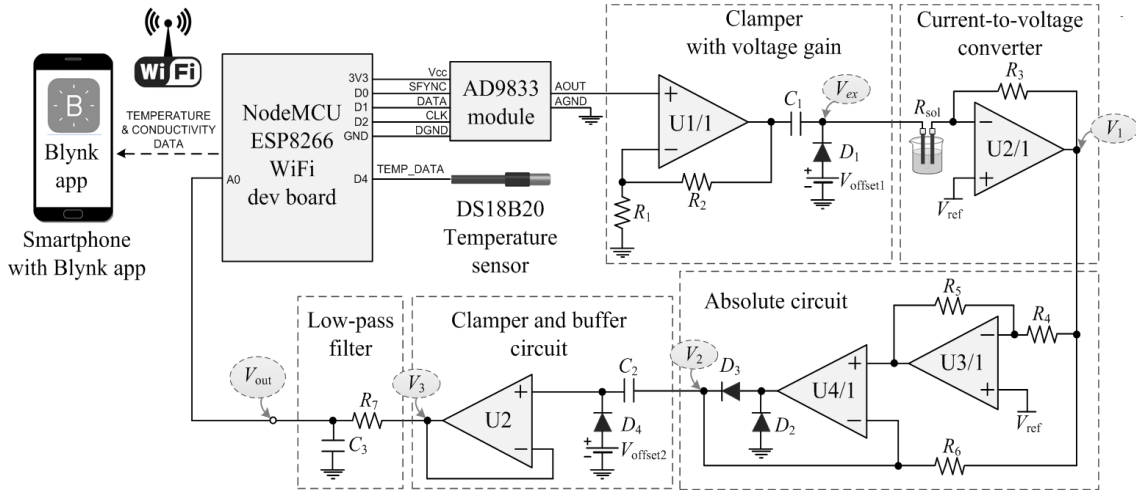


FIGURE 2. Proposed Internet-based conductivity measurement system

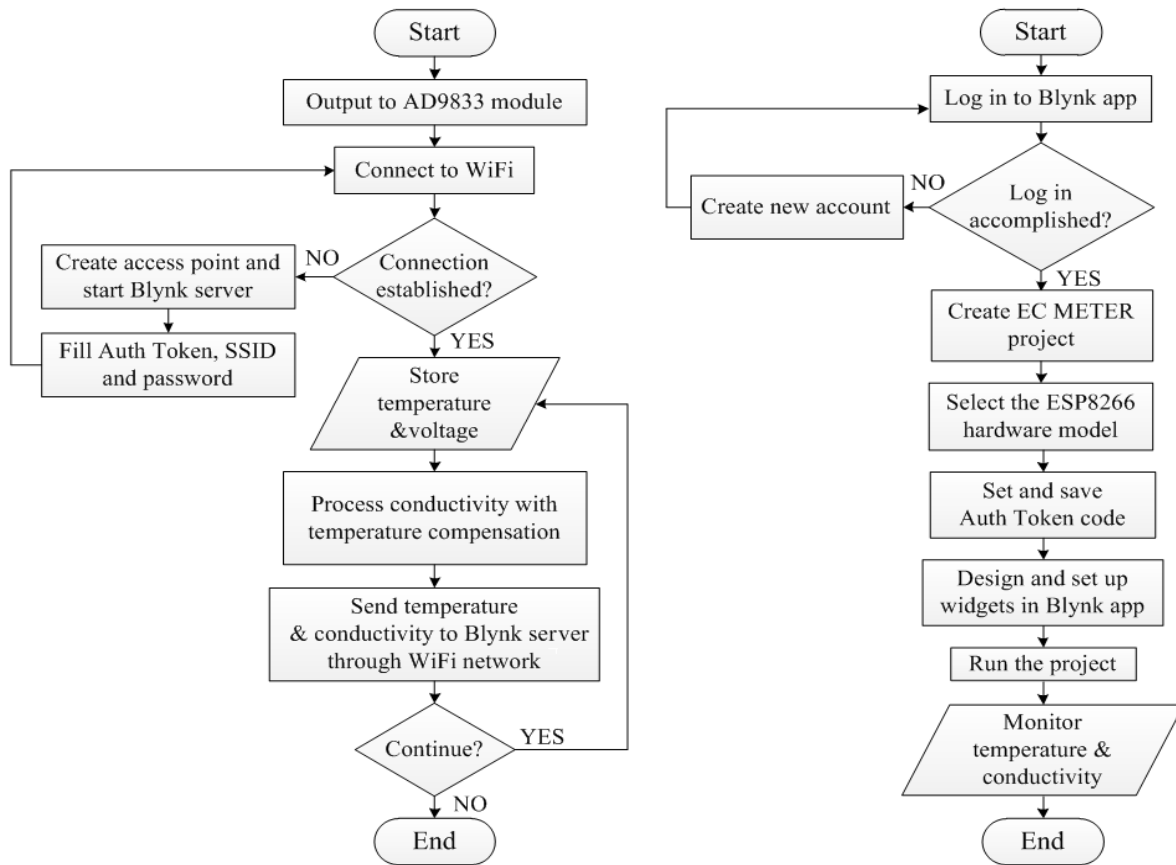
constant value. Then, the output voltage V_{out} can be rewritten as

$$V_{out} \cong BA_{v2}A_{v1}A_0 \left(\frac{R_3}{K} \right) \sigma \quad (9)$$

It has been noticed that the output voltage V_{out} achieved by the designed readout circuit is direct proportional to the conductivity σ . The unit of measurement for the conductivity is expressed in Siemens per centimeter (S/cm).

2.2. Microcontroller system and Blynk app. Software is developed for measuring the conductivity of solution through WiFi network. The designed software can be divided in the two highlighted parts: part of the NodeMCU ESP8266 WiFi dev board and the Blynk app on the smartphone. The NodeMCU ESP8266 WiFi dev board is a low cost microcontroller which has built in WiFi and analog-to-digital converter. It can allow any microcontroller to access to WiFi network by programming directly from the Arduino IDE and can also send data straight to the cloud. Figure 3(a) shows the procedure of the NodeMCU ESP8266 WiFi dev board for measuring the conductivity with temperature compensation. The digital pins D0-D2 of the NodeMCU ESP8266 WiFi dev board are used to drive the AD9833 module for generating the excitation voltage V_{ex} , demonstrated in Figure 2. After that the NodeMCU ESP8266 WiFi dev board is connected to WiFi. The digital pin D4 and the analog pin A0 are used to receive the temperature and output voltage V_{out} values, respectively. These obtained values are used to determine the conductivity at a common reference temperature. Then, the measured temperature and conductivity are sent to display on the smartphone by the Blynk app through WiFi network. In Figure 3(b), the EC METER project is created using the Blynk app to monitor the measured values from the NodeMCU ESP8266 WiFi dev board.

3. Experimental Setup. The readout circuit is designed using two commercially available operational amplifiers (opamps) with a single supply voltage. In Figure 2, the LM324 opamp, OP07 opamp and 1N4148 diodes are represented by the U1/1-U4/1 opamp, U2 opamp and D_1 - D_4 diode symbols, respectively. For experimental setup, the nominal values of circuit components are the following: $R_1 = 1 \text{ k}\Omega$, $R_2 = 2R_1$, $R_3 = R_4 = R_5 = R_6 = 1 \text{ k}\Omega$, $R_7 = 100 \text{ k}\Omega$, $C_1 = C_2 = 0.01 \text{ }\mu\text{F}$ and $C_3 = 1 \text{ }\mu\text{F}$. The supply voltage of the readout circuit was set to be 9 V. The NaCl solution with the conductivity in the range of 0.25-4.00 mS/cm, increased by 0.25 mS/cm was prepared. In this experiment, two electrodes were made from two carbon rods. The distance between them is 1 cm. The resin is used



(a) Flowchart for measuring the conductivity using the NodeMCU ESP8266 WiFi dev board

(b) Flowchart for creating the EC METER project using Blynk app

FIGURE 3. Flowchart for measuring the conductivity in the parts of the microcontroller system and the Blynk app

for handling construction to keep the distance between two electrodes stable. The excitation voltage V_{ex} with the frequency of 1 kHz and amplitude of 1.2 V_{p-p} was provided by the AD9833 module. After that, the investigated electric current which flows through the solution was converted to the voltage by the current-to-voltage converter before sent respectively to the absolute circuit, clamper and buffer circuit and low-pass filter. The output voltages of the readout circuit were sent to the NodeMCU ESP8266 WiFi dev board in order to evaluate the conductivity of the solution as explained in Section 2.

4. Results and Discussion. In order to verify the validity of the proposed system, the experiment was set up as discussed in the proposed method. From Equation (9), we have seen that the output voltage V_{out} is directly proportional to the conductivity σ . When we plot the results of the measured output voltage V_{out} against the conductivity input σ_{in} , the trend line of our results is approximately the straight line as expected in Equation (9).

Then, the relation between the output voltage V_{out} and the conductivity input σ_{in} in Figure 4 is used to find the conductivity σ_T at arbitrary temperature as shown in Figure 5. It is found that the conductivity σ_T increases linearly with increasing the solution temperature T . This is because increasing temperature makes the ions in the solution move faster and the conductivity increases. The linear temperature correction can be described by

$$\sigma_{T_{ref}} = \frac{100}{100 + \theta(T - T_{ref})} \sigma_T \quad (10)$$

or

$$\sigma_T = \frac{\sigma_{T_{ref}}\theta}{100}T - \left(\frac{\sigma_{T_{ref}}T_{ref}\theta}{100} + \sigma_{T_{ref}} \right) \tag{11}$$

where $\sigma_{T_{ref}}$ is the conductivity at T_{ref} , σ_T is the conductivity at T , T_{ref} is the reference temperature which is here 25°C, T is the solution temperature and θ is the temperature coefficient. The θ value can be calculated using the slope of the straight lines in Figure 5 as seen in Equation (11).

In this experiment, the θ values obtained at the conductivity input of 1, 2 and 3 mS/cm are 2.00, 1.93 and 2.02%/°C. The average of these values is 1.98%/°C. Then, the average

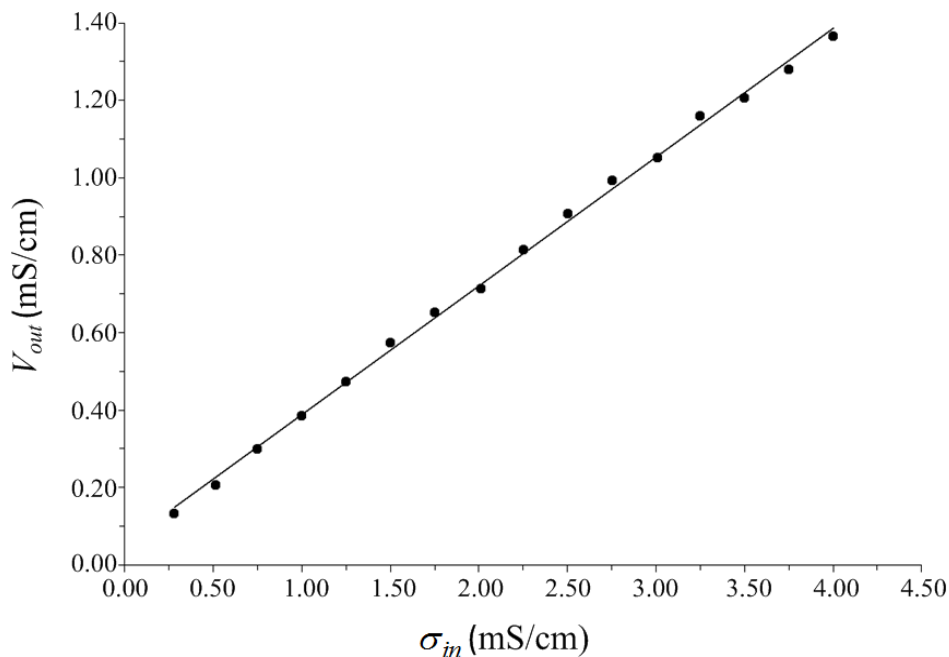


FIGURE 4. Relation between the conductivity input and measured output voltage

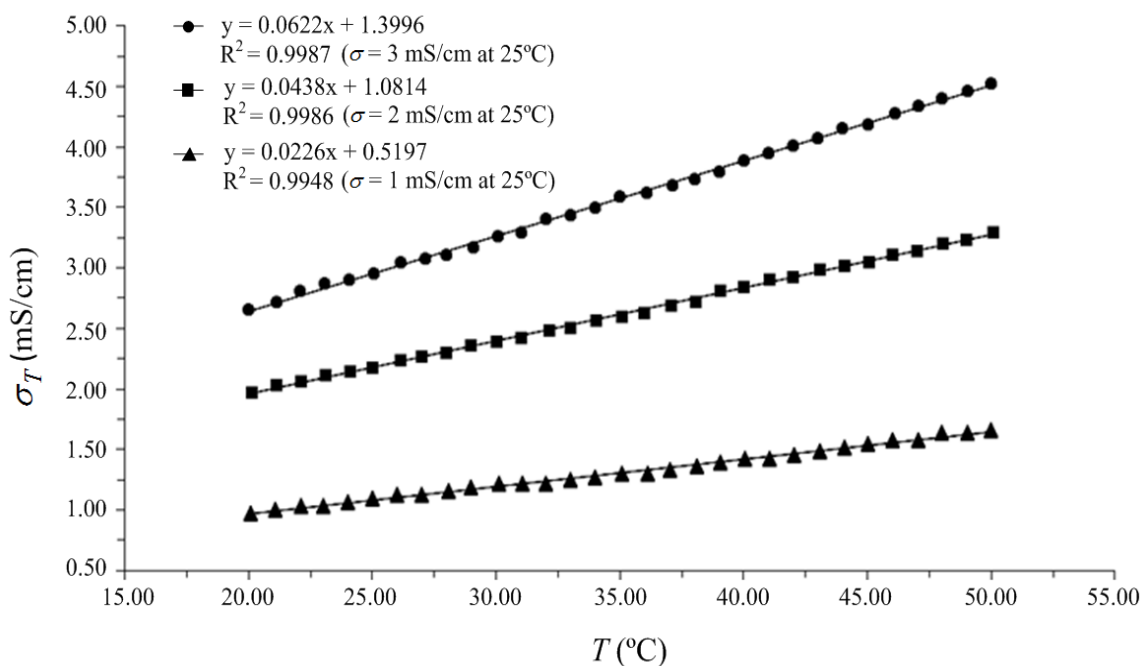


FIGURE 5. Plots of the conductivity output σ against the solution temperatures

value is replaced in Equation (10) in order to find the conductivity at T_{ref} . After that, we test the average value of θ by measuring the conductivity of 1, 2 and 3 mS/cm at temperatures 20, 30 and 35°C and calculate the conductivity at T_{ref} , compared with the conductivity at T_{ref} measured by the standard EC meter. It is found that the results from our proposed system with self-temperature compensation has a maximum error of 4.79% of full scale. We can monitor the solution temperature and the conductivity at T_{ref} through a smartphone via the Blynk app as demonstrated in Figure 6.

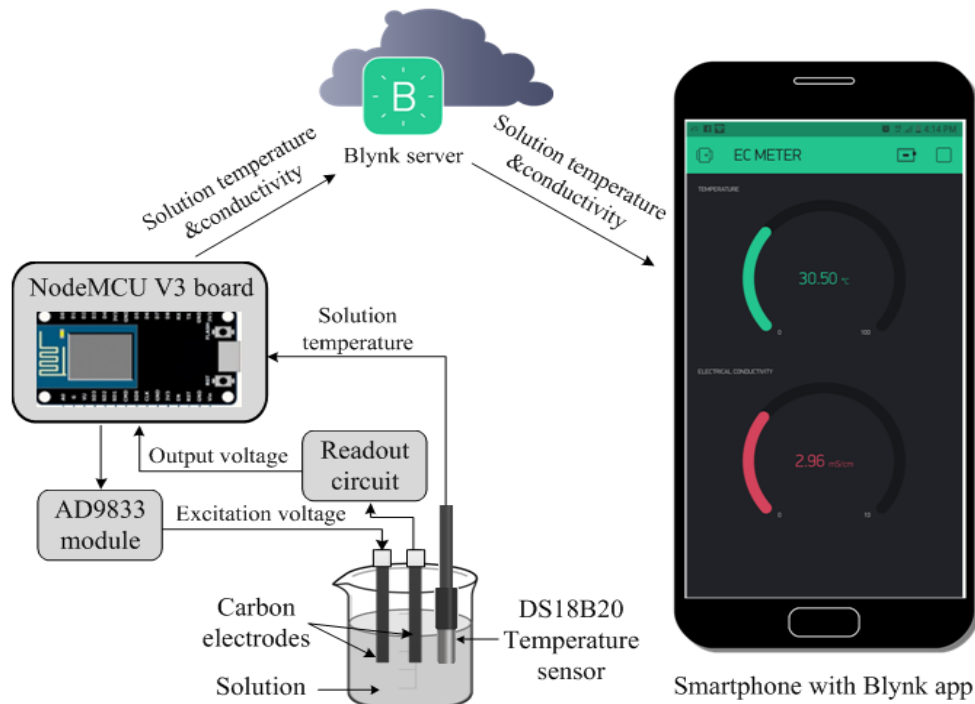


FIGURE 6. Displaying the temperature and conductivity on a smartphone

5. Conclusions. The goal of this paper was to design the Internet-based conductivity measurement system consisting of low-cost electronic devices: the AD9833 module, two single-supply opamps, DS18B20 temperature sensor and NodeMCU ESP8266 WiFi dev board. The experimental results show that the measured output voltage is linearly related to the conductivity input. The linear relation between the temperature and conductivity is also found. The obtained θ 's average value of 1.98%/°C is used to evaluate the conductivity at the reference temperature although the solution temperature are not the reference temperature. After measuring the conductivity of 1, 2 and 3 mS/cm at temperatures 20, 30 and 35°C, the conductivity at T_{ref} measured by the proposed system is compared with a standard EC meter. It is found that a maximum error is 4.79% of full scale. Moreover, we expect that the proposed system would help to complete the nutrient solution monitoring system for hydroponic farm or smart farm. In the future, we will develop the system that can measure and control other important parameters for plant growing, such as light and moisture.

Acknowledgment. This research was financially supported by National Science and Technology Development Agency (NSTDA), Thailand.

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