Tri-fold Safety Sensor for Locking Wheels Of Prams

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Abstract

Safety of prams on inclined surfaces can be ensured by determining the inclination of slope, load of pram, and presence of custodian of the pram. A sensor unit comprising of a mechanical variable resistor inclination sensor, a dielectric elastomer capacitance weight sensor and a membrane switch contact sensor will be designed to work in tandem with an Arduino board that will produce a signal if safety has been compromised.

Keywords: Inclination Sensor, Contact Sensor, Weight Sensor, Pram, Sensor System

I. Introduction

The aim of this sensor project is to ensure the safety of prams on inclined surfaces by the use of three sensors, an inclination sensor, a contact sensor and a weight sensor. A pram is defined as a four-wheeled trolley for a baby or child (henceforth referred to as the load), pushed by a person (henceforth referred to as the custodian) on foot. A pram's safety is deemed to be compromised if it is on an inclined plane, with no custodian taking hold of it, and carrying an excessively heavy load. The combination of these three factors increase the likelihood that a pram will roll down the slope, hence a signal will be generated if the threshold for each factor has been exceeded. The system architecture is shown in Fig. 6 in Appendix A.

The final intended purpose of the signal will be to trigger brakes for the pram to ensure its safety. However, in the scope of this project, the signal will only be used to light an LED, as proof of concept.

II. Sensor System Design

A. Inclination Sensor

Inclination sensors are devices that produce electrical signals that vary with angular movement [1]. They are generally classified into force balance sensors, solid state MEMS devices, fluid-filled sensors or rolling ball sensors [2]. For this project, the focus will be on rolling ball sensors due to their simplicity and reliability.

The sensor usually comprises of a cylindrical cavity and a conductive free mass inside, usually a blob of mercury or a rolling ball. The cavity is lined with a conductive material on which the ball can roll freely, forming an electrical connection. The system resembles a voltage divider, where the change in angular position of the metal ball due to inclination results in the change in voltage readings.

B. Weight Sensor

Weight sensors (or force sensors) are devices that produce an electrical signal which varies with the amount of force applied on it. Generally, resistors that vary in resistance with force applied are used for force sensors. However, capacitive sensors have been selected instead, due to their flexibility and ability to cover a wider area, making them more suitable to be placed on soft cushioned seats of a pram. This sensor will be placed on the seat of the pram, to determine the weight of the load on it.

Dielectric elastomer sensors [3] are based on the principle of parallel plane capacitors, where strain in the dielectric normal to the capacitor results in a proportional change in capacitance. By calculating the change in capacitance of the sensor, the strain acting on the sensor can be calculated, as can the stress and hence, weight of the load.

The capacitance of the sensor is measured using an Arduino Uno R3, using an RC circuit. Connecting the sensor to two Analog Output pins of the Arduino Board, the sensor is in series with the internal resistance of the Arduino Board (34800 Ohms), forming an RC circuit. Hence, the time constant of the circuit is as such

$$\tau = Resistance * Capacitance$$

where the time constant is the time required for the capacitor to charge to reach 63.2% of the voltage applied across it. The circuit diagram of the weight sensor is shown in Fig 7 in Appendix A, and the Arduino code and its explanation is in Appendix B.

C. Contact Sensor

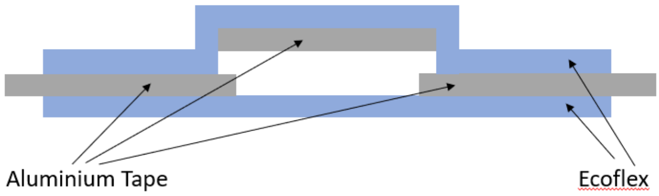


Fig. 1. Membrane Switch Diagram

Contact sensors are devices that determine if there are objects in contact with the sensor. This sensor will be used to determine if the custodian of the pram is holding onto its handles. Non-tactile membrane switches have been deemed to be most suitable for this project due to their ease of implementation and the principle behind how it works.

Membrane switches are normally open circuits that consist of two conductors in the same plane, and another conductor that closes the circuit placed on a membrane slightly above them, as shown in Fig. 1 above. When the membrane is displaced downwards, the conductor closes the circuit, completing the circuit.

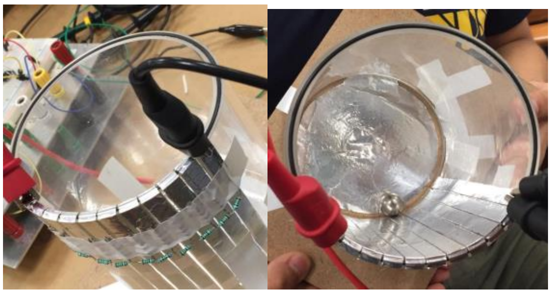
A membrane switch on the handle of the pram would require a small amount of force to switch on. Having two membrane switches attached on the handle (one facing the custodian and the other directly opposite it) ensures that the custodian is in position to stop the pram from moving if either switch is closed, as it implies that the custodian has a grip on the handles. The circuit diagram of the contact sensor is shown in Fig 8 in Appendix A.

III. Prototype Testing

A. Inclination Sensor

Initially, a strip of carbon paper was calibrated to test its suitability to be used as the conductive material for the inclination sensor. However, it was observed that the carbon paper wears off easily and does not produce linear variation of conductivity with length. Thus, it was concluded that with carbon paper, the readings are not reliable and long term durability will be an issue.

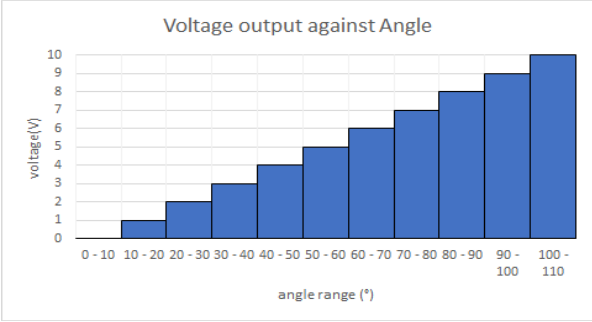
The prototype of the inclination sensor was tested on an acrylic cylinder as the base. Instead of carbon paper, 8mm thick aluminium strips were lined alongside with an angle of 10˚ from each other, with resistors connected in series as shown in Fig. 2 (a). The metal ball was allowed to roll freely on the aluminium strips while ensuring continuous contact with a sheet of aluminium foil on a flat wooden board at one end of the cylinder for 1D movement, illustrated in Fig. 2 (b).



(a) *(b)*

Fig. 2. Inclination Sensor Prototype

This prototype yielded satisfying results in terms of producing discrete voltage readings at each aluminium strip, as shown in Graph 1 below. However, the gaps between the aluminium strips act as 'grooves' which can affect the rolling of the ball and cause the ball to get stuck in the gaps. Furthermore, having many resistors in series largely increase power consumption.



Graph 1. Voltage outputs of inclination sensor

B. Weight Sensor

The sensor comprises of 5cm x 5cm x 1.5mm pieces of Ecoflex 00-30 [4] fabricated using an acrylic mold. By combining three pieces together as shown in Figs 3 and 4 below to form a multiple plate capacitor [5], the capacitance of the uncompressed sensor increases to 76.5 pF. This triples the amount of compression that the sensor is able to take while tripling the uncompressed resistance, effectively increasing the range of capacitance of the sensor, hence increasing the range of weight that the sensor can accurately detect.

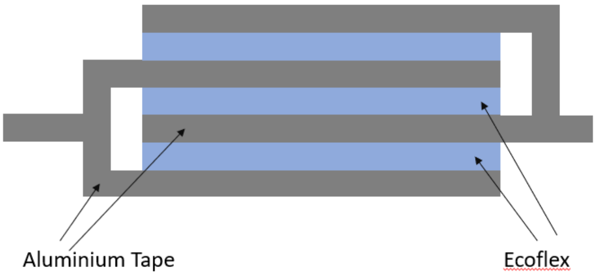


Fig. 3. Multiple Plate Capacitor Diagram

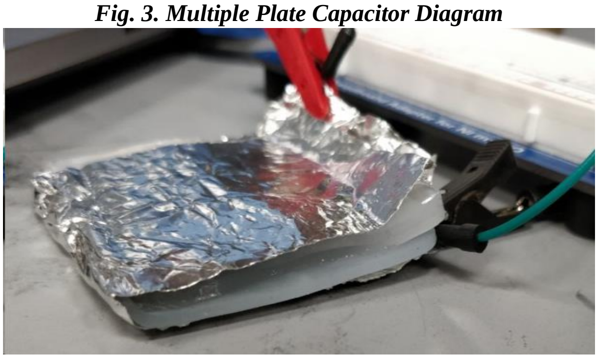
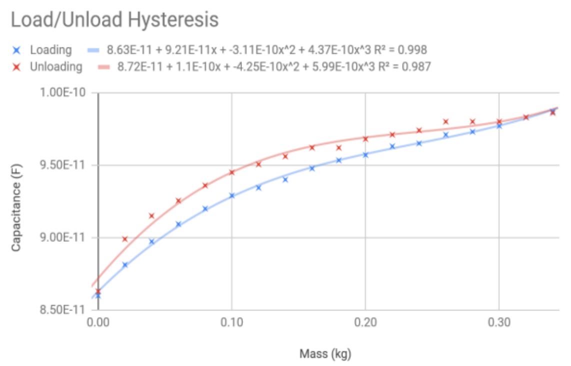
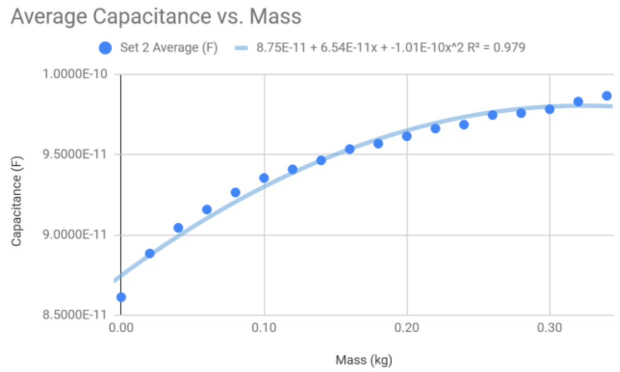


Fig. 4. Capacitive Weight Sensor Prototype

The weight sensor was tested with known weights up to 340g as a proof of concept. Two sets of 5 tests were carried out, with 3 load tests, where weight was steadily increased, and 2 unload tests, where weight was steadily decreased, for each set. Capacitance was measured at every weight interval, and two graphs of capacitance against weight were plotted with the readings obtained. As illustrated in Graph 2, the data sets for load tests and unload tests were averaged separately and plotted. In Graph 3, all data sets were averaged and plotted. Both graphs were fitted with a polynomial curve of degree 2.



Graph 2. Capacitance(F) against Mass(kg)



Graph 3. Averaged capacitance(F) against mass(Kg)

C. Contact Sensor

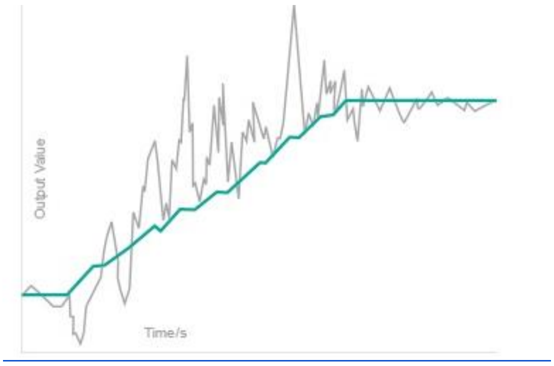
Due to time constraints, the contact sensor has yet to be fabricated at this current point in time. However, it is the least complex of all three sensors to fabricate and utilize, as only a boolean reading is required from this sensor (either on or off).

IV. Analysis

A. Inclination Sensor

Alternative designs have been considered for better accuracy and practicality. One possibility is to replace the cylinder and the wooden board with a piece of torus in which the metal ball fits exactly inside the diameter of the tube. Another possibility is to use a track-engraved cylinder to ensure that the ball rolls along the track when the sensor is tilted. One half of the track will be covered in full aluminium foil while the other half will be lined with aluminium foil strips, similar to the concept used in the earlier prototype.

For circuit design, both continuous and discrete variation of angle detection were compared. Continuous measurement uses a single continuous conductive medium, such as carbon paper, to generate a signal (resistance in this case) at every point on the medium, yielding a linear relationship with angle. Discrete angle measurement uses multiple conductive media, which does not generate exact values of inclination angles, but produces various signals at specific angles within a set range of angles. An example would be every 5 degrees from -10 degrees to +10 degrees, for a total of 5 discrete angles (±10, ±5, 0).



Graph 4. Tilt Measurement on a Moving Excavator

While continuous measurement seems to produce more accurate results, it does have its drawbacks. As Graph 4 above illustrates, when the sensor itself is in motion, the acceleration of its movement adds to the effect of gravity and creates possible fluctuation on the outputs. Meanwhile, the purpose of our sensor is to detect a threshold value to trigger an alarm, which implies that the signal only needs to reflect whether the inclination has reached the threshold and the detection of the exact inclination angle is not required. Hence, to reduce unnecessary fluctuation and to increase the reliability of our sensor, discrete measurement is preferred in the future designs.

To improve current circuit design, a multiplexer can be used as a signal detection device indicating which range of angles the signal is from for discrete measurement prototype.

A multiplexer (MUX) selects an output from n inputs. In microelectronics, n usually conforms the binary system to be the power of two. Fig. 5(a) shows a block diagram of a multiplexer: do, dl, d2 and d3 are the four inputs, and f, which can be expressed by f(d0,d1,d2,d3) is the output chosen from the inputs. A and B are the control signal inputs. Fig. 5(b) shows the inner structure of the multiplexer. [6]

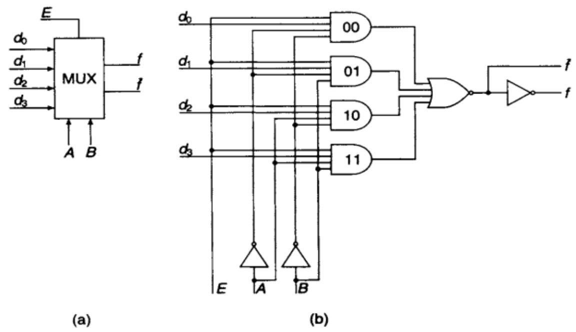


Fig. 5. (a) Block diagram of a 4-input multiplexer and (b) its gate implementation [6]

Current commercial inclination sensors are complex devices which are sensitive to both internal (circuitry) and external (environmental) influences, which can alter their performance significantly [7] (Powell, 2000). In contrast, our proposed sensor is simpler and yields more reliable results under the influence of electromagnetic field. Therefore, less calibration and maintenance are required, thus leading to lower cost.

B. Weight Sensor

From the testing of the sensor prototype, it can be seen that there is hysteresis in the sensor after it has been loaded, causing capacitance to increase. This is likely due to the Ecoflex retaining a deformed shape even after the weights have been removed. Another observation to be gleaned from the data is that the effect of weight on the capacitance saturates, and that the maximum capacitance remains the same even with the hysteresis effect.

This allows the averaging of all data sets, since the maximum capacitance remains the same, and the hysteresis effect does not increase with repeated trials. Using Graph 3 in previous page, the relationship between weight and capacitance can be modelled. The current sensor can detect a range of up to 340g, with the range of 76.5 pF to 98.9pF. At a clock speed of 16 MHz the precision of the Arduino clock is at ±62.5 nanoseconds. Given that the lowest capacitance of the sensor (76.5 pF) has the maximum rise time of 2.66 microseconds, the error introduced by the Arduino clock is negligible.

It is possible to scale up the capacitance range of the sensor. One such method would be to increase the number of Ecoflex pieces, while reducing the thickness of each piece. This would increase the capacitance of the sensor as a whole, as well as introduce more room for compression. Hence, the sensor will be able to take on heavier weights.

Another method would be to implement multiple of such sensors in a grid, allowing for weight of load to be distributed in a wider area, hence requiring each sensor to bear a reduced load.

V. Conclusions

In summary, two sensor prototypes have been fabricated and tested, and can be demonstrated during this interim. The weight sensor has proven to be able to precisely measure capacitance, though it will still require scaling up of the range to be applicable for the purposes of this project. The contact sensor will be fabricated and tested, and there are no apparent problems foreseen to be faced by it.

The inclination sensor prototype achieves its functionality and shows its advantages over existing ones. Further improvements including circuit redesign and shape redesign will be implemented for better precision and less error. The size of the sensor will also be taken into consideration so that the device will weigh less and be more portable and easier to install.

Factoring in assembly of the entire sensor system proves to be an issue, as the weight sensor is required to be on the seat of the pram, while the contact sensor is required to be on the handle of the pram. The current proposed setup as shown in Fig 9 of Appendix A will have the Arduino fixed alongside the inclination sensor on the poles near the seat to prevent obstruction to the custodian, the seat, and the folding of the pram. The contact sensor will be enclosed in an Ecoflex band around the handle to improve grip and reduce hindrance to the custodian, while the weight sensor will be enveloped in a soft outer casing to ensure comfort and insulation from the sensor's conductive plates.

Acknowledgements

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References

[1] "Tilt Sensor - Types, Working Principle and its Applications", *ElProCus - Electronic Projects for Engineering Students*. [Online]. Available: https://www.elprocus.com/tilt-sensor-types-working-principle-and-its-applications/. [Accessed: 02- Mar-2019].

[2] "Tilt Sensors Selection Guide | Engineering360", *Globalspec.com*. [Online]. Available: https://www.globalspec.com/learnmore/sensors_transducers_detectors/tilt_sensing/tilt_inclinometers. [Accessed: 02- Mar- 2019].

[3] N. Ni and L. Zhang, "Dielectric Elastomer Sensors", Elastomers, 2017.

[4] "Ecoflex™ 00-30 Product Information", *Smooth-On, Inc.*, 2019. [Online]. Available: https://www.smooth-on.com/products/ecoflex-00-30/. [Accessed: 03- Mar-2019].

[5] "Multiple Plate Capacitor | Electronic Components || Electronics Tutorial", *Electronics-tutorial.net*, 2018. [Online]. Available: http://www.electronics-tutorial.net/electronic-components/capacitors/multiple-plate-capacitor/. [Accessed: 03- Mar- 2019].

[6] B. Holdsworth, R. C. Woods and ScienceDirect, Digital Logic Design. (4th ed.) 2002.

[7] Powell, W. (2000). *The Electrolytic Tilt Sensor | Sensors Magazine*. [online] Sensorsmag.com. Available at: https://www.sensorsmag.com/components/electrolytic-tilt-sensor [Accessed 1 Mar. 2019].

[8] C. Basics, "How to Make an Arduino Capacitance Meter", *Circuit Basics*, 2019. [Online]. Available: http://www.circuitbasics.com/how-to-make-an-arduino-capacitance-meter/. [Accessed: 03- Mar- 2019].

Appendix A: Circuit and System Diagrams

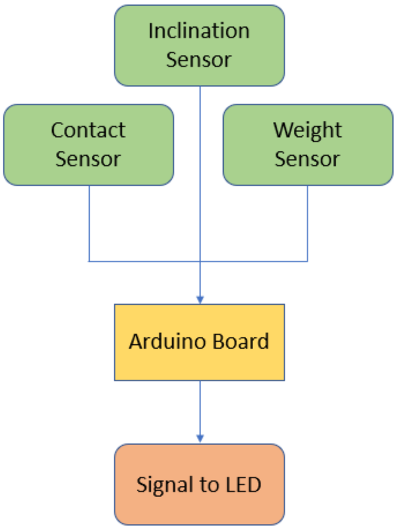

Fig. 6. System Architecture

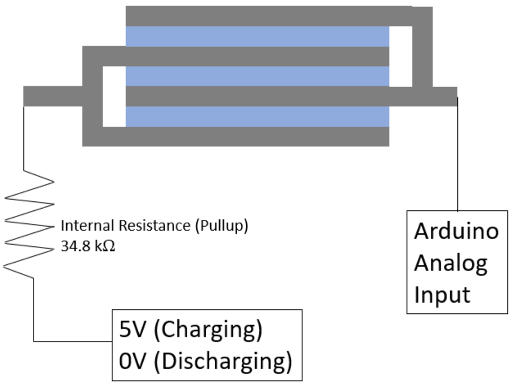

Fig. 7. Circuit Diagram for Weight Sensor

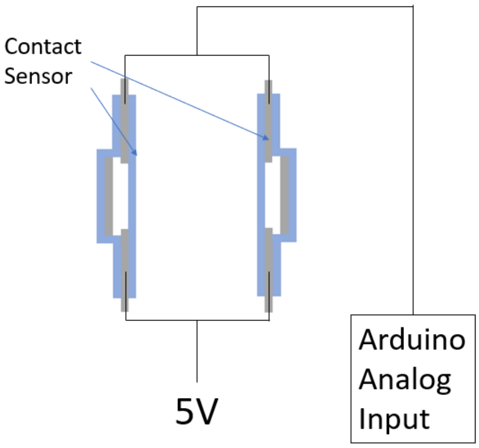

Fig. 8. Circuit Diagram for Contact Sensor

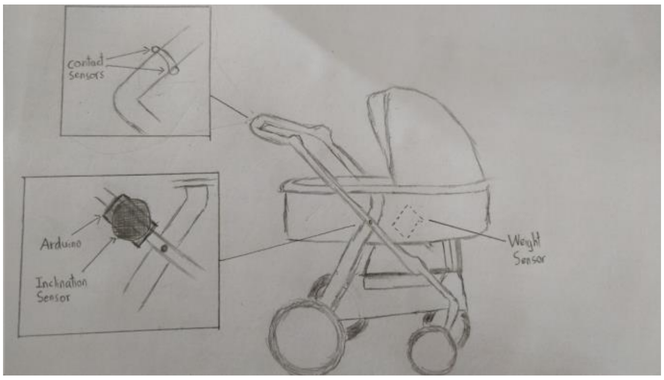

Fig. 9. Proposed Layout of Sensor System

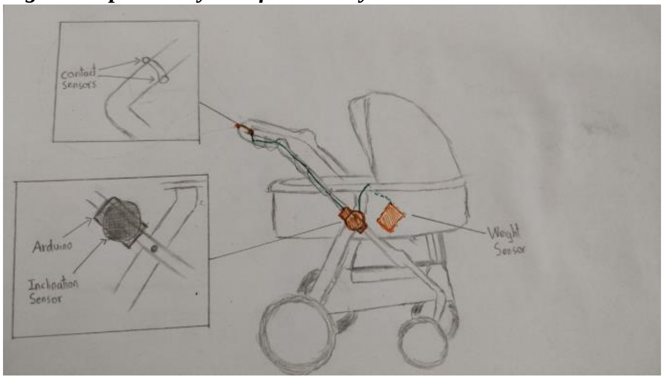

Fig. 10. Proposed Layout of Sensor System (in orange) with wiring (in green)

Appendix B: Arduino Code

/* The code first initializes values of stray capacitance and pull-up (internal) resistance, and sets the ADC value to be maximum at 1023 (value ranges from 0-1023 in 10 bits) */

```
const int OUT_PIN = A2;
const int IN_PIN = A0;
const float IN_STRAY_CAP_TO_GND = 24.48;
const float IN_CAP_TO_GND  = IN_STRAY_CAP_TO_GND;
const float R_PULLUP = 34.8;
const int MAX_ADC_VALUE = 1023;
```

/* Pins A0 and A2 are set as output pins and beings serial data transmission */

```
void setup()
{
  pinMode(OUT_PIN, OUTPUT);
  pinMode(IN_PIN, OUTPUT);
  Serial.begin(9600);
}

void loop()
{
```

/* Output pin is set to 5V, and reset to 0V after analog value voltage is read from input pin. If voltage value is higher than 1000, the picofarads equation is used. */

```
        pinMode(IN_PIN, INPUT);
        digitalWrite(OUT_PIN, HIGH);
        int val = analogRead(IN_PIN);
        digitalWrite(OUT_PIN, LOW);

        if (val < 1000)
        {
        pinMode(IN_PIN, OUTPUT);

        float capacitance = (float)val * IN_CAP_TO_GND /
(float)(MAX_ADC_VALUE - val);

        Serial.print(F("Capacitance Value = "));
        Serial.print(capacitance, 3);
        Serial.print(F(" pF ("));
        Serial.print(val);
        Serial.println(F(") "));
        }
```

/* Else, the capacitor is charged up to 0.4 seconds, till the digital value is logically high, and another analog reading is taken. Then, the micro/nano farads equation is used. */

```
        else
        {
        pinMode(IN_PIN, OUTPUT);
        delay(1);
        pinMode(OUT_PIN, INPUT_PULLUP);
        unsigned long u1 = micros();
        unsigned long t;
        int digVal;

        do
        {
        digVal = digitalRead(OUT_PIN);
        unsigned long u2 = micros();
        t = u2 > u1 ? u2 - u1 : u1 - u2;
        } while ((digVal < 1) && (t < 400000L));

        pinMode(OUT_PIN, INPUT);
        val = analogRead(OUT_PIN);
        digitalWrite(IN_PIN, HIGH);
        int dischargeTime = (int)(t / 1000L) * 5;
        delay(dischargeTime);
        pinMode(OUT_PIN, OUTPUT);
        digitalWrite(OUT_PIN, LOW);
        digitalWrite(IN_PIN, LOW);

        float capacitance = -(float)t / R_PULLUP
                / log(1.0 - (float)val /
(float)MAX_ADC_VALUE);

        Serial.print(F("Capacitance Value = "));
        if (capacitance > 1000.0)
        {
        Serial.print(capacitance / 1000.0, 2);
        Serial.print(F(" uF"));
        }
        else
        {
        Serial.print(capacitance, 2);
        Serial.print(F(" nF"));
        }

        Serial.print(F(" ("));
        Serial.print(digVal == 1 ? F("Normal") : F("HighVal"));
        Serial.print(F(", t= "));
        Serial.print(t);
        Serial.print(F(" us, ADC= "));
        Serial.print(val);
        Serial.println(F(")"));
        }
        while (millis() % 1000 != 0)
        ;
}
```

This code was obtained from Circuit Basics [8]

Equations:

$$C_{pico} = V_{in\,bits} * C_{stray} / (1023 - V_{in\,bits})$$
$$C_{micro/nano} = -t / (R_{internal} * log(1 - V_{in\,bits}/1023))$$