Preliminary study plate capacitor as a Plethysmometer sensor

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Abstract. In this research, we successfully designed a capacitor plate as a Plethysmometer sensor with a measured volume capacity of 1.5 ml, this capacity is obtained from a capacitor plate with a thickness of 0.5 mm width of 15 mm and a height of 200 mm. The sensitivity obtained is 0.36 / 0.1ml with a standard deviation of 0.012. The above results show that the linear capacitor plate sensor for the tested area has sufficient sensitivity that can measure the change of 0.1 ml to be used as a transducer in the Plethysmometer.

1. Introduction
The application of capacitive sensors for distance measurement has been one of the studies of the researchers. This cannot be separated from the ease of manufacture [1] and the ability to detect a wide range including the water [11]. The application of capacitive sensors for water level is also examined [3, 11], in this research, capacitive sensor is used for measure water level height in order cm. Capacitive sensor application for small displacement also observed [2], [5]. Capacitive sensor implementation also shows high precision for long distance measurement [8].

2. Plethysmometer and Plethysmometer sensor
Plethysmometer is a rat paw edema gauge. The working principle of Plethysmometer generally works based on Archimedes Law. Based on the displacement of the measuring fluid when the rat's paw is immersed in the measuring vessel, it will be known the volume of rat's paw swelling.

Most design work areas range from 0-7 ml for rats and 0 to 0.5 ml for mice as in Plethysmometer 37140 made by Ugo basile which is widely used by researchers [6]. Observation of volume change can be done visually it is plural used for manual plethysmometer, while for plethysmometer used sensor. The sensors used are generally conductive sensors such as plethysmometer 37140 Ugo basile. However, with this method, a special sensor fluid is required that the barrier of the type is known and has the potential to change due to contamination of the dirt from the mouse's feet when immersed.

In addition to conductivity based, the volume measurement can be based on the specific gravity of the sensor fluid [6]. Microscale scales to measure the weight of the moving sensor fluid, this method is accurate but less practical as it is still manual. In this research, capacitive sensors will be developed as sensors reader volume changes which will be applied to Plethysmometer.

3. Material and methods
The Plethysmometer will be designed based on Archimedes law, so that the outline contains the following components:

a. Water vessel
b. Tube Drop legs rat
c. The measuring tube contains a capacitive sensor

Water vessels are used to hold water. Water is used as an Archimedes fluid [6] whose volumes change will be read. Water from this vessel will be inserted into the capacitive sensor portion using the valve. Generally, for fluids a special substance is used, such as mercury in a manual plethysmometer, but water can be used as a fluid in a plethysmometer [6].

The immersing vessel is where the operator inserts the mouse's legs into it, while the measuring vessel is the vessel in which the capacitive sensor is installed. Between the water vessel and the dye is connected through the valve in order to adjust the amount of fluid volume present in the rat foot vessel and also equipped with a valve for the discharge of the unused fluid. The capacitive sensor portion is a U-tube. The full image of the capacitive sensor section is shown in figure 1.

![Figure 1. Plethysmometer sensor from front view.](image)

Capacitive sensor with the shape of this U pipe has two tubes of tube sensor and tube measuring or tube rat feet, sensor tubes containing capacitive sensors are composed of two plates as an electrode. The length of the plate is 200, the distance between the plate is 0.5 mm and the width is 15 mm. The sensor tube construction is shown in figure 2. In figure 2 the electrode plate will be placed in the tube. The electrode plate will form a capacitor as shown in figure 3.

![Figure 2. Plates capacitor inside the tube.](image)
Figure 3. Modeling the capacitor of Plethysmometer sensor.

Referring to the figure 3, the total plate area, $A$ is 3000 mm$^2$, $d = 0.5$ mm is the distance between plates, so the volume is 1500 m$^3$ or 1.5 ml. The capacitance total of the sensor is the sum of capacitance capacitor with area of $A_{\text{air}}$ and the capacitance of the sensor with the width of $A_{\text{water}}$ or can be written in equation (1).

$$
C_{\text{sensor}} = C_{\text{water}} + C_{\text{air}}
$$

$$
C_{\text{sensor}} = \varepsilon_{\text{water}} \varepsilon_0 \frac{A_{\text{water}}}{d} + \varepsilon_{\text{air}} \frac{A_{\text{air}}}{d}
$$

$$
\varepsilon_{\text{water}} = 80
$$

$$
A_{\text{air}} = A - A_{\text{water}}
$$

$$
C_{\text{sensor}} = \varepsilon_{\text{air}} \frac{79x A_{\text{water}} + A}{d}
$$

$$
\Delta C_{\text{sensor}} \approx 79 \Delta A_{\text{water}}
$$

Seen in the equation (2), the change in the volume of the filled sensor of water will be proportional to the magnitude of the capacitance change of the sensor.

4. Result and Comprehension

Sensor testing is done by inserting fluids into the sensor tube in sequence of 0.1ml. The readings of capacitance values are performed using LCR-9073. Table 1 shows the intended test results.

Based on table 1, the mean sensitivity was obtained at 0.37 uF / 0.1 ml and 0.36 uF / 0.1 ml with standard deviation of 0.008 for the first data and 0.013 for the second data. These values indicate good repeat ability and resolution.
Table 1. The test results.

| No. | Volume, ml | C, uF | ΔC, uF | No. | Volume, ml | C, uF | ΔC, uF |
|-----|------------|-------|--------|-----|------------|-------|--------|
| 1   | 0.1        | 5.34  | 0.37   | 1   | 0.1        | 5.26  | 0.37   |
| 2   | 0.2        | 5.71  | 0.37   | 2   | 0.2        | 5.63  | 0.37   |
| 3   | 0.3        | 6.09  | 0.38   | 3   | 0.3        | 6.01  | 0.38   |
| 4   | 0.4        | 6.46  | 0.37   | 4   | 0.4        | 6.34  | 0.33   |
| 5   | 0.5        | 6.82  | 0.36   | 5   | 0.5        | 6.07  | 0.36   |
| 6   | 0.6        | 7.20  | 0.38   | 6   | 0.6        | 7.06  | 0.36   |
| 7   | 0.7        | 7.57  | 0.37   | 7   | 0.7        | 7.43  | 0.37   |
| 8   | 0.8        | 7.93  | 0.36   | 8   | 0.8        | 7.80  | 0.37   |
| 9   | 0.9        | 8.31  | 0.38   | 9   | 0.9        | 8.15  | 0.35   |
| 10  | 1.0        | 8.68  | 0.37   | 10  | 1.0        | 8.51  | 0.36   |
| 11  | 1.1        | 9.04  | 0.36   | 11  | 1.1        | 8.88  | 0.37   |
| 12  | 1.2        | 9.40  | 0.36   | 12  | 1.2        | 9.23  | 0.35   |
| 13  | 1.3        | 9.77  | 0.37   | 13  | 1.3        | 9.59  | 0.36   |
| 14  | 1.4        | 10.13 | 0.36   | 14  | 1.4        | 9.96  | 0.37   |

Mean: 0.37
Standard deviation=0.008

Mean: 0.36
Standard deviation=0.013

The results of the first and second data experiments also show a linear nature, as shown in the first graph and the graph into figure 4 and figure 5.

![Figure 4](image1.png)

**Figure 4.** Data plotting from first sampled data.

![Figure 5](image2.png)

**Figure 5.** Data plotting from second sampled data.

Modeling with linear regression yields an equation $Y = 3.687*X + 4.981$, for the first graph and $Y = 3.607*X + 4.906$ for the second graph. These results indicate that the capacitive sensor being tested has a linear character.
5. Conclusion
In this study successfully demonstrated the feasibility of plate capacitors to be used as sensors in the Plethysmometer measuring instrument. Sensor made has a capacity of 1.5 ml, this capacity is obtained from the plate capacitor with a distance between plate 0.5 mm, width of the plate 15 mm and height 200 mm.

The results show that the sensor has a good sensitivity of 0.36 / 0.1 ml, and has a good repeatability is shown by a small standard deviation value of 0.012. The sensor also shows a linear character that can be approximated by a linear equation $y = 98998 x + 333$.

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