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The Determination of Water Turbidity Using Interdigital Capacitor Sensor

***Abstract**. This research presents the determination of water turbidity using an interdigital capacitance sensor. In this study's experiments, murky water was mixed with thirteen samples that ranged from 0 to 1000 NTU using Kaolin clay, and the capacitance value was measured from the interdigital capacitor sensor on five models at different lengths of L. In the experiment, the frequency adjustment of the supply was used to compare the capacitance of the interdigital capacitor sensor. The results indicate that the value capacitance of the sensor rises as the bias frequency reduces. When supplying voltage from a 1-volt source at a frequency of 500 Hz, the maximum capacitance is 5945.28 pF, so the range can be expanded to measure the water level more accurately and to continue developing a standard turbidity meter system. The maximum capacitance is 5945.28 pF when supplying voltage from a 1-volt source at a frequency of 500 Hz, so the range can be expanded to measure the water level more precisely and continue to develop a standard turbidity meter system.*

***Streszczenie.** W pracy przedstawiono wyznaczanie mętności wody za pomocą pojemnościowego czujnika międzypalcowego. W eksperymentach tego badania mętną wodę zmieszano z trzynastoma próbkami o zakresie od 0 do 1000 NTU przy użyciu glinki kaolinowej, a wartość pojemności zmierzono z międzypalcowego czujnika kondensatora na pięciu modelach przy różnych długościach L. W eksperymencie regulacja częstotliwości zasilania wykorzystano do porównania pojemności międzycyfrowego czujnika kondensatora. Wyniki wskazują, że wartość pojemności czujnika wzrasta wraz ze zmniejszaniem się częstotliwości polaryzacji. Przy zasilaniu napięciem ze źródła 1 V o częstotliwości 500 Hz maksymalna pojemność wynosi 5945,28 pF, więc zakres można rozszerzyć, aby dokładniej mierzyć poziom wody i kontynuować rozwój standardowego systemu miernika mętności. Maksymalna pojemność wynosi 5945,28 pF przy zasilaniu napięciem ze źródła 1 V przy częstotliwości 500 Hz, więc zakres można rozszerzyć, aby dokładniej mierzyć poziom wody i kontynuować rozwój standardowego systemu miernika mętności. (**Oznaczanie mętności wody za pomocą międzycyfrowego czujnika pojemnościowego**)*

Keywords: Water Turbidity, Nephelometic Turbidity Units, Interdigital Capacitor Sensor
Słowa kluczowe: Mętność wody, nefelometryczne jednostki mętności, międzypalcowy czujnik pojemnościowy

Introduction

Currently, the development of sensors for measuring instruments is widespread in industrial applications, weather forecasting, and smart agriculture [1–5], such as measuring the amount of water in the air, measuring the specificities of various liquids, measuring water quality, etc. The interdigital electrode capacitor [6–10] is a popular sensor that is still used in the above-mentioned applications. The design is simple and uncomplicated. It is a measure of the desired specific value, such as turbid water or adulteration in rubber juice.

From literature reviews, research on how sensors develop has grown in a number of different ways. Researchers created the interdigital electrode capacitor (IDC) sensor to measure the insulation of electrical wires, moisture in concrete soil moisture, percentage of sugar concentration, and adulteration in raw milk [11-15]. The research mentioned above used a printed circuit board, causing the liquid contact to not fully contact the sensor, resulting in a low capacitance value and a narrow measurement range. It is not detailed, but there have been studies that have solved the problem since expanding. The ribs of the interdigital capacitor were widened and double-sided, and the epoxy strips were removed for better contact with the liquid [16–17] Therefore, the researcher presented the novel technique of an interdigital capacitor level sensor with non-substrates on the printed circuit board (PCB), resulting in an increased capacitance value between 10 and 300 nF that is more detailed and can be applied to applications that require detailed water level measurements.

Theory and Principles

The basic idea of capacitance is that two metallic plates sandwiched between an insulator retain energy in the form of an electric field. The relationship between the current through the capacitor and the voltage across the capacitor over time is shown by Equation 1, and the capacitance at the passive resistance at alternating current is inverselyproportional to capacitance and frequency.

$$i_C = C\frac{dv_C}{dt} \tag{1}$$

$$X_C = \frac{1}{2\pi fc} \tag{2}$$

The interdigital capacitor sensor uses the principle of paralleling the copper discs. There are positive and negative poles when the copper is in parallel, resulting in increased capacitance when capacitance is measured in Farads (Farad, F). The structure of the interdigital capacitor sensor is shown in Fig. 1.

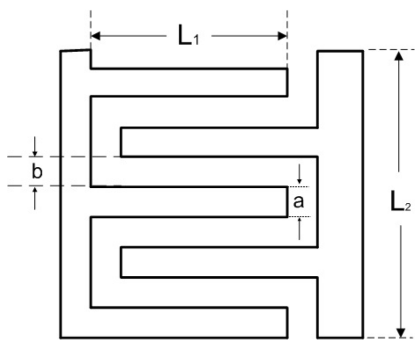

Fig. 1 Structure of interdigital capacitor sensor [16]

The design of the C_{pu} value in Equation 3 has the following components: ε_0 is the permittivity of free space (8.854×10−12 F/m), ε_1 is the relative permittivity of the material under test, ε_2 is the relative permittivity of material between electrodes, and ε_3 is the relative permittivity of the PCB substrate. The K is elliptic integral the first of kind, with a being the width of the tines and b being the spacing of the tines. Finding the total capacitance of the interdigital capacitor level sensor in Equation 4 consists of L being the length of the teeth and N being the number of teeth [16].

(3)
$$C_{PU} = \varepsilon_0 \left(\frac{\varepsilon_1 + \varepsilon_3}{2}\right) \frac{K\left(\sqrt{1-\left(\frac{a}{b}\right)^2}\right)}{K\left(\frac{a}{b}\right)} + \varepsilon_0 \varepsilon_2 \frac{h}{a}$$

(4)
$$C = C_{pu}(N-1)L$$

The researcher has designed the interdigital capacitor sensor by substituting Equation (3-4) to find the capacitance value by entering the parameters h = 0.105 mm, a = 3 mm, b = 3 mm, and N = 13. The free space permittivity is $\varepsilon 1 = \varepsilon 2 = 1$, and the substrate's (Epoxy) relative permittivity is $\varepsilon 3 = 4.6$. The capacitance varies according to the contact between the copper plate and the water and the turbidity of the water generated.

Experimental method

The experimental method to compare the capacitance from turbid water preparation to measure turbidity uses kaolin clay with the chemical formula Al2O3, 2 SiO2, and 2 H2O [18] mixed by the Nephi method, and the emitted concentration through a standard turbidity solution is expressed in NTU (Nephelometic Turbidity Units) [19-22]. Thirteen samples were made at 0, 50, 100, 200, 300, 400, 500, 600, 700, 800, 900, and 1000 NTU, scientifically mixed, and compared with the HACH 2100Q standard turbidimeter. The example in the experiment is shown in Figure 2.

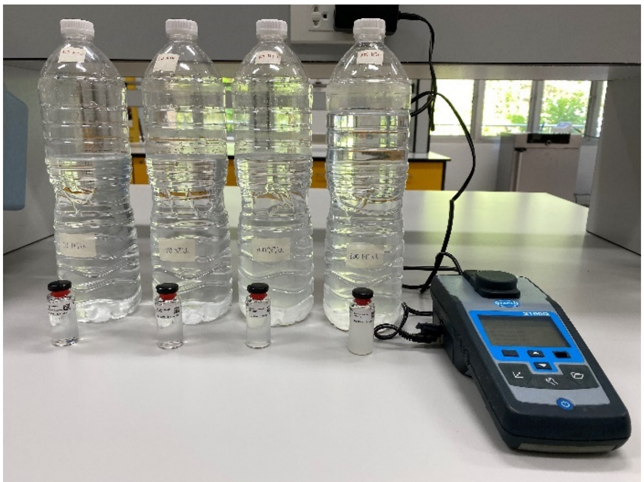

Fig. 2 Setup of Water Turbidity

The capacitance measurements from interdigital capacitor sensor printed circuit boards with epoxy at the relative permittivity of substrate $\varepsilon_3 = 4.6$ and thickness copper of h = 0.105 mm. The five models with different sizes a, b, and L are shown in Table 1.

Table 1. Shows the peak voltage (V_{peak}) values after adjusting the capacitor (C4) and inductance values (L4).

IDC model	a (mm.)	b (mm.)	L (mm.)
1	3	3	10
2	3	3	20
3	3	3	30
4	3	3	40
5	3	3	50

Fig. 3 Setup of Water Turbidity The fabricated the Interdigital Capacitor Sensor.

Results

Fig. 4 shows the capacitance measurement of the interdigital capacitor sensor using an LCR meter (Keysight E4980AL) that has a frequency measurement feature from 20 Hz to 500 Hz with a measurement accuracy of 0.01% and includes Kelvin clip leads. The experimental method measures measurements using parallel cycle mode, with each model measuring 1000, 900, 800, 700, 600, 500, 400, 300, 200, 100, 50 and 0 NTU for 12 measurement intervals. The measurement was repeated three times to find the best capacitance and frequency values. The three measurement frequencies are 10 kHz, 1 kHz, and 500 Hz.

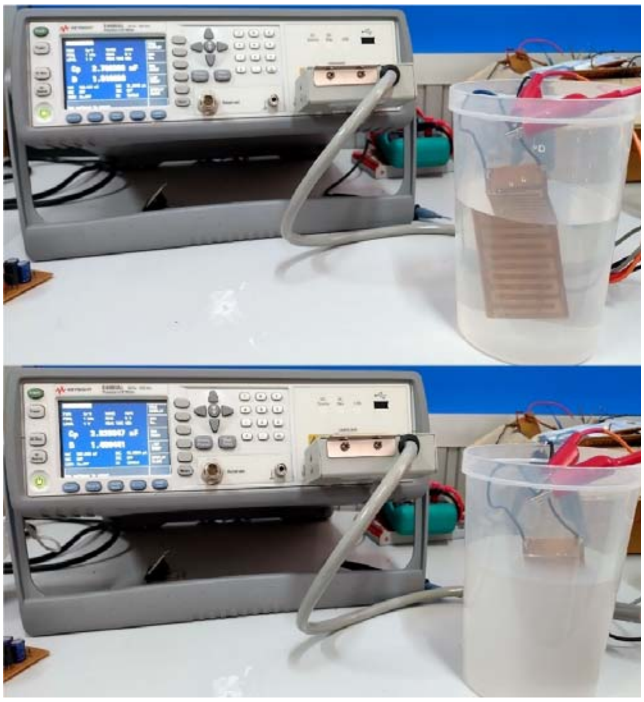

Fig.4. The experimental for measurement capacitance value.

The result of this experiment was to measure the capacitance using a scale according to five models (Table 1) at frequencies of 10 kHz, 1 kHz, and 500 Hz to prove the difference in the correlation coefficient. The experiment at a frequency of 10 kHz yielded the following results: Model 1 at length L = 10 mm had a capacitance between 292.99 pF and 438.55 pF and a correlation coefficient (R2) of 0.9692; Model 2 at length L = 20 mm had a capacitance between 306.02 pF and 698.44 pF and a correlation coefficient of 0.9037; Model 3 at length L = 30 mm had a capacitance between 735.44 pF and 779.75 pF and a correlation coefficient (R2) of 0.9667; Model 4 at length L = 40 mm had a capacitance between 1167.52 pF and 1250.82 pF and a correlation coefficient of 0.9852; Model 5 at length L = 50 mm had a capacitance between 1205.91 pF and 1378.77 pF and a correlation coefficient of 0.9618. These results are shown in Fig. 5.

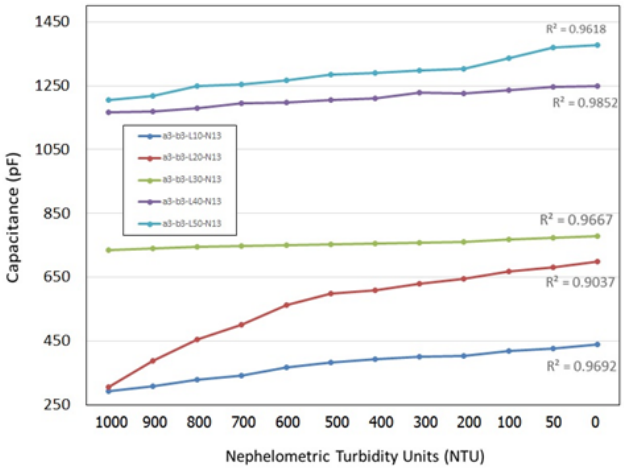

Fig.5. The result of capacitance value for 10KHz (5 model)

The experimental results in Figure 6 use a frequency of 1 kHz in the experimental results as follows: Model 1 had a capacitance between 292.99 pF and 438.55 pF and a correlation coefficient of 0.9692; Model 2 had a capacitance between 306.02 pF and 698.44 pF and a correlation coefficient of 0.9037; Model 3 had a capacitance between 735.44 pF and 779.75 pF and a correlation coefficient of 0.9667; Model 4 had a capacitance between 1167.52 pF and 1250.82 pF and a correlation coefficient of 0.9852; Model 5 had a capacitance between 1205.91 pF and 1378.77 pF and a correlation coefficient of 0.9618.

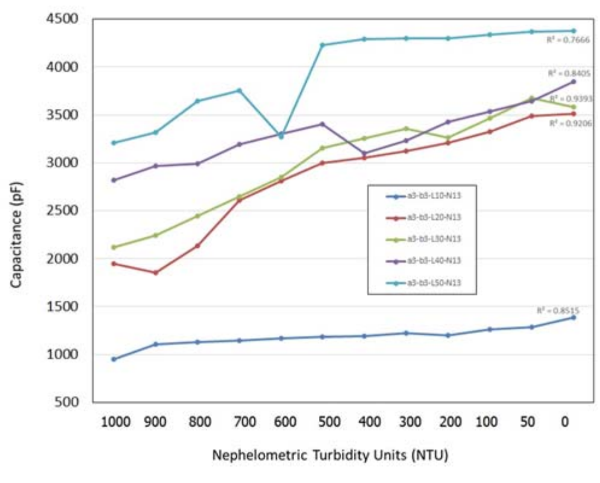

Fig.6. The result of capacitance value for 1KHz (5 model)

The results of the experiment performed at a frequency of 500 Hz were as follows: The capacitance ranged from 1163.14 to 2308.11 pF, and the correlation coefficient was 0.9799 for Model 1. The capacitance ranged from 1810.45 pF to 3512.11 pF, and the correlation coefficient was 0.9983 for Model 2. The capacitance ranged from 2112.55 pF to 5492.74 pF, and the correlation coefficient was 0.9766 for Model 3. The capacitance ranged from 2395.84 pF to 5945.31 pF, and the correlation coefficient was 0.97 for Model 4. The capacitance ranged from 2574.17 pF to 4925.84 pF, and the correlation coefficient was 0.9905 for Model 3. Fig. 7 shows the results of this experiment.

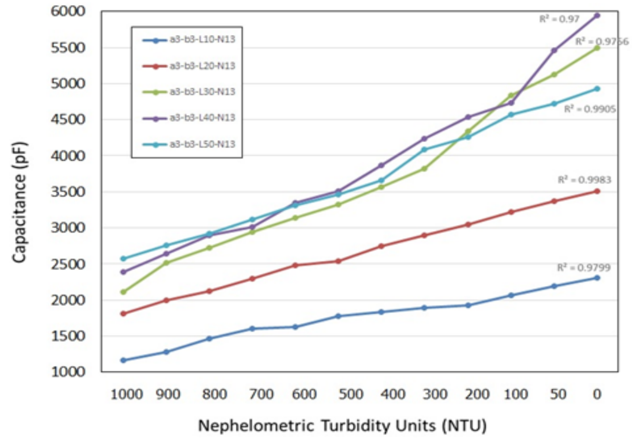

Fig.7. The result of capacitance value for 500Hz (5 model) .

Conclusions

This research presents the determination of water turbidity using an interdigital capacitance sensor. The experiment was carried out by combining turbid water with Kaolin clay using the nephelometric method and comparing the intensity of the transmitted light, which is how standard turbidity solutions are measured in NTU. The interdigital capacitor sensor in five models with different L-value lengths was used to measure capacitance. The experimental results show that the frequency of the capacitance measurement source increases when the frequency decreases, causing increases in the capacitance. At a voltage of 1 volt and a frequency of 500 Hz, the maximum capacitance is 2395-5945.28 pF. The correlation coefficient was 0.9704, but the best correlation coefficient in the range of magnitudes at L = 20 mm at 500 Hz was 0.9983. So, it can increase the measuring range to get a better idea of the water level so that it can be used with a microcontroller to convert value standards and make a turbidity meter system that works better.

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