EE318 Electronic Design Lab Report, EE Dept., IIT Bombay, May 2005

DESIGN OF PRESSURE SENSING BASED CONTROLLER FOR AN ARTIFICIAL LIMB

Group No: B10

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PROBLEM STATEMENT

To design a pressure sensing based controller for an artificial limb which is robust, cheap and durable for sufficiently long time. Robustness means the artificial limb must be capable of operating in noisy conditions and must be least effected by physical changes such as temperature. Durability means the artificial limb must operate for sufficiently long time without replacement of pressure sensors. This is as per the requirements of a worker working in industry who has lost his hand in an accident.

For the design of this controller, we have divided the problem into three sections namely: circuit design, capacitor design and software for microcontroller.

1. BLOCK DIAGRAM

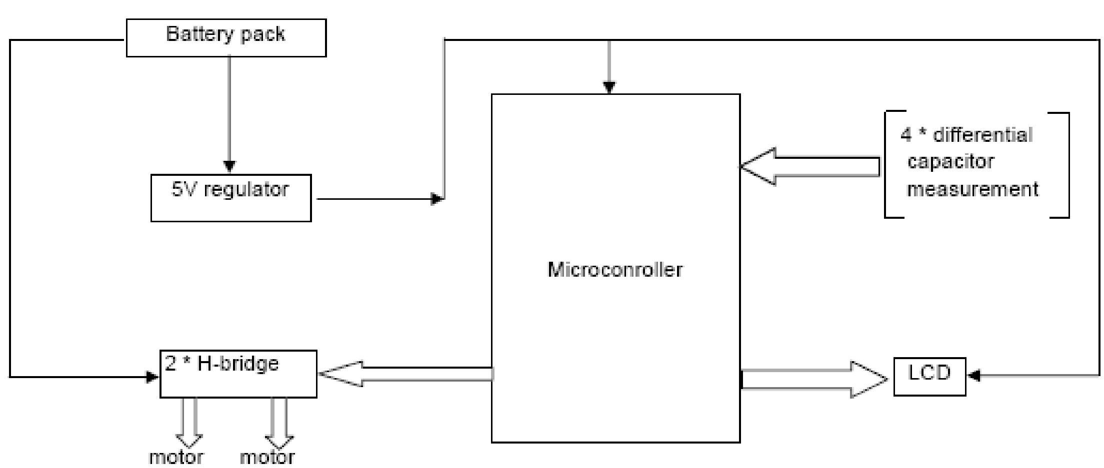

Figure 1: Complete block diagram

The input is taken from the four differential capacitors. Corresponding to the pressure applied, the voltage is obtained which acts as in input. The microcontroller is programmed to take in the input and corresponding to the input, it sends the Pulse Width Modulation (PWM) signals to the motors. An H-bridge is used to have bidirectional rotation of motor. Microcontroller is also programmed to display the differential capacitance measured on the Liquid Crystal Display (LCD). A five Volt regulator is used to give constant 5 Volt supply to the circuit.

2. CIRCUIT DESIGN FOR MEASUREMENT OF DIFFERENTIAL CAPACITANCE

Since the pressure sensor being designed has to be robust, a circuit is chosen such that its operation is not effected by presence of noise.

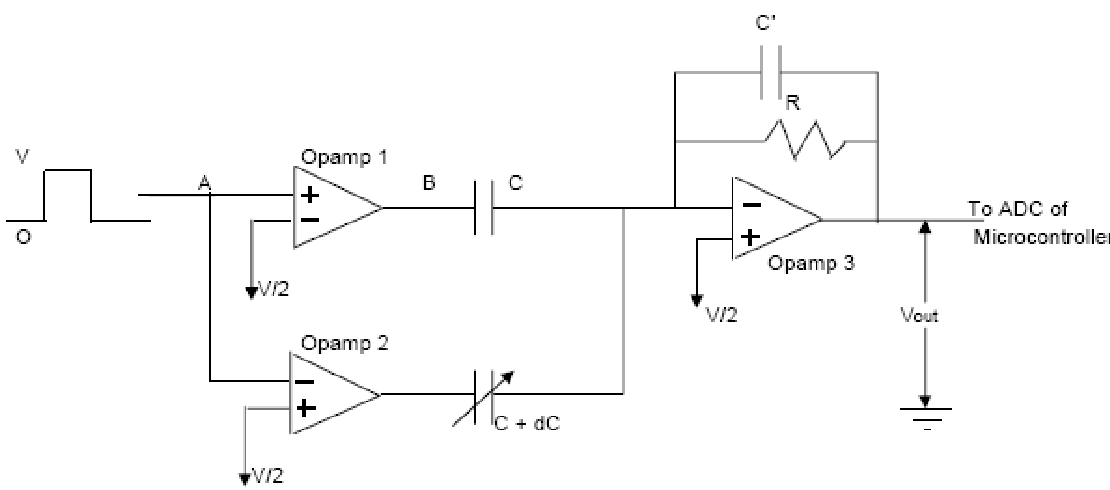

Figure 2: Circuit for measuring differential capacitance

A pulse is sent as an input to the op-amps. Since the input V given is greater than V/2 the op-amp 1 goes into saturation with output voltage being V. Now the charge Q1 flowing through C is

$$Q1 = (V - V/2) * C$$

Similarly the op-amp 2 goes into negative saturation. Hence the charge Q2 through (C+dC) is

$$Q2 = (0 - V/2) * (C+dC)$$

Therefore the net charge flowing through C is Q2 – Q1.

$$Q1 + Q2 = -V/2 * dC$$

The output voltage at the op-amp 3 is

$$V_{out} = V/2 + (V/2 * dC)/C'$$

This voltage is proportional to dC. Hence by sending a pulse as the input the output voltage of the above circuit helps us in measuring the differential capacitance dC.

3. SIMULATION RESULTS

The circuit in figure 2 has been simulated in PSpice for different values of the capacitances ranging from micro-Farads to pico-Farads. Output voltages for capacitors having different capacitances are measured. Few of the simulations have been shown below.

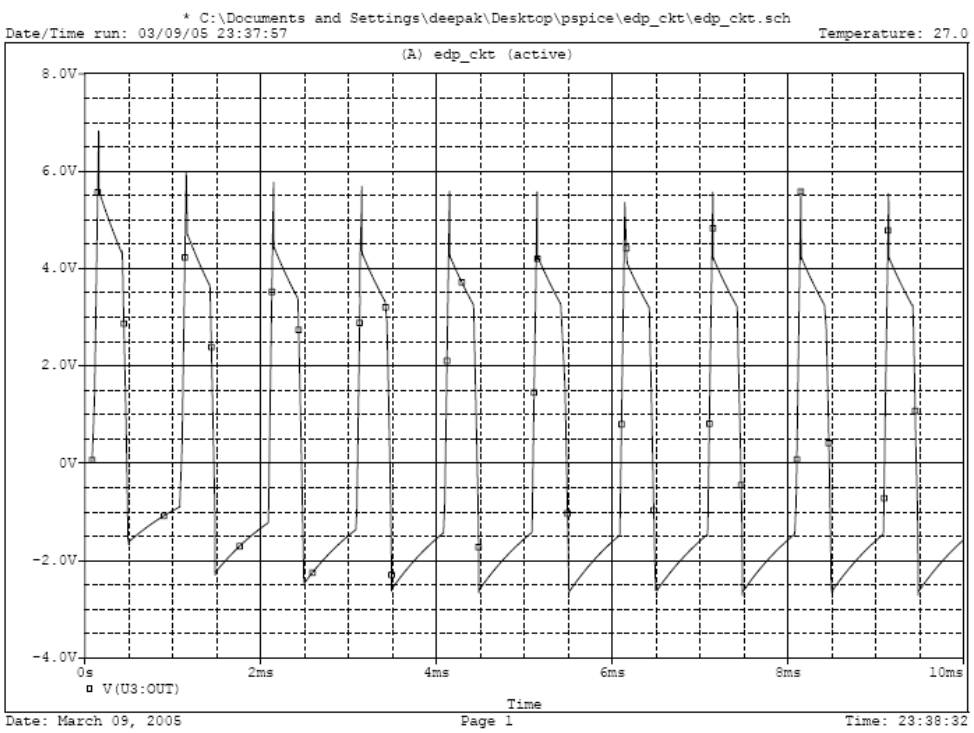

Figure 3: Capacitance 10-14 nF

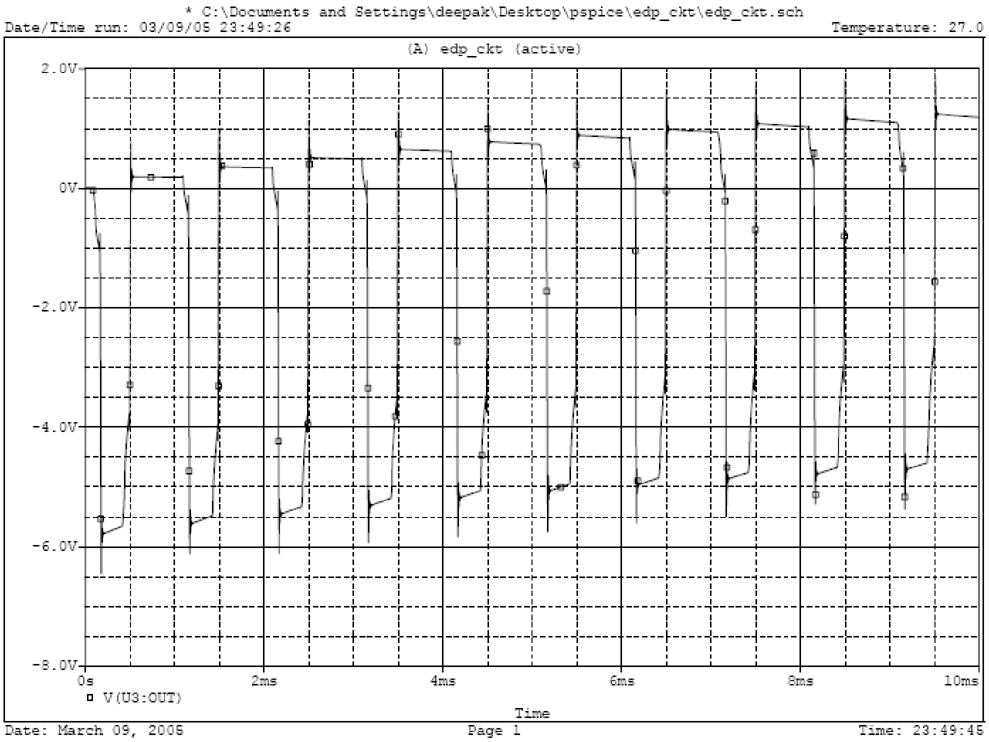

Figure 4: Capacitance 80-100 pF

From the above figures we could see the variation of output voltage with different capacitances (C).

4. PRESSURE SENSOR DESIGN

As seen in the previous section, the circuit was simulated for different values of capacitance. Ideally a capacitance of around 100pF was desired to minimize the effect of stray capacitances. But due to the size constraints for the sensor (max 3cm x 3cm x 1cm), such a large capacitor could not be realized using the dielectric materials available to us. With these constraints a capacitor of about 20pF was realizable.

We know that capacitance $C = K*E_0*A / d$

It turns out that for the given specifications a high (K = approx. 200) dielectric constant material is required which also must be compressible.

An extensive research was carried out by us to find a compressible high dielectric constant material. The dielectric constant of various materials researched by us is shown in the table below.

S. No.	Substance	Compressible / Uncompressible	Dielectric Constant
1.	Polyurethane	Compressible	Approx. 1*
2.	Polyvinylidene difluoride (PVDF)	Uncompressible	Approx. 10*
3.	Polystyrene	Compressible	Approx. 1*
4.	Barium/Calcium titanate	Uncompressible	Approx. 1000
5.	Strontium titanate	Uncompressible	Approx. 250
6.	Strontium Barium Niobate (SBN)	Uncompressible	Approx. 300
7.	Pure Water	Uncompressible	Approx. 80

* There are various grades of the same material having different dielectric constants.

Table 1: Dielectric constants of different materials

Following are the conclusions made after our research on materials having high dielectric constant:

1. We concluded that there are very few compressible substances having high dielectric constant. Most of these are in stages of research or are patented, hence are not easily available.

2. Then we thought of using oils or water put in a deformable plastic bag (or balloon) having high dielectric constant. But this turned out to violate our specification of robustness. This is because the capacitance would then become function of temperature. In case of oils and water which have high temperature coefficients, any reasonable change in room temperature would cause capacitance to change, which is not desirable.

3. Using gels having high dielectric constant has problems of its own. They are not compressible to the extent which was required by us.

4. Finally, we came to the conclusion of using an uncompressible high dielectric constant material together with a compressible sponge as shown in the Figure 5. SBN was used as uncompressible high dielectric constant material and polyurethane for sponge.

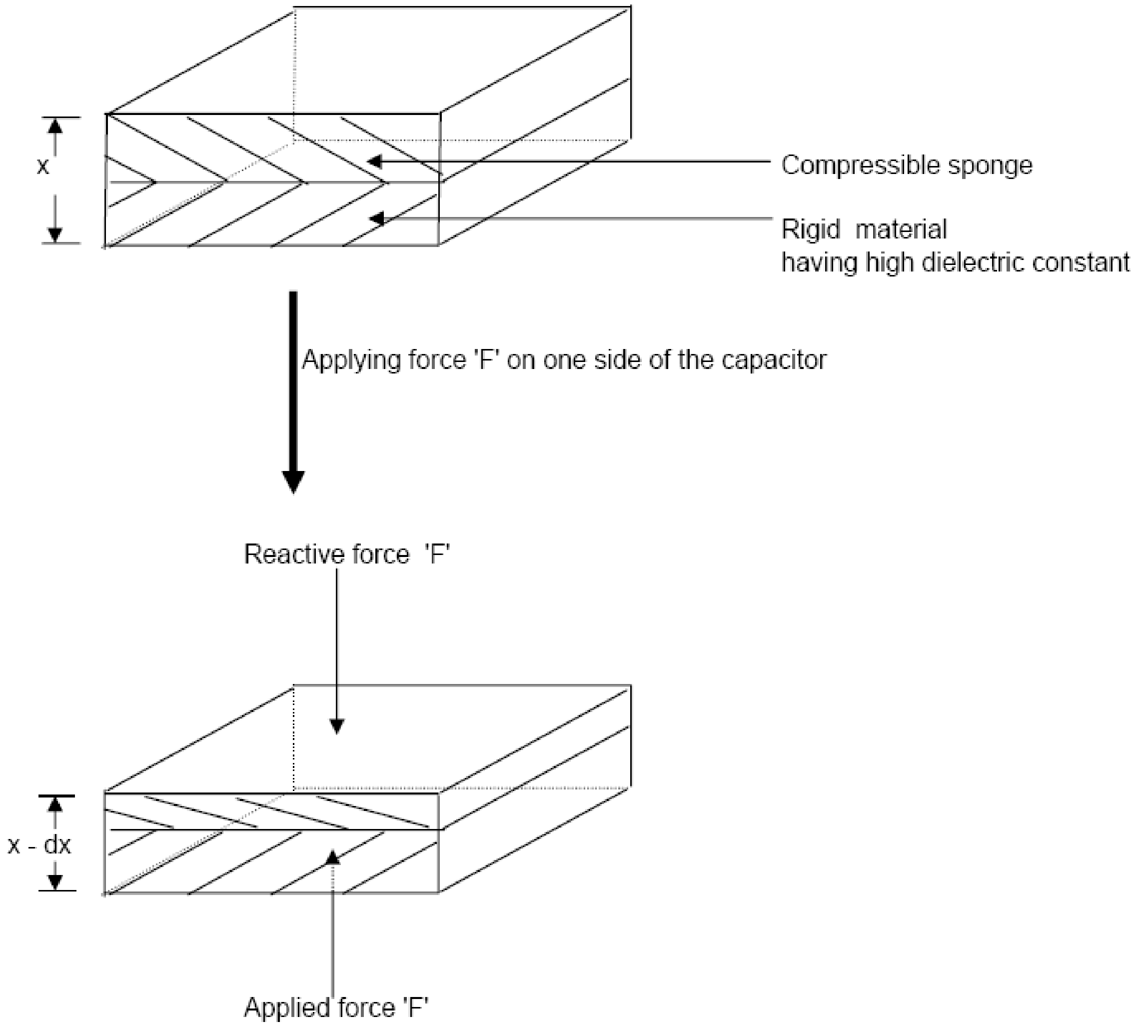

Figure 5: Variation in capacitance by application of force exerted by hand muscles on one side of the capacitor

The SBN crystal used in for designing the sensor had diameter 1.3 cm and thickness of 2.5 mm.

A= π *0.65*0.65 = $1.327*10^{-4}$ m^2, k= 300

Thickness of sponge d' (in mm)	Range of ΔC measured (in pF)
1.5	5
2.5	20
3	9

Table 2: Variation of ΔC with thickness of sponge d'

The upper limit on ΔC is obtained by applying maximum force on the sensor. The lower limit of ΔC corresponds to zero force applied on the sensor.

Since, sensitivity is directly proportional to change in capacitance, higher sensitivity is obtained when thickness of sponge d' is 2.5mm.

The sensitivity decreases as d' is increased beyond a certain limit (2.5 mm was observed) because the capacitance of the pressure sensor can be thought of as series combination of capacitor having SBN crystal as dielectric material and of capacitor consisting of sponge. Since the capacitance of the sponge capacitor is very small the overall capacitance decreases. Therefore, sensitivity is decreased.

Precautions to be taken while designing the pressure sensor:

1. SBN crystalline solid was coated with silver on both sides, since the area of contact on both plates is not same due to surfaces being rough and uneven. Hence to have uniform area of cross section silver coating was done. Without applying silver coating the capacitance was turning out to be about 5pF. After silver coating the differential capacitance up to 20pF could be measured.

2. It was observed that having small thickness of sponge reduced the performance of the sensor. This was because sponge being porous gives rise to non uniform electric field between the plates. Hence the effective cross section area is reduced. The differential capacitance measured was about 10pF to 15pF.

3. It was observed that presence of any foreign matter on the plates of the sensor reduced the sensitivity. This is because the contact between the SBN crystal and the plates deteriorates and hence sensitivity decreases.

5. SOFTWARE FOR MICROCONTROLLER (AVR MEGA16L)

The AVR MEGA16L microcontroller is used because it has the following advantages over the standard 89S51/52 controller:

- In-built 8-channel ADC
- Three PWM Channels
- Low voltage operation till 2.5V (crucial for low-voltage battery operation)

The main algorithm of the controller is given as below:

1) Initialize the ports.
2) Initialize the pulse width modulator.
3) Initialize the LCD.

4) Initialize an array of size four.
5) Read the inputs form the four sensors and store their corresponding values in the array.
6) The outputs displayed are the values of array, which are proportional to the differential capacitances.
7) The width of the pulse is defined to be proportional to the difference of the two sensors which are used for the same degree of freedom.

6. CONCLUSION

The designed circuit having the desired specifications was successfully demonstrated.

Following improvements can be made to the project:

1) Improvements can be made in the design of pressure sensor. This is because making a pressure sensor requires precise cutting tools so as to get dimensions of sponge and capacitor plate accurately. Lack of availability of precise cutting tools results in wide differences in values obtained theoretically and experimentally.
2) Designing the proposed pressure sensor requires a rigid high dielectric constant material. We had implemented it using SBN crystals, but it’s not easily available and therefore cannot be used for mass production. Crystals of Barium or Strontium Titanate can be used instead since it can be produced by large scale industries and also these materials have high dielectric constants.