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Mechatronics Department
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Sensor Technology ELCT 903

Project Name: Touch Piano screen based on capacitance transducers

Project Number: 35

Team Number: 1

Milestone Number: 5

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Brief review about touch capacitive piano:

The piano is played on a keyboard, which consists of a row of keys, and the player strikes the keys with their fingers and thumbs to make the hammers strike the strings. As a result of the hammers' rebound, the strings can keep vibrating at their resonance frequencies. The sounding board receives these vibrations via the bridge, allowing for a more efficient coupling of the acoustic energy to the air. Otherwise, the sound won't be louder than what the strings themselves directly generate. The damper stops the string's vibration when the key is released. Then afterwards came the digital or the electronic piano which used metal strings that magnetically transmitted vibrations to an amplifier and loudspeaker. The analogue signal is amplified, electronically altered with effects, and sent to speakers in an electrical piano. The upcoming types of pianos are supposedly capacitive key pianos that can work just by touching it and most recent projects tackle this problem. Recently, capacitive sensing has become a more attractive and popular sensing mechanism for mechanical stimuli, especially in the sense of touch, with good power consumption, sensitivity, and adaptive configurations of sensing. The enhancement of the flexibility of the electrode material is an important issue since it is the primary component of the wearable sensor. Conductive nanomaterial and polymers have been used as electrode materials in capacitive sensors. Moreover, modified sensing interfaces and structures are also explored to further enhance the sensitivity of the sensor. With all these advancements in the capacitor the capacitive pianos have the possibility to work just by hovering over the keys and can also distinguish between a long or short press thus outputting different audios or sounds on a single key.

Project idea and specifications:

The whole idea of the touch piano simply is using seven capacitive sensors as keys or inputs where the microcontroller can recognize and differentiate them thus outputting seven different audios using a passive buzzer according to the key that is pressed. Another possible feature that can be implemented in this project is to adjust the volume of the different audio according to the duration of the key press which are either a long press meaning higher volume and a short press meaning lower volume and this can be done in future work once the first prototype is perfect. In simple terms to make a capacitor all that's needed are two parallel conductive plates which will be the user's finger and the part of the pcb where it has been etched separated by a dielectric material which is air. Detecting the change of capacitance is not as easy as sensing the toggle of the GPIO pin's value or off. When the conductive plate is touched, the change in capacitance can be detected using the "CapacitiveSensor" library in Arduino.

Components list:

1x Arduino Nano https://ram-e-shop.com/product/arduino-board-arduino-nano/

8x Resistors (1Mega Ohm) https://ram-e-shop.com/product/fixed-resistances-125/

1x 18650 Battery cell https://ram-e-shop.com/product/lithium-rechargeable-battery-18650-3-7v-purple-without-pins/

1x 18650 Battery cell holder https://ram-e-shop.com/product/battery-holder-18650x1/

1x 18650 battery Charging Module https://store.fut-electronics.com/collections/battery-charger-accessory/products/lithium-battery-charger-and-protection-module

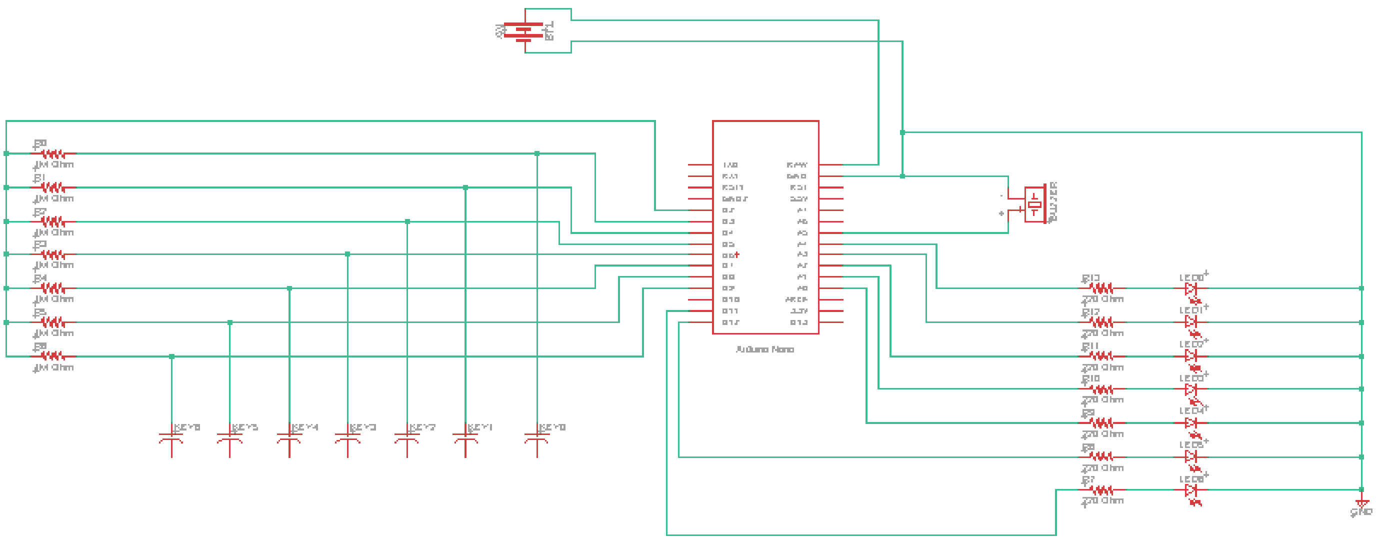
1x DC to DC Voltage Booster https://ram-e-shop.com/product/dc-dc-200/

1x Passive Buzzer https://store.fut-electronics.com/collections/buzzer/products/passive-buzzer

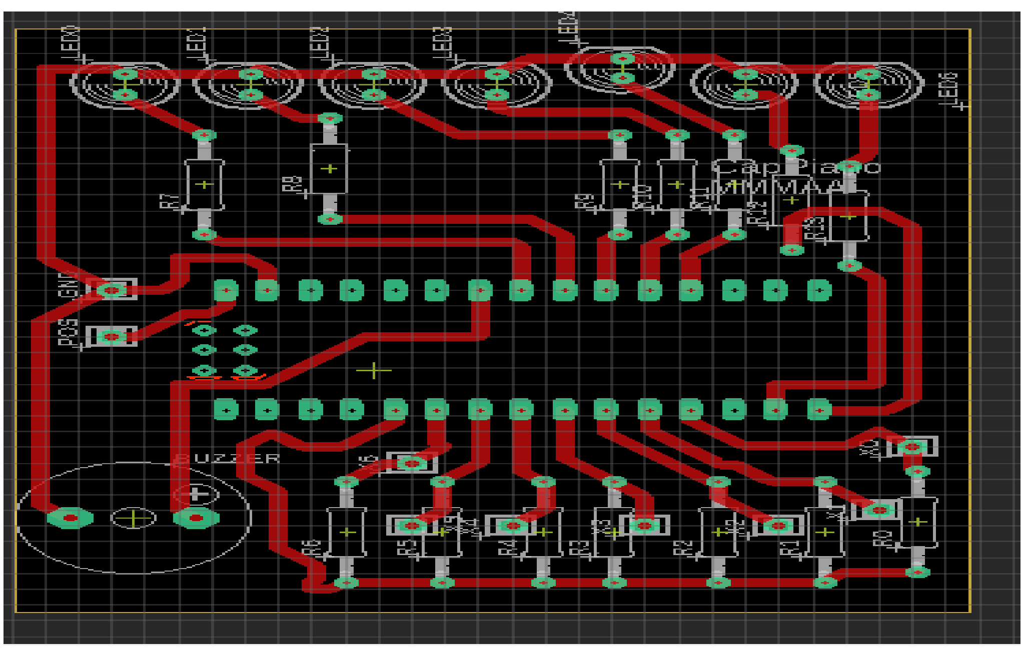
1x PCB

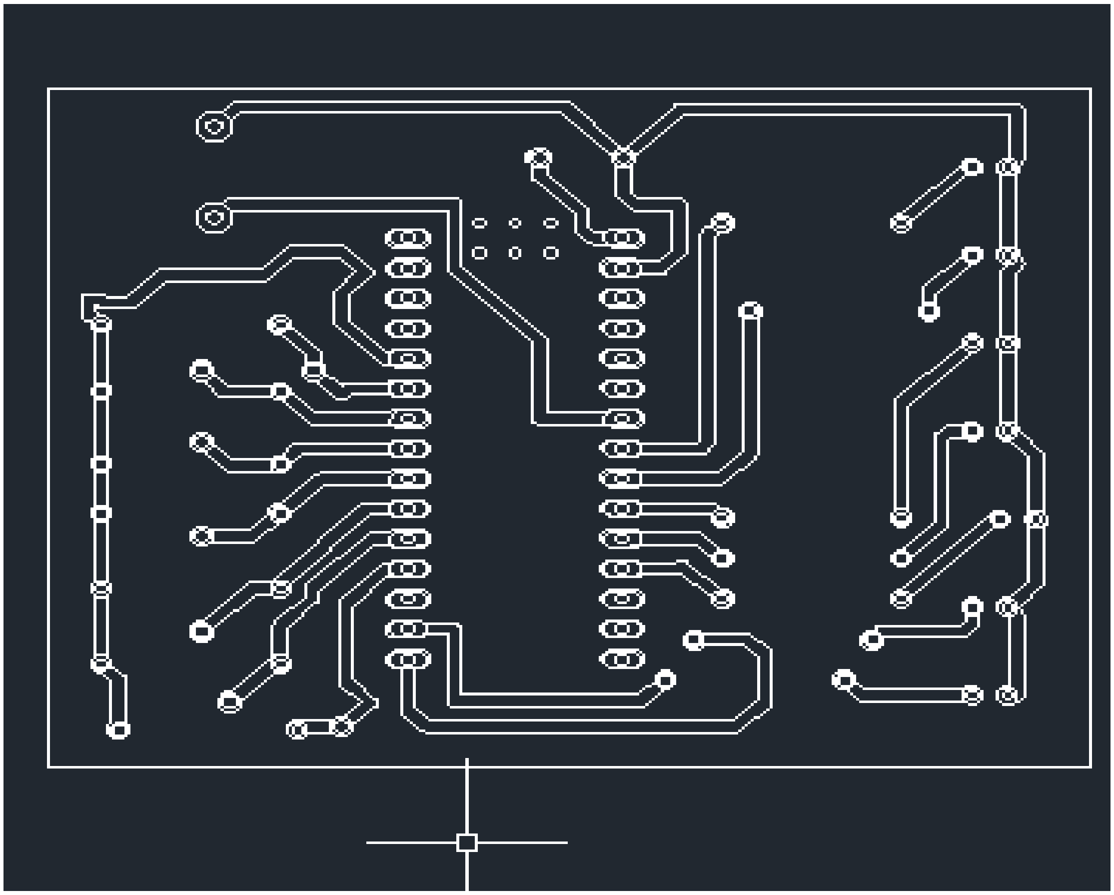
Progress Report:

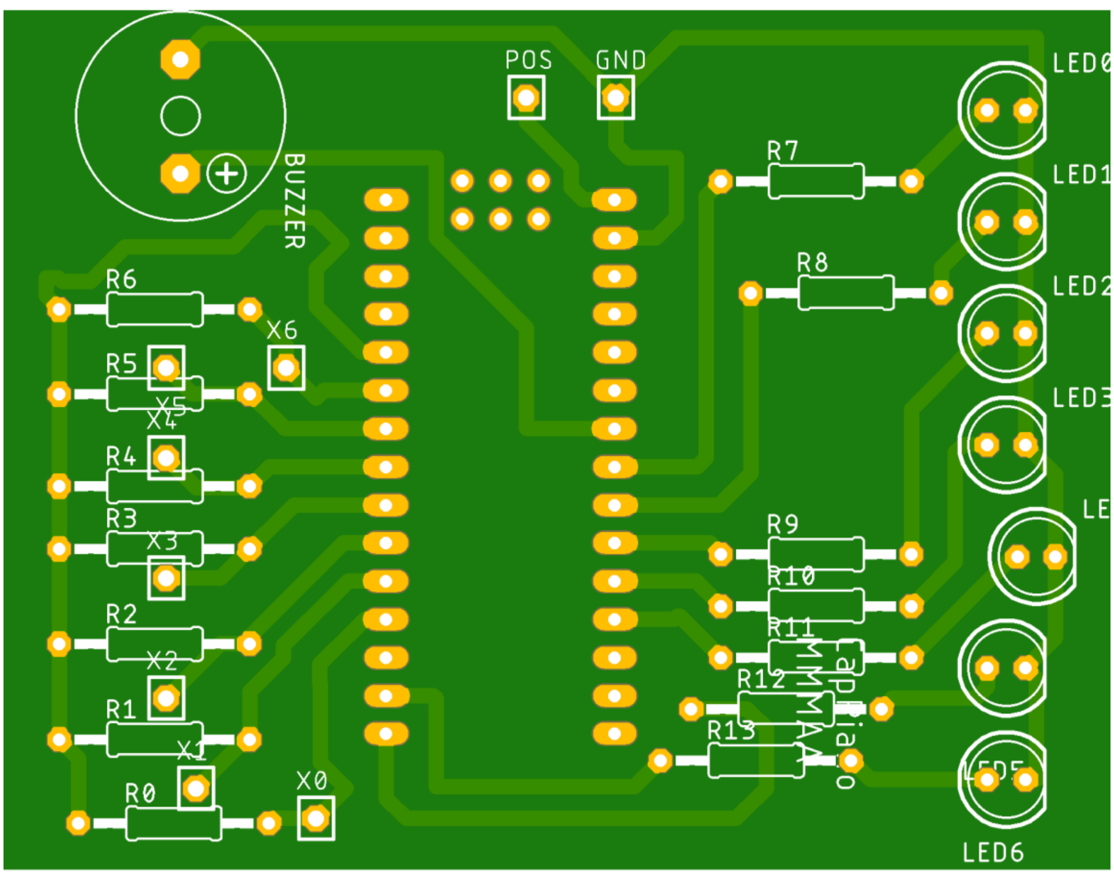
1. Research was made on the project.
2. Components were bought and ready to assemble.
3. Circuitry was developed.



4. PCB board was designed and manufactured.

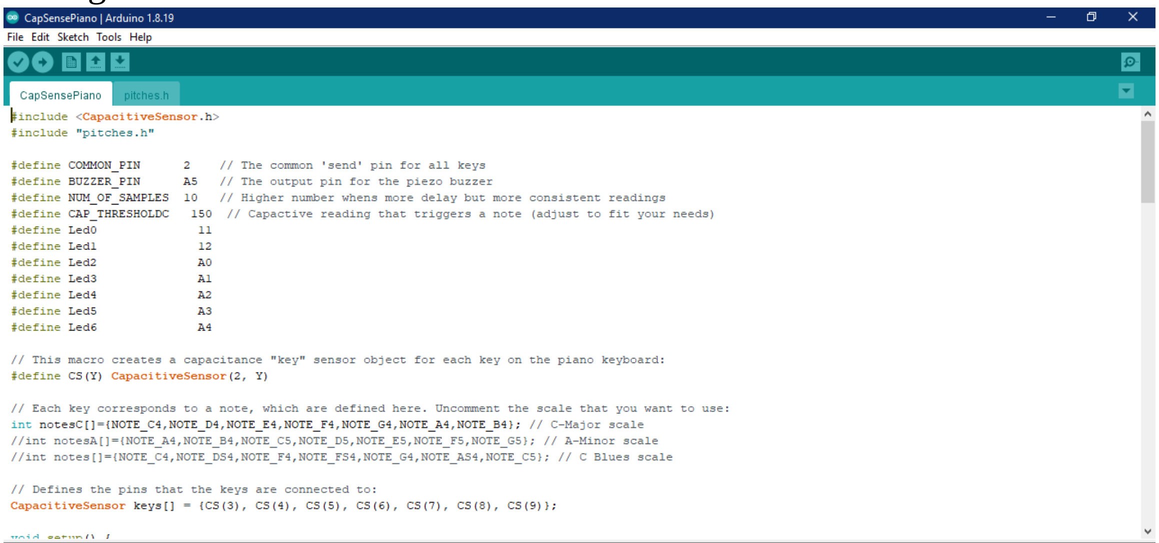






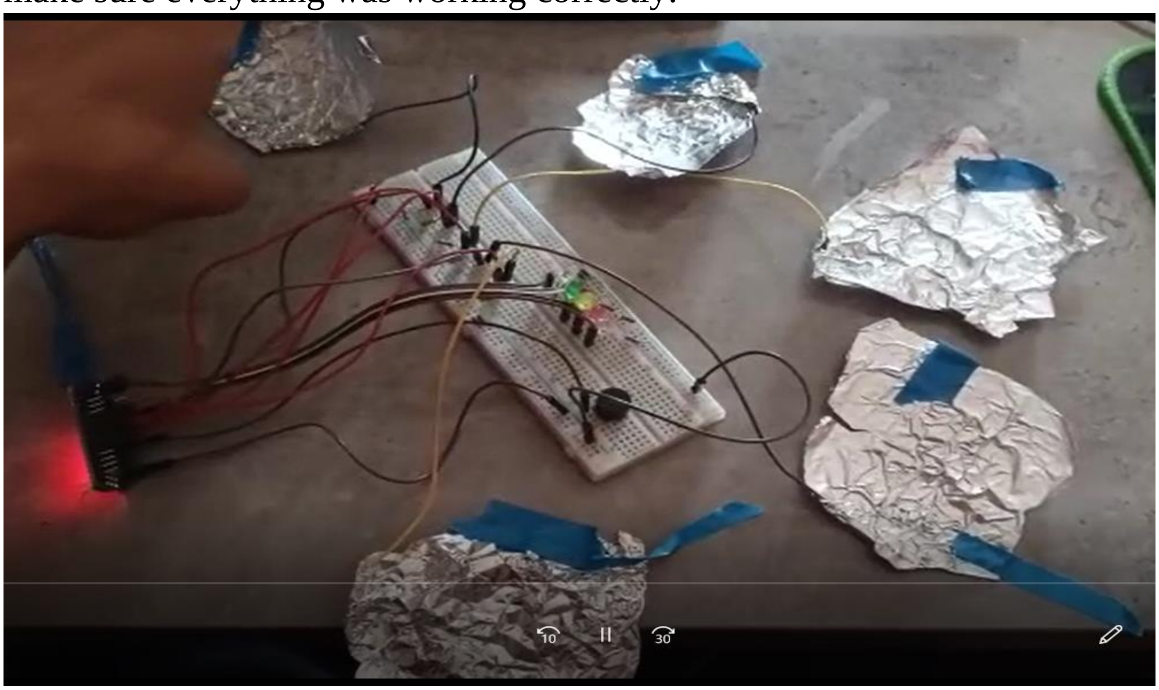
BUZZER
POS
GND
LED0
LED1
LED2
LED3
LED5
LED6
R0
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
X0
X1
X2
X3
X4
X5
X6

5. Code was written and uploaded on Arduino. Basically, it works as follows: A sender pin sends signal to a receiver pin. Then Arduino measures the time it takes for the receiver a pin to receive the signal. As its well known in an RC circuit there some delay between input voltage and output voltage which is called the time constant and thus the Arduino measures this time and use it to calculate the capacitance but in arbitrary units. The higher capacitance, the higher the time.

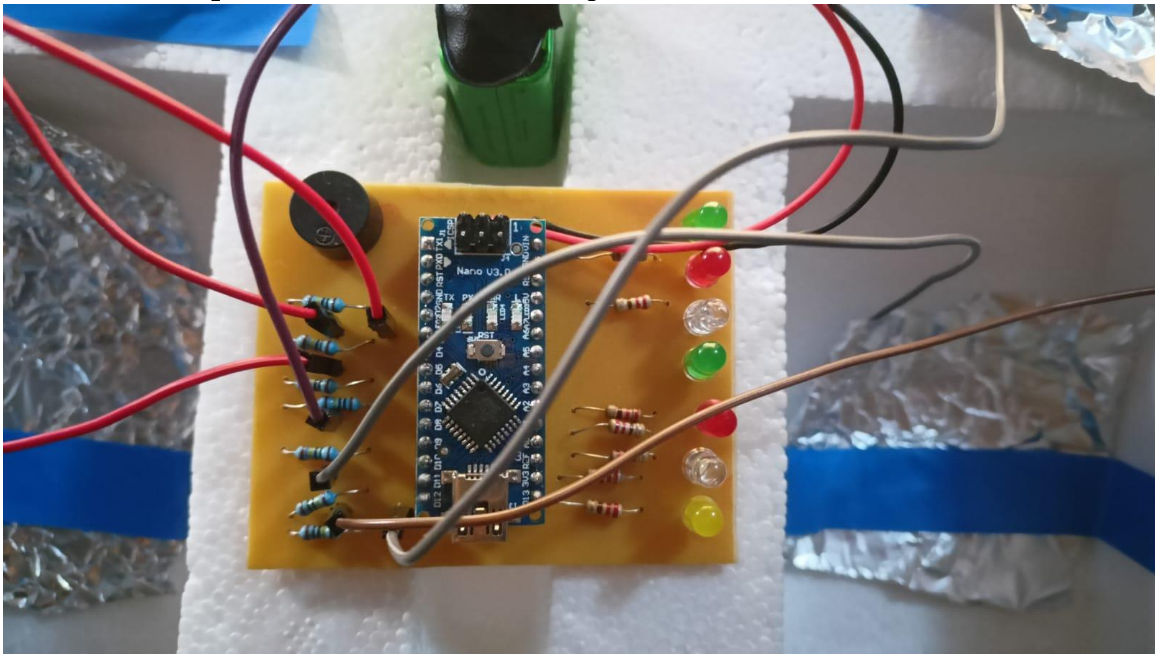



```
#include <CapacitiveSensor.h>
#include "pitches.h"

#define COMMON_PIN      2    // The common 'send' pin for all keys
#define BUZZER_PIN      A5   // The output pin for the piezo buzzer
#define NUM_OF_SAMPLES  10   // Higher number whens more delay but more consistent readings
#define CAP_THRESHOLDC   150  // Capactive reading that triggers a note (adjust to fit your needs)
#define Led0             11
#define Led1             12
#define Led2             A0
#define Led3             A1
#define Led4             A2
#define Led5             A3
#define Led6             A4

// This macro creates a capacitance "key" sensor object for each key on the piano keyboard:
#define CS(Y) CapacitiveSensor(2, Y)

// Each key corresponds to a note, which are defined here. Uncomment the scale that you want to use:
int notesC[]={NOTE_C4,NOTE_D4,NOTE_E4,NOTE_F4,NOTE_G4,NOTE_A4,NOTE_B4}; // C-Major scale
//int notesA[]={NOTE_A4,NOTE_B4,NOTE_C5,NOTE_D5,NOTE_E5,NOTE_F5,NOTE_G5}; // A-Minor scale
//int notes[]={NOTE_C4,NOTE_DS4,NOTE_F4,NOTE_FS4,NOTE_G4,NOTE_AS4,NOTE_C5}; // C Blues scale

// Defines the pins that the keys are connected to:
CapacitiveSensor keys[] = {CS(3), CS(4), CS(5), CS(6), CS(7), CS(8), CS(9)};
```

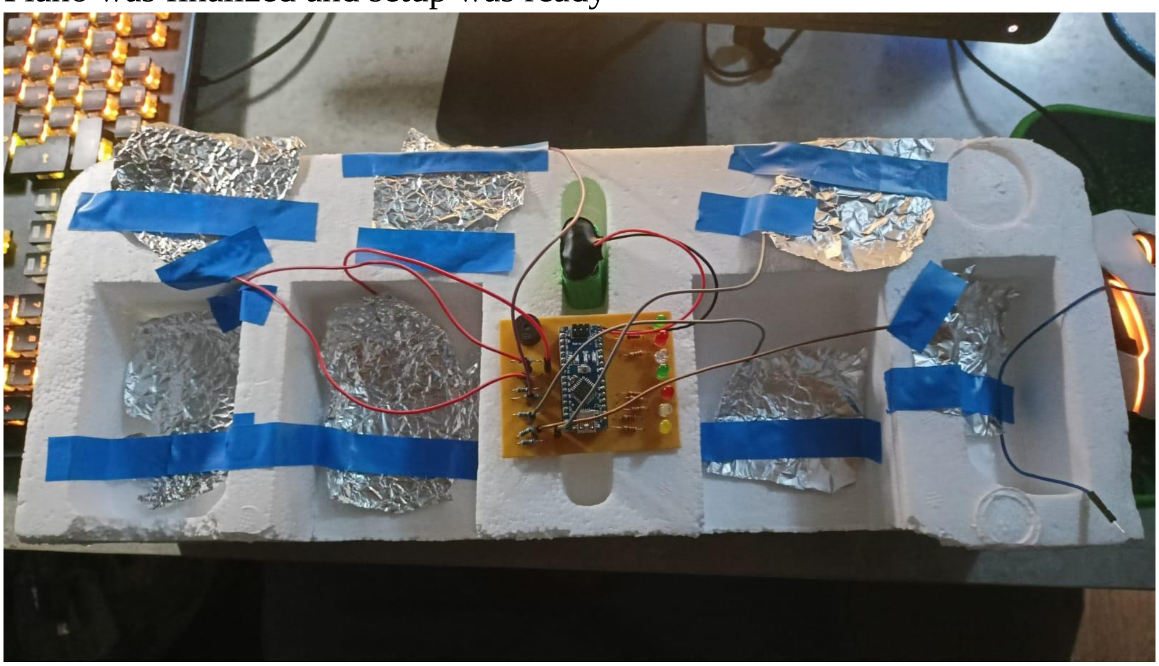
6. Code and circuitry were tested on a breadboard with the components to make sure everything was working correctly.



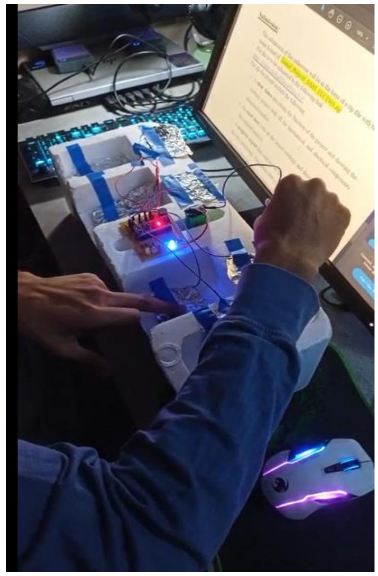
7. PCB and components were soldered together



8. Piano was finalized and setup was ready



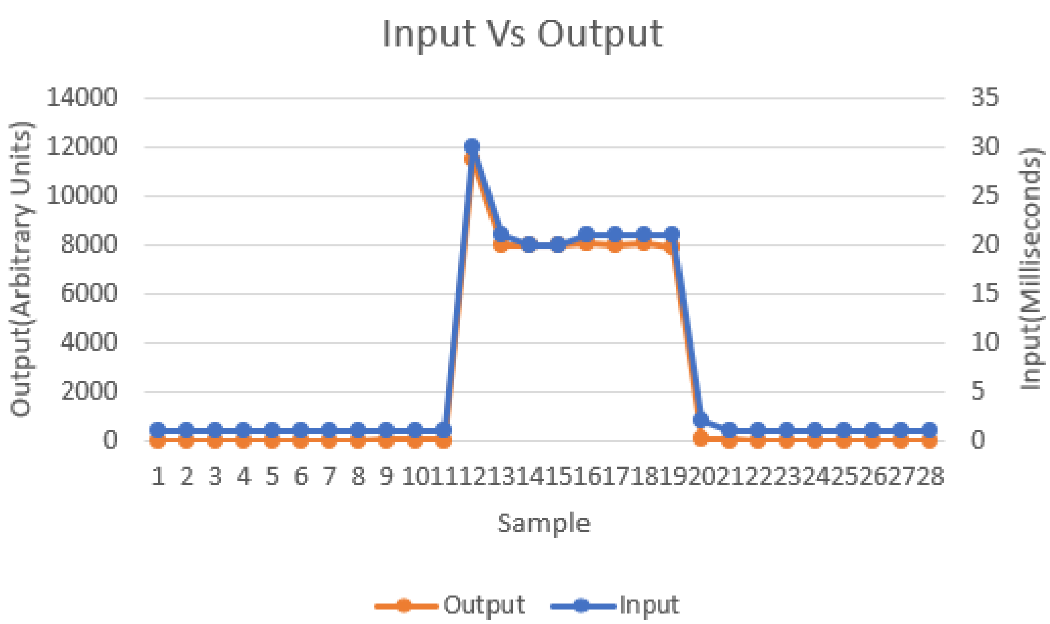
9. Tested the final product and worked as intended

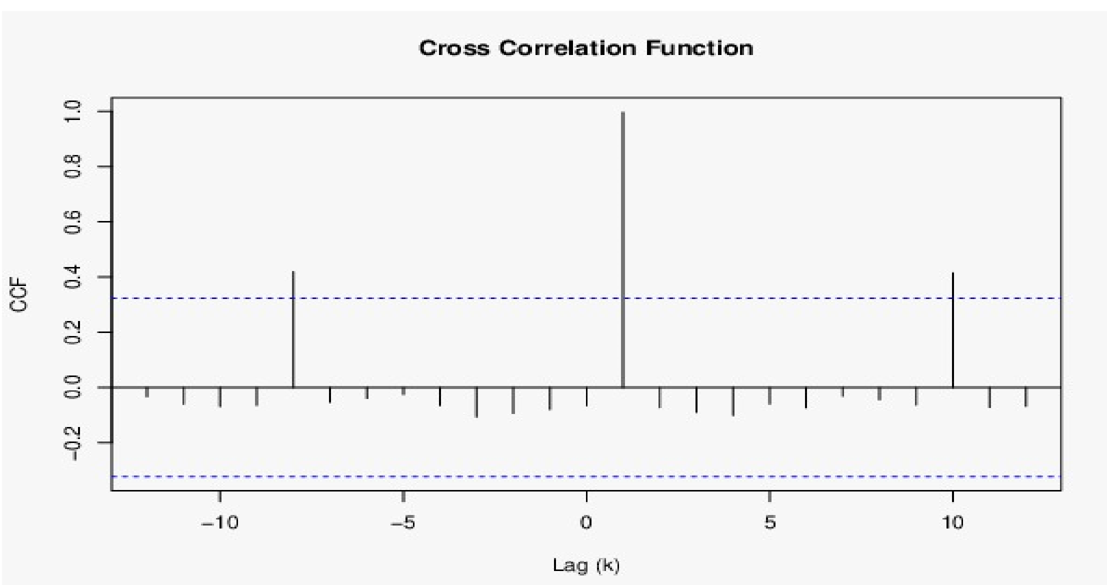


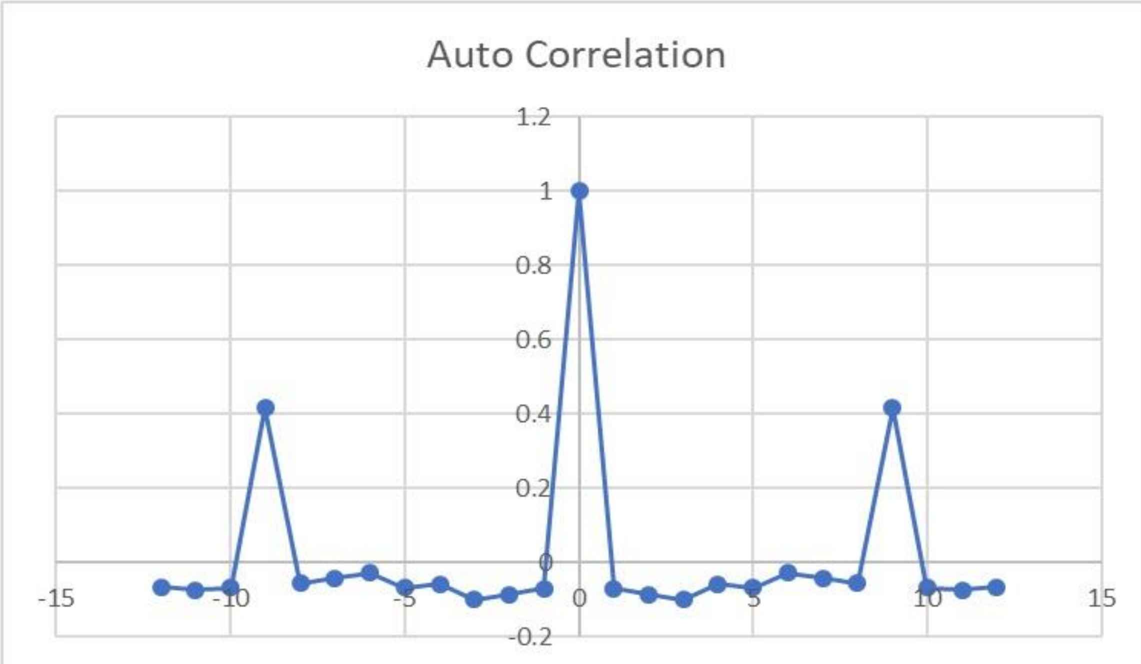
10. Improved on the design and overall look of the product

11.Characteristics and readings

a. Output is the capacitance in arbitrary units.
b. Input is the time in milliseconds.
c. Resolution = Smallest change = 7908 arbitrary units
d. Sensitivity = Max output / Max input = 68625/174 =
   = 394.3965517 arbitrary units/ms
e. Standard Deviation = Resolution * Sensitivity
   = 3118887.931

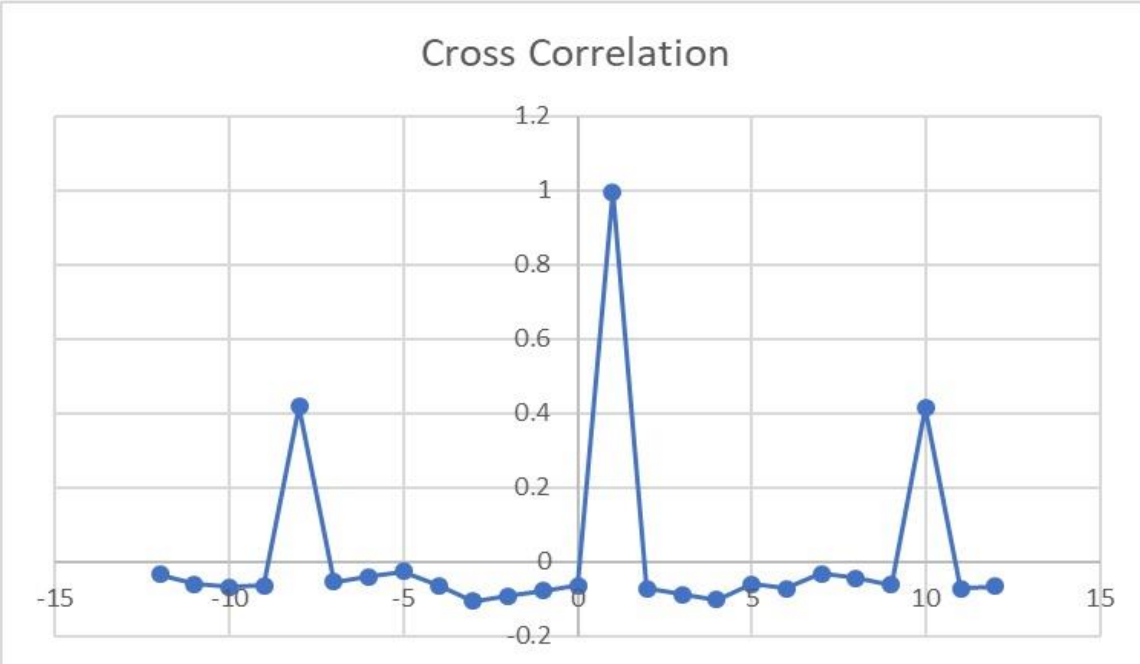






Auto Correlation data

Lag	Value	Lag	Value
-12	-0.0662062927941972	0	1
-11	-0.0734925586884804	1	-0.0705975011622147
-10	-0.0691648171929965	2	-0.0872463857498584
-9	0.416227475311117	3	-0.100410006753664
-8	-0.057048614727936	4	-0.0579493781770414
-7	-0.0429768616635528	5	-0.0683886029991145
-6	-0.0293223584648403	6	-0.0293223584648403
-5	-0.0683886029991145	7	-0.0429768616635528
-4	-0.0579493781770414	8	-0.057048614727936
-3	-0.100410006753664	9	0.416227475311117
-2	-0.0872463857498584	10	-0.0691648171929965
-1	-0.0705975011622147	11	-0.0734925586884804
		12	-0.0662062927941972



Cross Correlation Data

Lag	Value	Lag	Value
-12	**-0.033552933583369**	0	**-0.0653521394067079**
-11	**-0.0606521017242916**	1	**0.996256864778712**
-10	**-0.0679692200080865**	2	**-0.0721238368185577**
-9	**-0.0640923998830103**	3	**-0.0888736820119851**
-8	**0.418626273898603**	4	**-0.101987397425721**
-7	**-0.0534586243471571**	5	**-0.0596517514187829**
-6	**-0.0396104332496399**	6	**-0.0731209767303093**
-5	**-0.0256047110006229**	7	**-0.0318775446980341**
-4	**-0.0648444493153413**	8	**-0.0440842421777302**
-3	**-0.106841982293459**	9	**-0.0626140527663694**
-2	**-0.0930269441936679**	10	**0.414056031301388**
-1	**-0.0792197732757929**	11	**-0.0715237719670072**
		12	**-0.0674413093998998**

f. Transfer function:

The system is assumed to be a first order system with a varying time constant as capacitance changes with respect to distance.

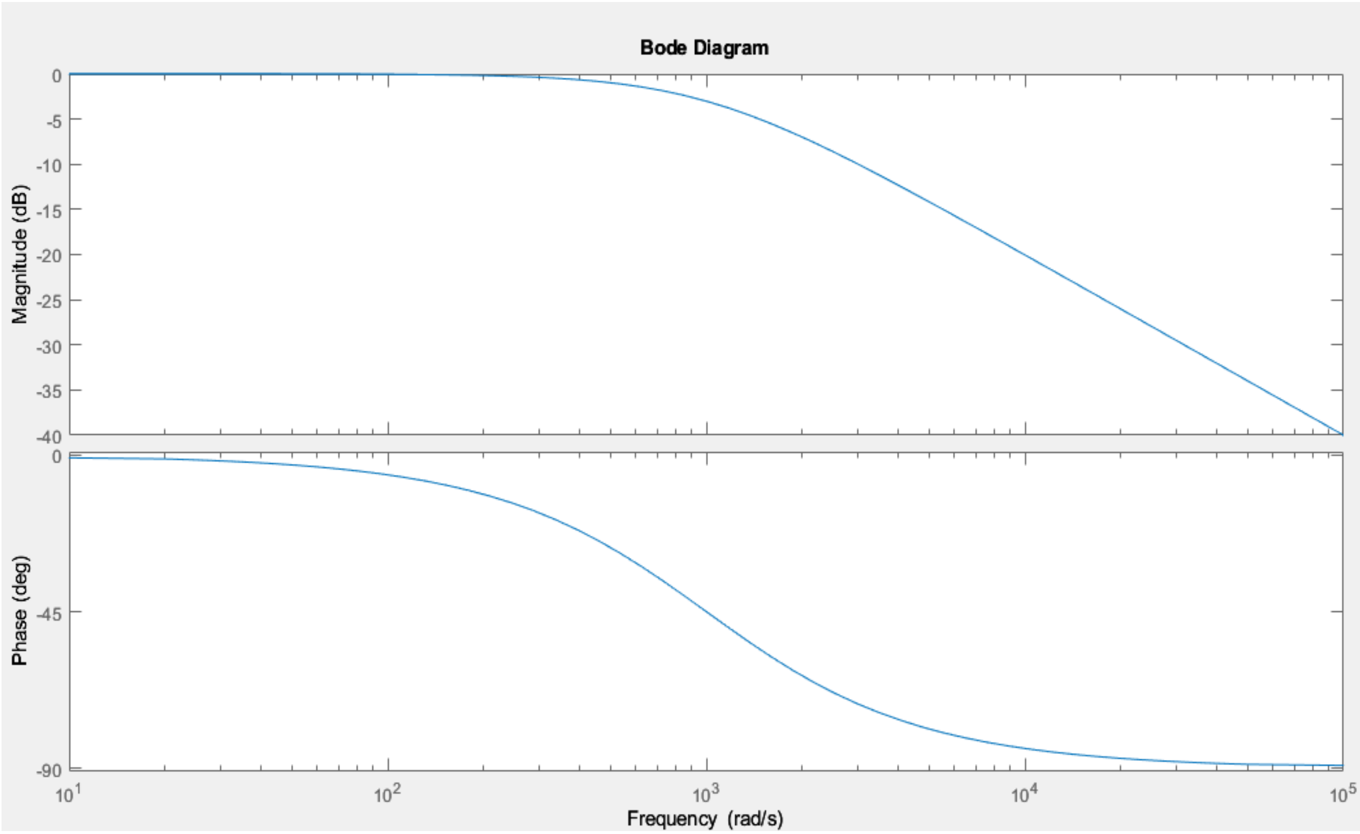
TF = $\frac{1}{Ts + 1}$

Two cases were studied when pressed and when unpressed (High time and low time constant respectively)

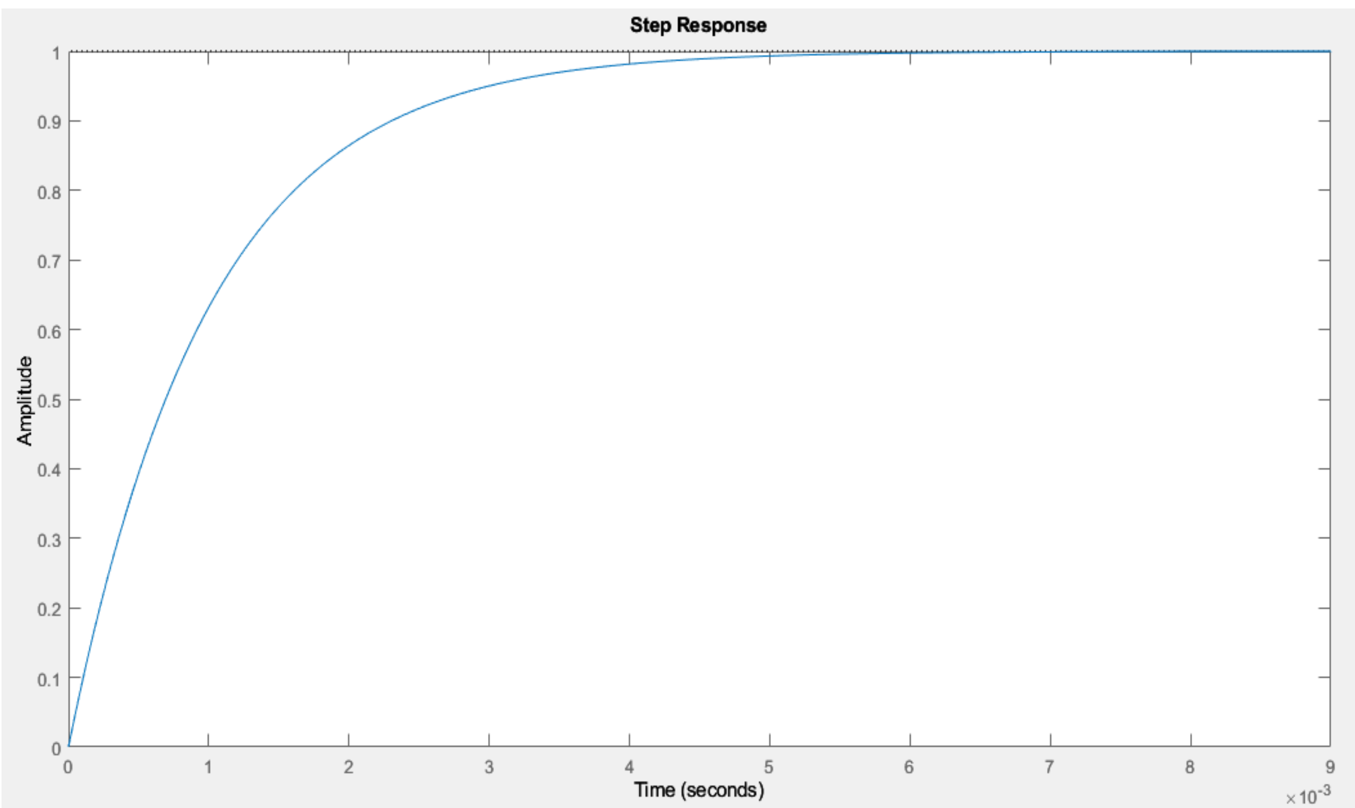
Test case 1: Not pressed; Low time constant around 1 millisecond

TF = $\frac{1}{0.001s + 1}$

Bandwidth of the sensor when not touched at time constant 0.001: 997.6283 rad/s



Bode Diagram
Magnitude (dB)
0
-5
-10
-15
-20
-25
-30
-35
-40
Phase (deg)
0
-45
-90
10^1
10^2
10^3
10^4
10^5
Frequency (rad/s)



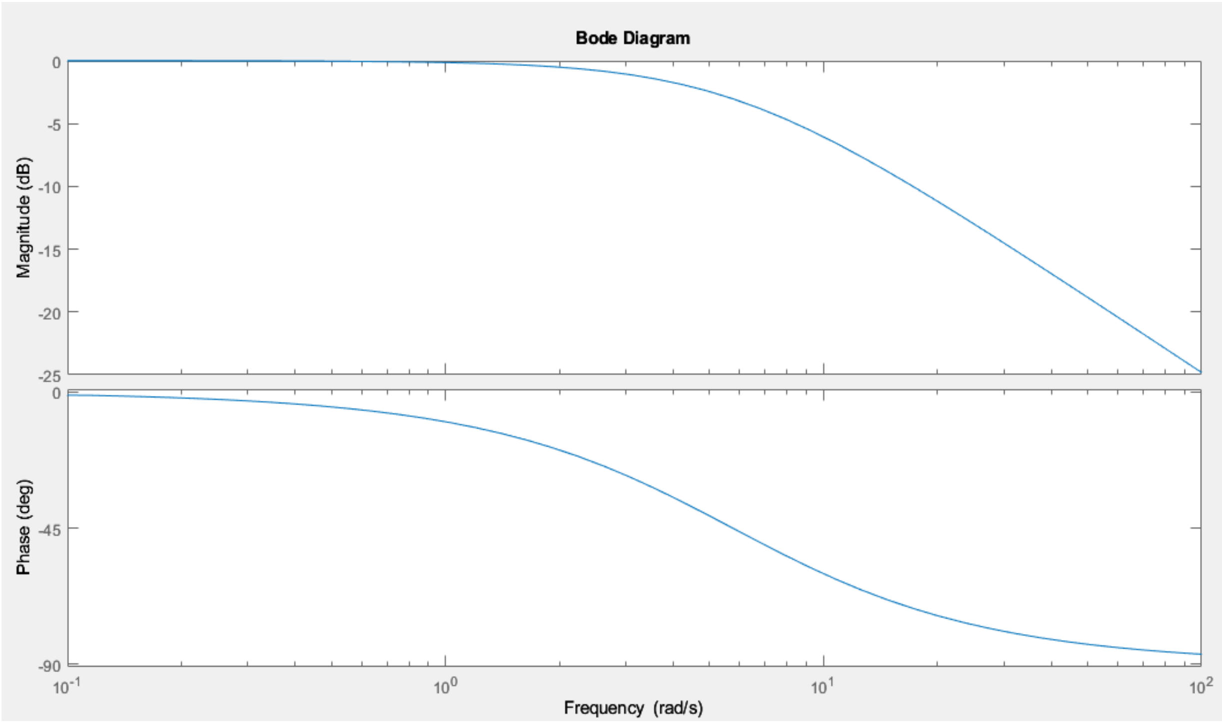
Step Response
Amplitude
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9
Time (seconds)
$\times 10^{-3}$

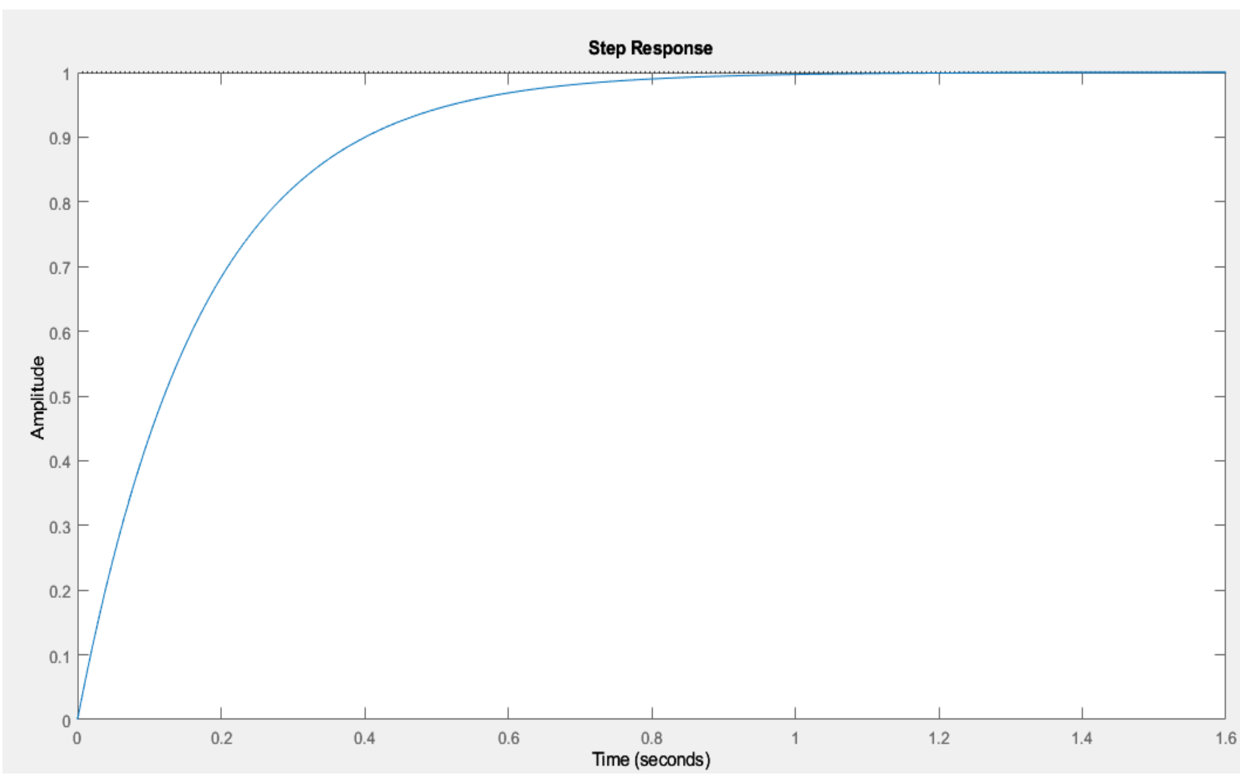
Test case 2: Pressed; How time constant around 174 milliseconds

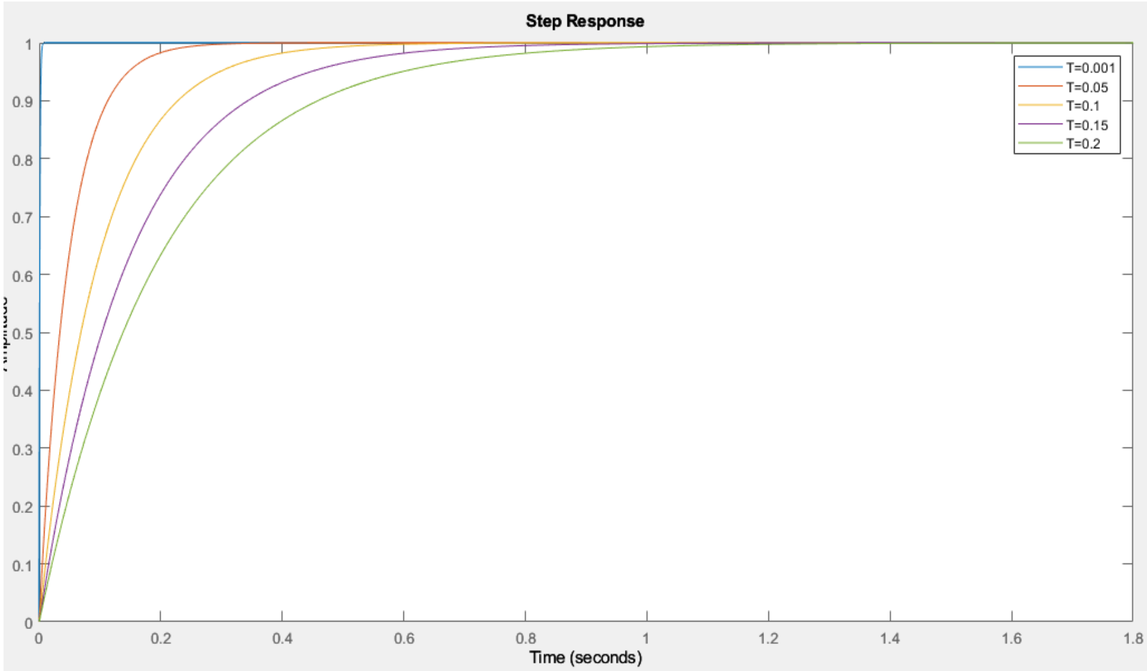
TF = $\frac{1}{0.174s + 1}$

Bandwidth of the sensor when not touched at time constant 0.174: 5.7335 rad/s

Thus, the bandwidth can vary from 997.6283 rad/s to 5.7335 rad/s.


Bode Diagram
Magnitude (dB)
0
-5
-10
-15
-20
-25
Phase (deg)
0
-45
-90
10^{-1}
10^{0}
10^{1}
10^{2}
Frequency (rad/s)


Step Response
Amplitude
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Time (seconds)



As can be seen from the previous graph that as it takes longer to reach a steady state that means the time constant is longer and thus the capacitance is higher.

As the time constant increase, the response takes longer thus that means capacitance has increased.

Similarly, as seen here there is a direct relation between input which is time and output which is capacitance in arbitrary units.