Investigation on Low Cost Capacitive Flood Sensor Operation and Optimization Based on Arduino Microcontroller

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***Abstract*— Flash flood problems often occurred on urban area. In Kuala Lumpur, SMART tunnel is built to handle this problem. Using a same concept, a low cost capacitive flood sensor is developed to overcome this problem on certain area around Kuala Lumpur. The development of flood sensor is based on Arduino microcontroller which used CapacitiveSensor library to detect the flood water level. The flood sensor is constructed from copper media which is implemented on the FR-4 PCB. The sensitivity of the flood sensor is tested under two different methods which used a single and parallel-plate capacitor respectively. The relationship between flood sensor sensitivity with different resistance values, temperature, size and gap between plates is investigated. All measurements taken were in an arbitrary unit which indicated the capacitance of the sensor. From the investigation done on the capacitive flood sensor, it is described that the flood sensor is easy to implement, low cost and has a high sensitivity and reliability of the results.**

***Index Terms* — Capacitive flood sensor, single-plate capacitor, parallel-plate capacitor, sensitivity.**

I. Introduction

Flooding problems always occurred in the largest cities such as Kuala Lumpur which has a record of large number of populations [1]. Flooding problems caused major traffic congestion during rainy season in Kuala Lumpur and also certain area around it. To deal with this problem, a SMART tunnel is built by the government to overcome the traffic congestion and to alleviate the flooding problem. SMART is an acronym for Stormwater Management and Road Tunnel, consists of two main tunnels which are the storm water tunnel and motorway tunnel [2]. The storm water tunnel used to divert the flood water into the bypass tunnel which located in the lower channel of the motorway tunnel thus preventing spillover on the road. The motorway tunnel provided the motorist with an alternative route linked with the city centre to avoid the traffic congestion.

Using the same concept of SMART tunnel, this project developed a low cost flood sensor system to detect the flood water level when flash flood occurred. Instead of using a high technology, this project used FR-4 printed circuit board (PCB) to construct the flood sensor. FR-4 is a composed material made from a woven fiberglass cloth with an epoxy resin binder [3]. The Arduino microcontroller is used to control the whole system process. Arduino is an open source single-board microcontroller which comes with a free software development environment. Instead of using FTDI USB-to-serial driver chip for other microcontrollers, Arduino features the Atmega16U2 programmed as a USB-to-serial converter which appears as a virtual com port to software on the computer [4].

This paper will discuss on the low cost capacitive flood sensor operation and optimization. This paper is divided into several sections. Section 2 briefly explains on the capacitive sensor theory and operation. Section 3 explains the system development method. Section 4 briefly explains on flood sensor system. Section 5 explains about the whole process programming in Arduino Uno microcontroller. Section 6 mentioned the method used to analyze the capacitive flood sensor. Section 7 stated the results and the discussions on the analysis done. In last section, everything is concluded and the recommendation to optimize the performance of the capacitive flood sensor for future development is stated.

II. Capacitive Sensor

Capacitive sensor can be used to directly detect variety things such as motion, chemical composition and also electric field [5]. But in this application, capacitive sensor indirectly detects the fluid (water) level and converted the variables into dielectric constant. Theoretically, capacitor is defined as the ratio between the charge, Q and the voltage difference, V between them or in other word means capacitance [6]. The relationships are shown in Eq. (1).

$$C = \frac{Q}{V} \tag{1}$$

Capacitance is a property that exists between any two conductive surfaces within some reasonable proximity [7]. It is described as how the electric field between two conductive objects with a space between them responds to the voltage difference applied to them. When a voltage is applied to the conductive objects, an electric field is created between them. The electric field caused positive and negative charges to gather on each conductive plate. Alternating voltage applied to the sensor resulting in charges to continue to change their position due to the changing of voltage polarity. The sensor detected the alternating electric current produced from the movement of charges. The amount of current flow is determined by the capacitance. And the capacitance is determined by area, distances and type of nonconductive material between the plates [8]. The relationships of parameters which influence the variation of the capacitance are shown in Eq. (2).

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d} \tag{2}$$

where ε_0 : Constant 8.854 x 10^{-12} (F/m)
ε_r : Relative permittivity of dielectric constant
A : Area of plate (m^2)
d : Distance between two conductive plates (m)

The equation in Eq. (2) shows that the capacitance is directly proportional to the surface area and dielectric constant of material between the conducting plates. Therefore, any changes in area of plate and distance between the plates will affect the capacitance reading.

III. METHODOLOGY

The developed system is divided into two parts. As shown in Fig 1, the first part is on hardware and software implementation of flood sensor system.

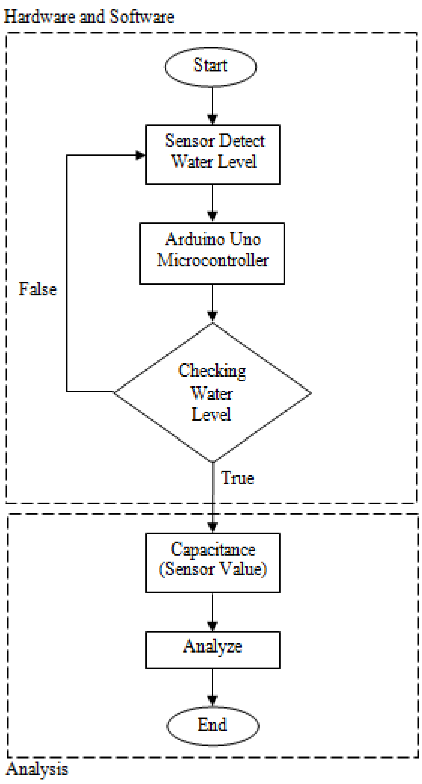

Fig 1. Flowchart of analyzing capacitive sensor

In this system, the water level is detected by the flood sensor. The water level is then compared to determine whether it is on the safest, caution or dangerous level respectively. The resulted signal is then will toggle the Arduino Uno through serial communication port. Arduino Uno printed the capacitances which are in arbitrary unit (sensor value) on the serial monitor. The sensor values are analyzed to determine the capacitive sensor sensitivity and accuracy.

IV. FLOOD SENSOR SYSTEM

The flood sensor system is developed based on Arduino Uno microcontroller. Arduino Uno is a microcontroller board based on Atmega328. It has 6 analog inputs, 14 digital input/output ports where 6 of it can be used as a PWM output ports. For this system, the Arduino Uno microcontroller used the CapacitiveSensor library to turn two of its digital input/output pins into a capacitive sensor. The two pins here act as send pin and receive pin respectively. The receive pin is the sensor terminal. Fig 2 shows the construction of the flood sensor. The sensor only required high resistor value and two plates of FR-4 PCB covered with insulated material. One plate of FR-4 PCB is connected to the receive pin to sense the electrical capacitance of water. While the other plate is connected to the ground plane to stabilize the sensor values and also increased sensor sensitivity. The LEDs represent the indicator for flood water level. The green, yellow and red LED will turn on when the flood water level reached the safest, caution and dangerous levels respectively. If the flood water reached caution level, the buzzer will produced an alert sound as a warning signed. The red LED will turn on when the flood water have reached the dangerous level and the water are drained using the water pump.

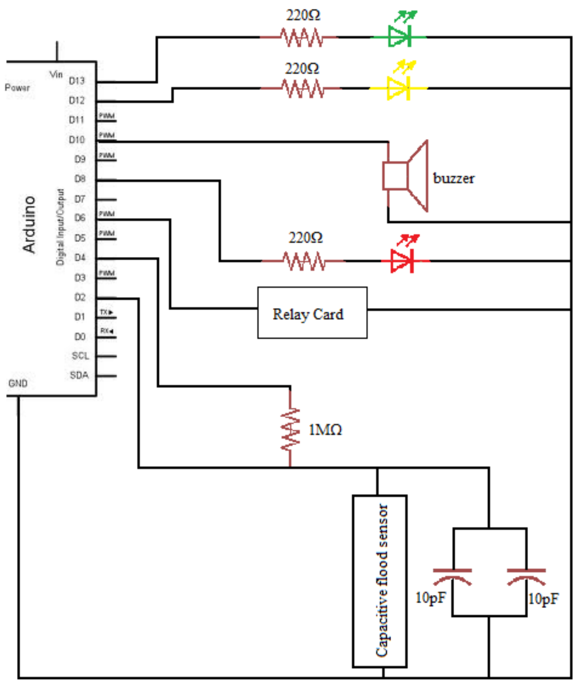

Fig 2. Minimum circuitry of flood sensor system

As shown in Fig 3, the water pump is controlled by the relay card which received its signal from Arduino Uno microcontroller.

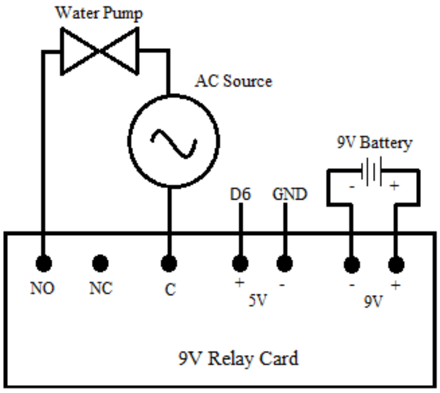

Fig 3. The relay card

V. ARDUINO PROGRAMMING

CapacitiveSensor library is used in Arduino Uno programming to turn the Arduino pins into capacitive sensor. The send pin is toggled by the CapacitiveSensor method to a new state. And electrical pulse is then sent to the receive pin to change to the same state as the send pin. Based on the changes of the state, the CapacitiveSensor library was able to detect a capacitance values which are reported and printed on the serial monitor in sensor value unit. The whole programming process for this flood sensor system is shown in Fig 4.

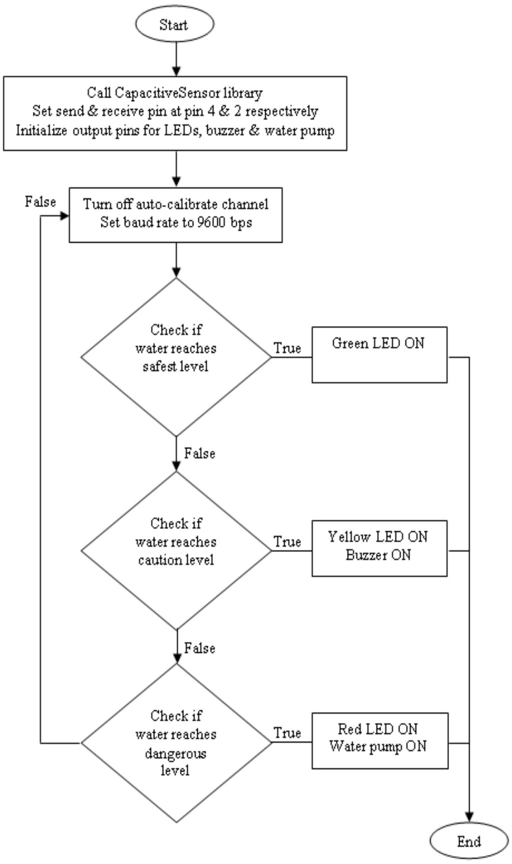

Fig 4. Flowchart of whole programming

VI. ANALYSIS METHODS

Analysis on the flood sensor is done using two different methods which are based on single plate capacitive sensor and parallel-plate capacitive sensor as shown in Fig 5 and Fig 6 respectively. The relationship of capacitance with different size of sensing area and distances between plates is investigated.

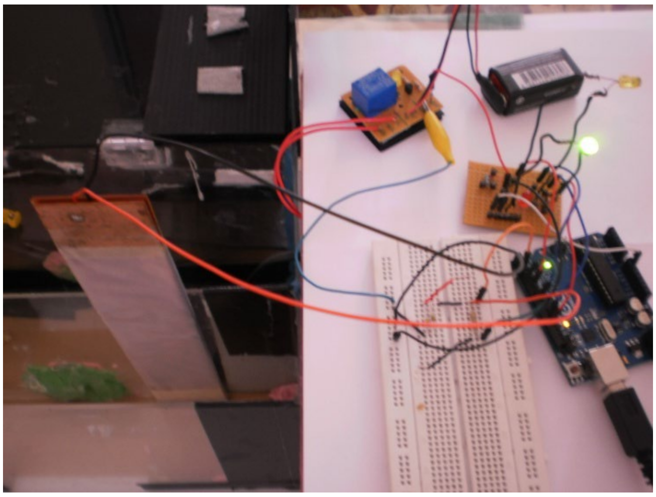

Fig 5. Single plate capacitive sensor

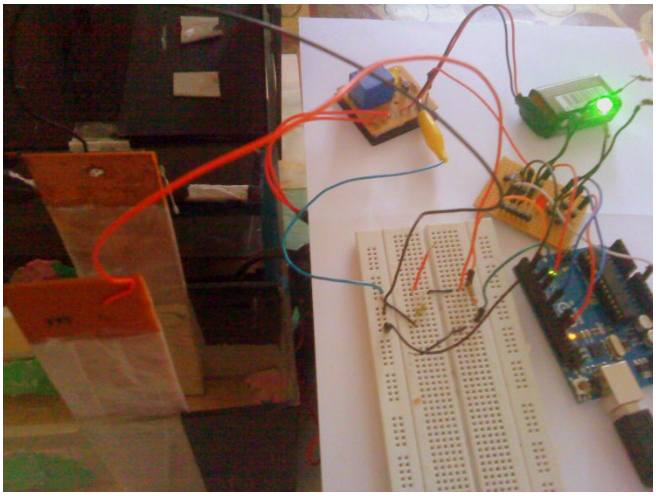

Fig 6. Parallel-plate capacitive sensor

Both methods mentioned earlier are used to analyze the sensitivity of the sensor besides observing its relationship between the capacitance with different size of sensing area and the gaps. Moreover, the error measurement and parameters that may affect the reading of sensor such as temperature is considered too as it contributed to the performance of the sensor.

VII. RESULT AND DISCUSSION

Measurements and analysis have been done to determine the performance of the flood sensor. The tested parameters are the flood sensor sensitivity, the sensitivity error and the offset error.

A. Sensitivity

The sensitivity of the sensor is determined based on difference resistance used in parallel to the sensor. The relationship of sensitivity and the resistance value is investigated. The sensitivity for this flood sensor is dependent to the resistance used in sensor development as shown in Table 1 and Fig 7.

Table 1. The sensitivity readings based on different resistance values

Resistance Values (ohm)	Sensitivity (Sensor Value)	
	Single plate capacitive sensor	Parallel-plate capacitive sensor
100k	1168	1804
500k	2843	4407
1M	4908	8517
5M	6973	10301
10M	12947	22078
50M	23558	43182

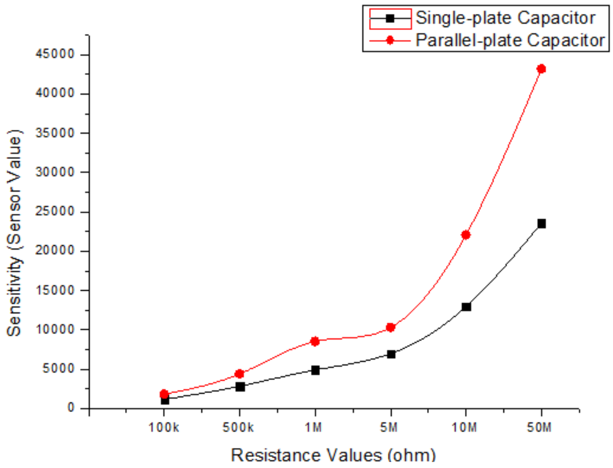

Fig 7. The relationship of sensor sensitivity and resistance values

Based on Fig 7 and Table 1 above, the sensitivity of the sensor is determined by the resistance value. The sensitivity of the sensor is increased with the increasing of resistance value. A medium value of resistance gave an absolute touch to the capacitive sensor to activate while a larger value of resistance provided proximity to the capacitive sensor. Grounding issue is the other important thing. It is recommended to place a ground plane behind the sensor plate and connect it to the ground as it worked to increase the sensitivity of the sensor and stabilize the sensitivity readings too.

The capacitances also get affected by the temperature. The readings of capacitance in sensor value unit were different when tested under room temperature and high temperature as shown in Fig 8 and Fig 9 respectively. Changes in temperature mean changes in the dielectric properties. These changes will affect the capacitance of the sensor.

Table 2. The capacitance readings under room temperature

Water depth (m)	Capacitance (Sensor Value)	
	Single plate capacitive sensor	Parallel-plate capacitive sensor
0.03	444	805
0.06	1811	1915
0.09	2988	3761
0.12	3851	5516
0.15	5916	7584

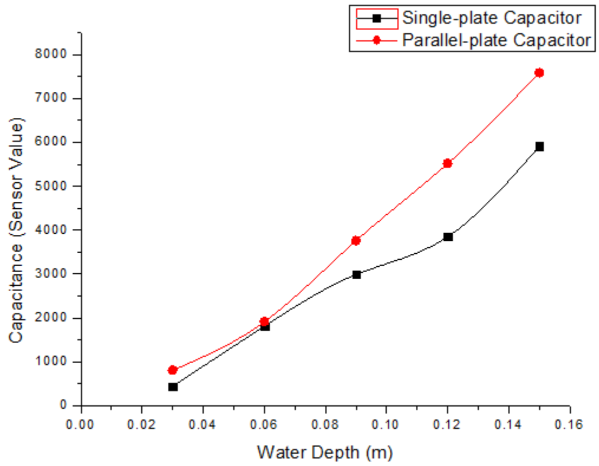

Fig 8. Capacitance under room temperature

Table 3. The capacitance readings under high temperature

Water depth (m)	Capacitance (Sensor Value)	
	Single plate capacitive sensor	Parallel-plate capacitive sensor
0.03	634	1503
0.06	2261	3492
0.09	3888	5699
0.12	5263	7470
0.15	6374	8856

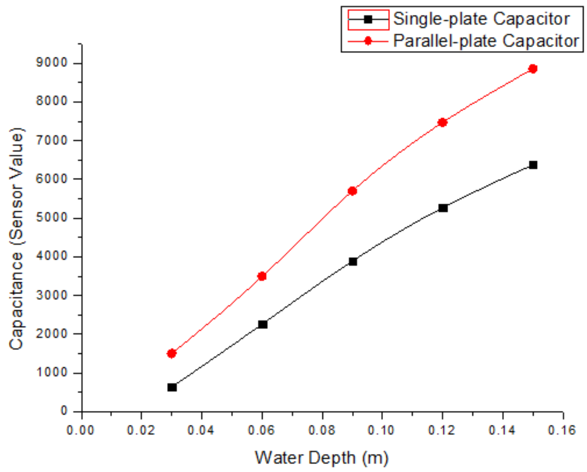

Fig 9. Capacitance under high temperature

Based on Fig 7, Fig 8 and Fig 9 respectively, it can be described that the parallel-plate capacitor has a higher sensitivity if compared to the single-plate capacitor. The parallel-plate consists of the sense plate and the ground plane plate. The gap between sensor plate and the ground plane plate is fixed to 0.045m. The ground plane act as a shield to the sensor plate as it forced and only allowed the target water to form the electric fields with the sensor plate. To increase the sensitivity of the single-plate capacitor, it is recommended that a ground plane connected to the ground is shielded behind the single-plate. This will create a guard which surrounded the back and side of the sensed area and protect electric fields from spread to other conductive object.

Table 4 and Fig 10 described the relationship of capacitance and the distance between parallel-plate capacitor. The water depth level is fixed to 0.075m. The figure shows that the capacitance is decreased as the distance between the plates became wider. The electric fields formed from wider gap are weak than the electric fields formed at closer gap thus reduced the sensitivity of the sensor.

Table 4. The capacitance readings based on different gaps between plates

Gap between plates (m)	Capacitance (Sensor Value)
0.03	4013
0.06	3777
0.09	3515
0.12	3419
0.15	3065
0.18	2966
0.21	2777
0.24	2616
0.27	2488
0.30	2381

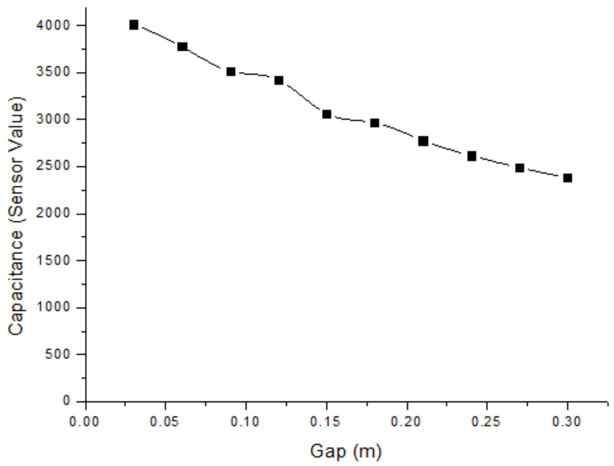

Fig 10. The relationship of capacitance and the gap between plates

B. Sensitivity Error

Indicates the slope of the actual value varied from the slope of the ideal value by comparing the actual slope with the ideal slope [8].

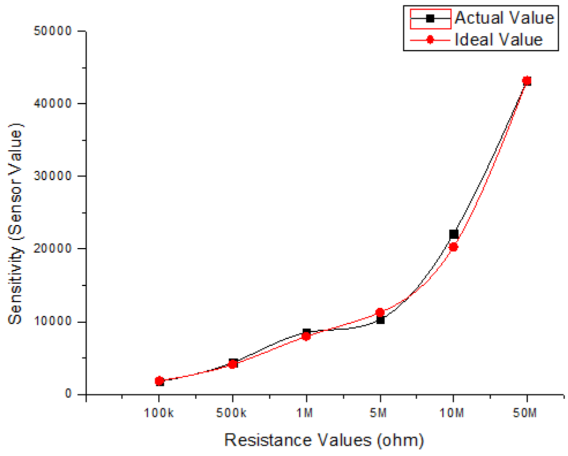

Fig 11. The sensitivity error

The sensitivity error from graph in Fig 11 is calculated based on the slope of the plotted data. The slope of the actual value is compared to the slope of ideal value. The data in the graph represents the sensitivity of parallel-plate capacitor only as the development of the flood sensor is based on parallel-plate capacitor method and all the error measurements taken after this is based on this method. The sensitivity error occurred due to the surrounding environments which are influent by the humidity and the temperature and those parameters are uncontrollable. To alleviate this error, measurements are tested and taken several times under the same conditions in order to get the best results.

C. Offset Error

An error occurs when a constant value is added to the output values [8].

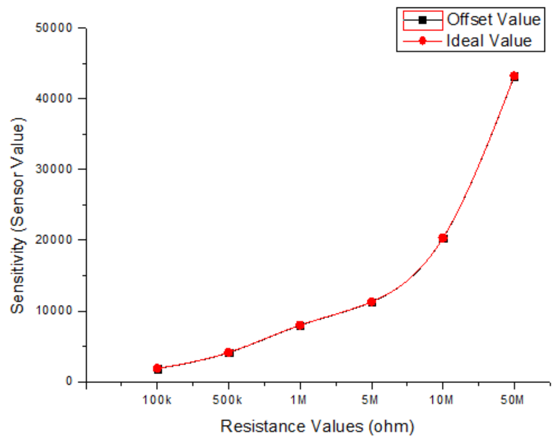

Fig 12. The offset error

The offset error in Fig 12 is gained after the sensor is calibrated to 0 sensor value. The constant value which appeared after the calibration is added to each measurement. The offset error obtained is 25 in sensor value unit which is too small to see through the graph. The offset error occurred due to the temperature changes.

D. Noise

Noise is an interference or unwanted signal that can interrupt the performance of one device or equipment.

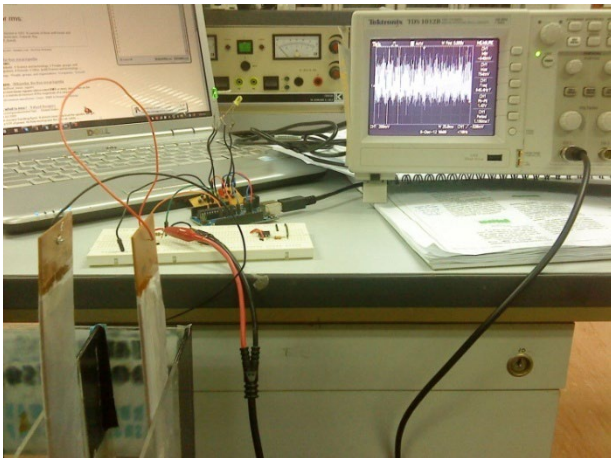

Fig 13. Instrument used to measure noise

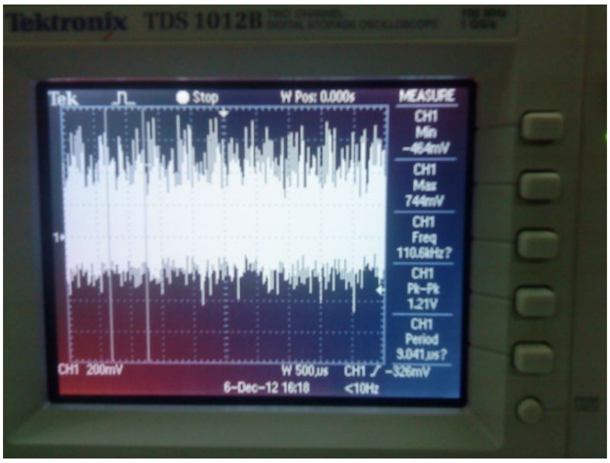

Fig 14. The noise reading

The noise of the flood sensor is measured by the oscilloscope as shown in Fig 13. From the obtained results, the sensor captured 1.21V peak-to-peak value at 110.6 kHz within 9.041us period times as shown in Fig 14. Even the sensor has a perfect gap constant, the sensor stills has a large amount of noise. This could cause an instantaneous error in the capacitance readings. It is recommended that the sensor is connected with other interface circuits that can filter out the noise.

VIII. CONCLUSIONS

The investigation on low cost capacitive flood sensor has been conducted in this study. The flood sensor has showed the capacitive operation in detecting the flood water level. The performance of the low cost capacitive flood sensor has approved that the sensor can be used in medium applications such as water level detector. From the analysis and obtained results, the flood sensor still needs a lot of improvement to optimize its performance. Other recommendations that can be applied besides the recommendations mentioned in earlier sections is the sensing area need to be smooth and parallel towards the target surface. Rough surface may caused an error in measurement reading as the sensor will only measure the spotted area and give an average reading of the target surface. Moreover, the target size must be 30% larger than the diameter of the sensing area in order to obtain an accurate measurement [7]. Furthermore, the sensor surface must be same with target shape when do a calibration and taking a measurement. For an example, flat sensor surface used to measure curved target shape will introduced an error caused by the changes in electric field behavior. Lastly, the FR-4 PCB used to develop the low cost capacitive flood sensor need to be replaced with other material that are oxidizable in order to prevent the sensor from being oxidized. The sensor was easy to implement, low cost and has a high sensitivity and reliability of the results.

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