UNIVERSITY OF MORATUWA

Faculty of Engineering

BM4111 : Medical Electronics & Instrumentation

Mini Project – 2019

Capacitive Force Sensor

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This report is submitted as a partial fulfillment of the requirements

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Table of Contents

Introduction

This documentation is based on the mini-project which was done as a partial fulfillment of the requirements for module BM4111. The main objective of the mini project is to design a force sensor using a capacitor. This was done in two major stages as follows.

1. Identify the characterization of the sensor
2. Circuit design

Then the output of the final stage fed in to a microcontroller and accessed through a personal computer. In the following sections of this report, these stages are described briefly.

Characterization of the sensor

The capacitive sensor used for the force measurement :

Single Tact miniature force sensor

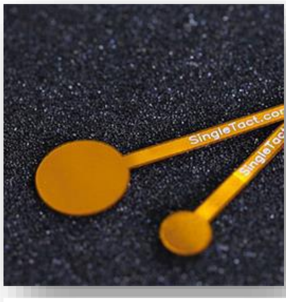

Figure 1:SingleTact sensor

Capacitance range: Pico Farads

Sensor thickness : 0.35 mm

Sensor compression : 10um at full load

Sensor Response Time : <1 ms

Tail length : 50 mm

In order to identify the characterization of the sensor with the variation of the applied force

Relationship between the Capacitance and the Force

The capacitance of a capacitor can be expressed with the following equation.

$$C = \frac{A\varepsilon}{d}$$

Where A – surface area of the parallel metal plates

ε – electro statistic constant

d – distance between the parallel metal plates

Therefore, we can change the capacitance of a capacitor by changing the gap between the parallel metal plates. The above mentioned force sensor is designed based on this principal. In other words, by applying a force on the metal plates, the distance between them can be reduced. As a result the capacitance of the capacitor gets changed. This scenario is depicted in the following figure.

By applying the force F, the distance between the metal plates has reduced by a x distance. This implies that the variation of the applied force can be captured by measuring the variation in the capacitance. Therefore the capacitance of the force sensor was measure by increasing the applied force continuously. The resulting variation of the capacitance is given under the ‘Results’ section.

Figure 2:Force application to a capacitor

Circuit Design

The main objective of the circuit design is to capture the variation in the capacitance and convert it in to a parameter which can be read by the microcontroller. Therefore, a timer circuit was used to capture the capacitance.

Timer

The LMC555 timer was used for the implementation [1]. The timer was used in the astable mode to produce a stable oscillating signal, so that the output frequency can be adjusted by changing the resistors or capacitors[2]. The schematic diagram is given below. The force sensor is depicted as the C capacitor.

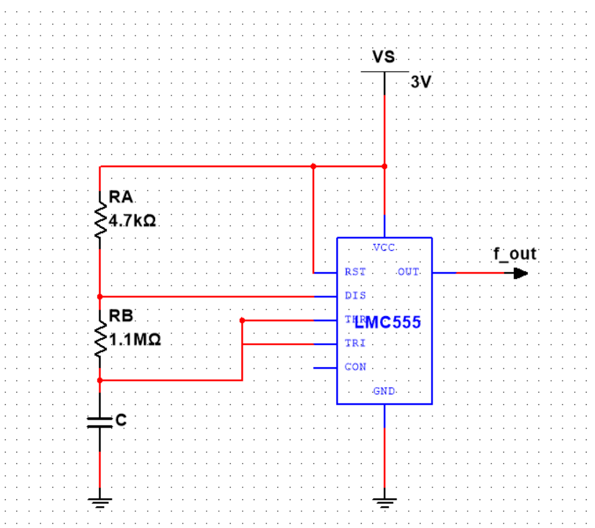

Figure 3:Timer circuit

$$Duty\ cycle = \frac{R_B}{R_A + 2R_B}$$

$$Duty\ cycle = \frac{1.1 \times 10^6}{4.7 \times 10^3 + 2 \times 1.1 \times 10^6}$$

$$Duty\ cycle = 49.9\%$$

$$f_{out} = \frac{1}{(R_A + 2R_B) \times C \times ln(2)}$$

$$f_{out} = \frac{6.5 \times 10^{-7}}{C}$$

$$f_{out} \propto \frac{1}{C}$$

The output frequency varied as shown in the equations. Thus the output frequency and the sensor's capacitance has a inverse relationship. Through the sensor characterization stage, we identified that there is a non-linear relationship between the force and the capacitance which leads to a linear relationship between the output frequency and the applied force. Then a frequency to voltage converter circuit was implemented to generated the microcontroller input.

F-V convertor

The LM331 precision Voltage-to-Frequency converter was used in the simple frequency to voltage converter mode with 10kHz full scale for the circuit implementation. The schematic diagram of the circuit is shown below.

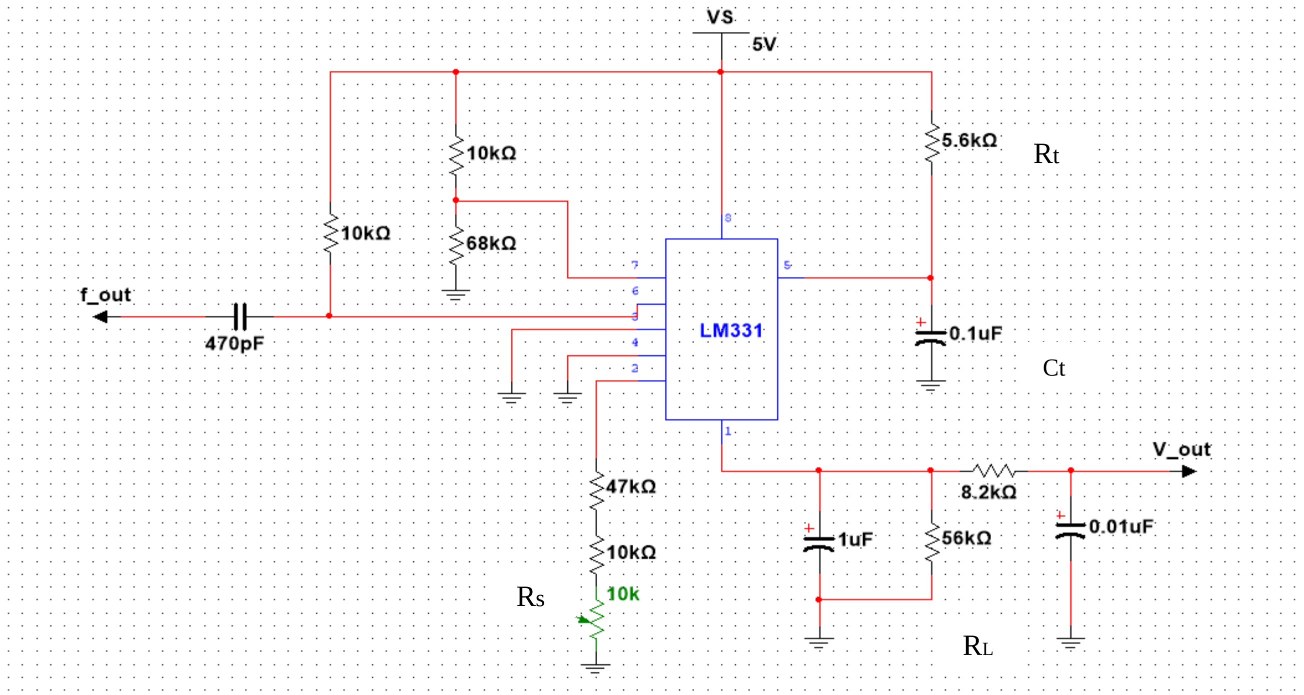

Figure 4:F-V converter circuit

According to the datasheet of LM331, the input frequency and the output voltage has a linear relationship for a constant Rs (The equations shown here are derived based on the details extracted from the datasheet).

Since the given power supply is only 3.7 V, the PowerBoost 500 Basic - 5V USB Boost charge pump was used to supply a 5 V voltage to this circuit [2].

$$V_{out} = f_{out} \times 2.09 \times R_t \times C_t \times \frac{R_L}{R_s}$$

$$V_{out} = f_{out} \times 2.09 \times 5600 \times 0.1 \times 10^{-6} \times \frac{56000}{R_s}$$

$$V_{out} = \frac{65.5}{R_s} \times f_{out} \Longrightarrow V_{out} \propto f_{out}$$

Micro controller firmware

The development board which we used for our project is an Adafruit Feather board (Adafruit Feather M0 WiFi - ATSAMD21 + ATWINC1500). This board will serve two main functions of our project.

1. Analog to digital conversion
2. WiFi transmission of ADC sample to a laptop.

We powered our development board and our main circuit separately. Because of this microcontroller needs 3.3V and our main circuit need 5V (we power through 5V power booster).

Creating WiFi access point

Our main use is to create connection between microcontroller and laptop through WiFi. For that we used developed in build class in the Arduino (Firmware_FeatherAtmelwifi_ap). From that development board automatically create WiFi access point when powered.

Each development board have a unique ID. To receive data from the board, connect to the WiFi access point created by the board with the following login:

- SSID: Feather<ID>
- Password: FeatherBoard<ID>

Pin description

We read the analog signal through A1 pin (A0 is the reference pin) and convert that analog signal to digital through sampling process and sent to our laptop through WiFi.

Matlab receive class

The development board transmit the data to our computer using the UDP protocol. This protocol is supported by the instrument control toolbox in Matlab. We used “WiFiUDPlogger.m” class to receive, decode, store and plot the data. This class handle the connection between the computer and development board. Through this class we can map the data according to our use.

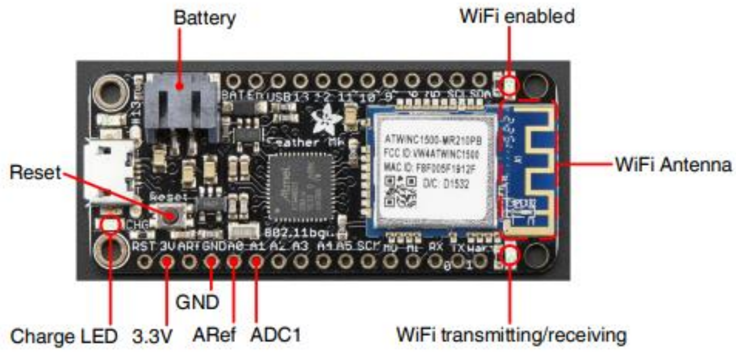

Figure 5:Microcontrollor

The original output was inverted and reduced from a constant for this task since the shape of the relationship was $V_{out} = -m.Force + const$

Results

Initial results were obtained by checking the variation between the applied force and the capacitance. The variation can be plotted as follows.

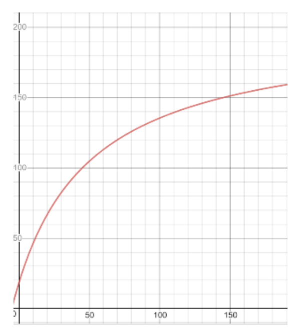

Figure 6:Capacitance Vs. Force

The original output signal was affected by the electronic noise. Therefore a lowpass filter was combined to the circuit. The live plot of the output signal before and after the application of LPF is given below. These results were obtained before applying the modifications to the code.

The live plot after applying the mentioned modifications to the code is as follows. This also depicts the variation of voltage with the application of force around 11 seconds. The first fissure shows the plot for a smaller force compared to the second figure.

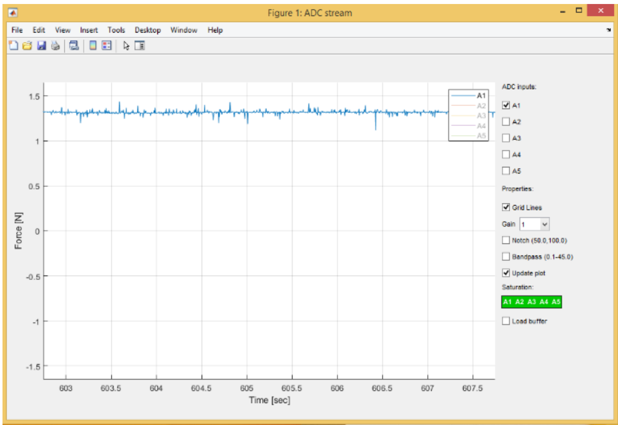

Figure 7:Without LPF

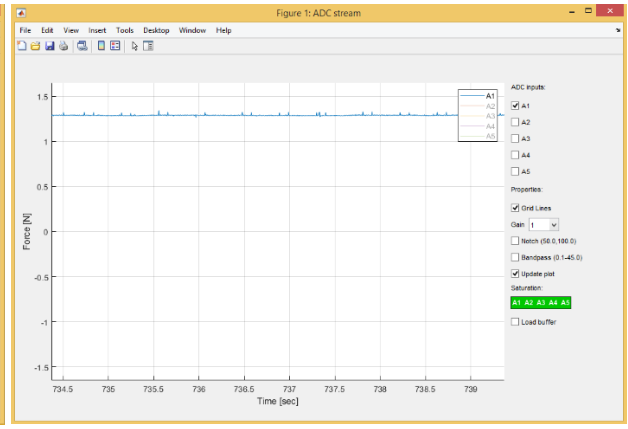

Figure 8:With LPF

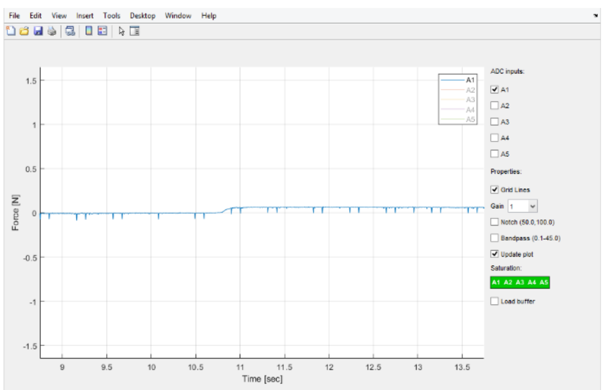

Figure 9:Application of smaller force

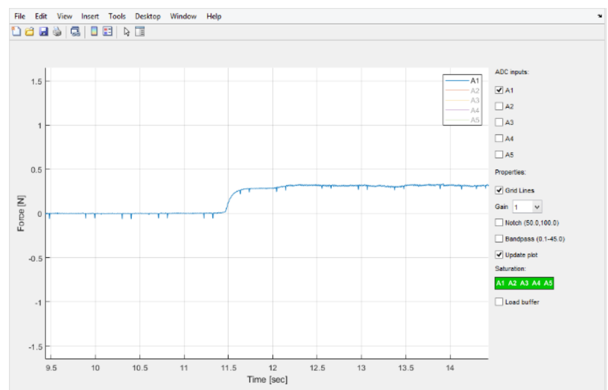

Figure10:Application of larger force

Discussion

The main objective of this mini project was to measure the applied force to the sensor using the capacitance. During the given time period, we were able to identify the relationship between the capacitance and the force, convert this variation in to a voltage variation and visualize it in live plots of MATLAB software. We were unable to convert the voltage values to the actual force measurements in the live plots. One reason for this is the time duration we spent to finalize the circuit design. Due to the unfamiliarity with the operation of timer ICs, we had spent a bit more time than expected. Another major obstacle we had was the designing force application structure. Due to the small size of the capacitive sensor, it was hard design a stable structure to apply large forces like 45N to the sensor. As a result, we were not able to do the final calibration of the sensor, which converts the output voltage to the force values. A new structure need to be designed for the further improvements.

When considering the application of this capacitive force sensor, it can be used for gait analysis, where two sensors attached to the heal and the foot. Due to the smaller size and the higher sensitivity, it can be easily used for posture tracking also.

References

[1] LMC555 CMOS Timer datasheet

[2] https://www.electronics-tutorials.ws/waveforms/555_oscillator.html

[3] LM131A/LM131, LM231A/LM231, LM331A/LM331 Precision Voltage-to-Frequency Converters Datasheet