Intracranial Pressure Sensor

Final Report

Team:

Brad Lindevig (Leader)
Nick Shiley (BSAC)
Evan Flink (Communicator)
Luke Juckett (BWIG)

Client:

Dr. Joshua Medow, M.D.

Advisor:

Professor Bahr

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Abstract

Hydrocephalus is a serious yet treatable disease that affects 1 in 500 births. It is characterized by an abnormal increase in intracranial pressure due to the accumulation of cerebrospinal fluid. The common treatment is a shunt system implanted within the brain that drains cerebrospinal fluid into other parts of the body. In order to detect whether the shunt system is functioning properly, a device that passively and accurately monitors intracranial pressure is wanted. The criterion for this device requires it to be passively powered, biocompatible and implanted for 10 to 20 years. A user interface must also be developed that accurately measures intracranial pressure from the sensor. This semester a prototype of the sensor was built along with a user interface system that has been tested to accurately relay pressure.

Intro/Background

Hydrocephalus is a condition that increases intracranial pressure (ICP) in the brain by the accumulation of cerebrospinal fluid (CSF) in the ventricles and subarachnoid spaces of the brain[3]. Hydrocephalus is primarily caused by problems with the body absorbing the CSF, blockage of the CSF flow inside the head, or the overproduction of the fluid [3]. The increase of ICP can lead to enlargement of the head, bulging fontanelle in infants, convulsions, mental disability and possibly death [3]. The condition can either be diagnosed during the third trimester of pregnancy, at the birth of the child, or it can be acquired later in life by bleeding inside the head, a severe head injury, an infection, or a tumor [3]. Hydrocephalus affects 1 in every 500 births making it one of the most common birth defects and the leading cause of brain surgery for children in the U.S [2].

The accepted treatment for hydrocephalus is the Ventriculoperitoneal shunt (cerebral shunt), which has not changed much since it was developed in 1960 [2, 3]. The shunt is surgically placed in the ventricular space of the brain, located within the cerebrum. It consists of a small catheter that is threaded behind the ear with a one-way drainage valve that subdermally diverts CSF from the brain to the abdominal cavity where the fluid can be reabsorbed by the body [3].

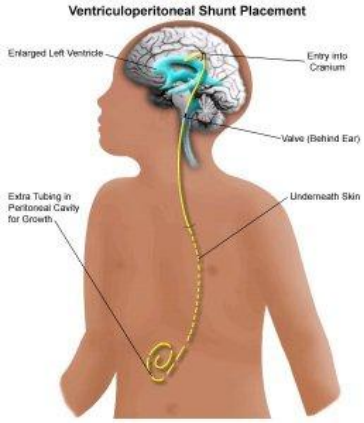

Figure 1. A diagram of a shunt system in a patient.

Ventriculoperitoneal shunt malfunctions are a serious problem for patients with hydrocephalus. 50% of all shunt systems fail within the first two years after implantation therefore requiring frequent medical checkups [2]. Further surgery is needed to replace or repair the failed components. However, the major problem with shunt malfunctions is that there are no reliable ways to diagnose whether it is failing from outside the skull. The reason being is that, the early symptoms of rising pressure in the brain vary widely: everything from headaches, to flu-like symptoms, to seizures [2, 3]. Because of the many symptoms, diagnoses are unreliable and potentially incorrect, neither of which bode well for the patient [2]. Therefore, the only way to

correctly diagnose shunt malfunctions is exploratory surgery, which poses a high risk for the patient [2].

ICP sensors are implantable devices that can measure the pressure inside the skull to determine shunt functionality. Current ICP sensors are quite flawed. They are all restricted to battery life and temporary implantation. Many ICP sensors have a wire that extends out of the skull, which could lead to infection and other physical hazards.

Problem Statement

The main goal of this project is to minimize the number of invasive procedures for a patient suffering from hydrocephalous in order to determine shunt functionality. To complete this goal our group designed a wireless ICP sensor that does not require a battery. This sensor transmits accurate ICP data over a long period of time though a user interface developed in LabVIEW 8.2.

Overall Design

The final sensor design consists of two parts: the capsule and sensor. The capsule holds the sensor in place, through the use of epoxy, approximately 5mm below the dura (Figures 2-4).

Figure 2: Schematic drawing of the capsule

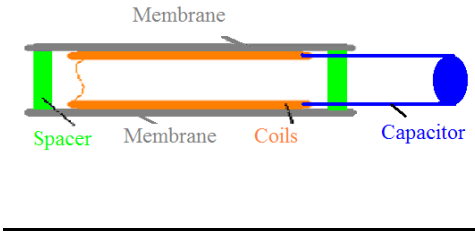

Figure 3: Schematic drawing of the sensor

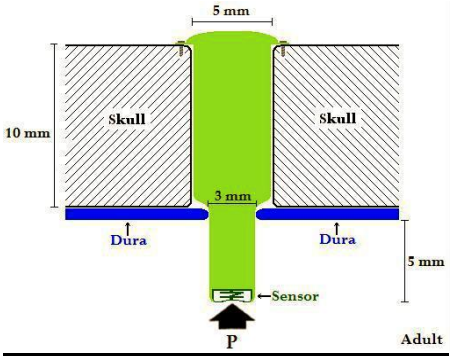

Figure 4: Drawing of where the ICP will be located in a patient

Capsule Design

The capsule holding the sensor is in the shape of two cylinders stacked on top of each other, one being 3mm in diameter and the other being 5mm in diameter. The upper part of the capsule is directly screwed into the skull and the lower section penetrates the Dura of the brain.

The final design of the capsule is going to be made of the biocompatible material Delrin 150. However, the prototype capsule is made of acetyl copolymer, which is not biocompatible, but is inexpensive and has many similar characteristics to Delrin 150.

Sensor Design

The internal sensor creates a tank circuit which consists of two coils that are placed facing one another (Figure 5). These coils act as an inductor and a capacitor. Such a circuit has a characteristic frequency at which its resistance is very large; this is called the resonant frequency. At any other frequency, its resistance is low (Figure 6).

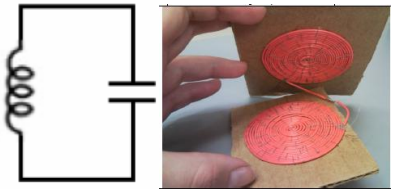

Figure 5: The schematic of the tank circuit is on the left and a large scale prototype is on the right.

$$f_{resonant} = \frac{1}{2 \cdot \pi \cdot \sqrt{L \cdot C}}$$

L = Inductance
C = Capacitance

Figure 6: Resonant frequency equation

$$C = \frac{\varepsilon_0 \cdot A}{d}$$

C =Capacitance
d = Distance
A = Area
ε_0: Dielectric constant

Figure 7: Capacitance equation

According to the capacitance equation the distance between coils will determine the capacitance and thus the resonant frequency of the tank circuit (Figure 7). ICP either pushes together or pulls apart the membrane which holds these coils in place, changing distance and resonant frequency. This change in resonant frequency is sensed by the interrogating device that powers the tank circuit inductively and can be translated into ICP through our program in LabVIEW 8.2. The interrogating device consists of a cylinder wrapped with copper wire which creates an inductor. While this inductor has a current running

through it and is placed near the tank circuit, it will inductively create a current in the tank circuit through electromagnetism.

In order for the tank circuit to fit inside the sensor the coils have a diameter of 2.5 mm. These coils have an inductance value of 8.0 μH and a capacitance value of 1.6 pF (Figure 8). This means the resonant frequency should be 44 MHz. Our interrogating device is not able to oscillate as such a high value. Therefore, adding another 1.0 pF capacitor to complete the tank circuit will lower this resonant frequency to 35 MHz, which is measurable.

The original design of the sensor utilized a saline solution which would replace the added 1.0 pF capacitor soldered to the tank circuit. To generate a saline solution to test the sensor in the phantom tester is not achievable in the amount of time provided due to the complexity of obtaining the correct concentration throughout the column of water. The final design will incorporate the saline solution in the body to act as a capacitor and complete the tank circuit.

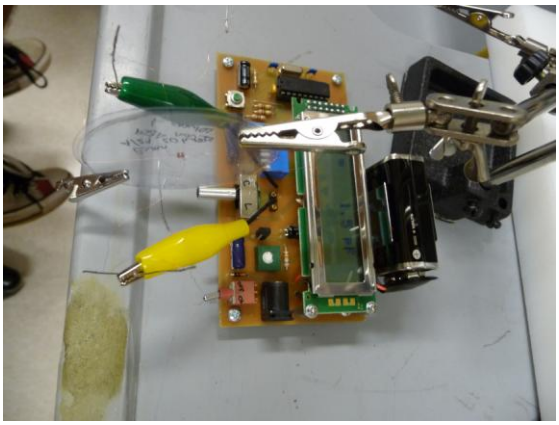

Figure 8: Testing of coils

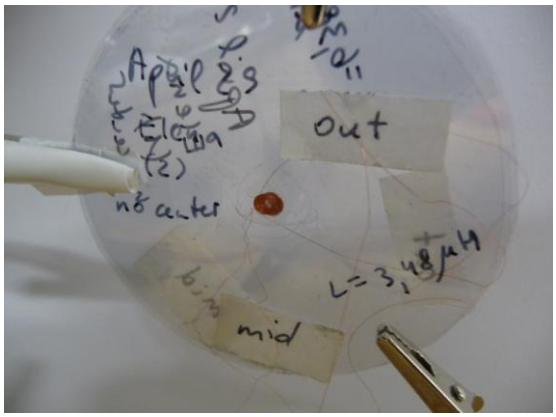

Figure 9: One 2.5mm diameter coil surrounded by cellulose acetate

$$y_c = \frac{3(m^2-1)r^4P}{16m^2E_yt^3}$$

m =Poisson's ratio
r = Radius of membrane
P = Pressure of environment
t = Thickness of membrane
Ey = Young's modulus

Figure 10: Membrane deflection equation

The 2.5 mm coils fabrication utilized 40 gauge copper wire that was turned 20 times between two sheets of cellulose acetate that are each .1 mm thick (Figure 9). The coils are glued to the cellulose acetate to make the coils stay in their form. The cellulose acetate also acts as the membrane for the sensor which is responsible for the movement of the coils.

Cellulose acetate is biocompatible and it satisfies our membrane deflection equations. The result of the membrane deflection equation has to be less than 5% of 3 mm radius of the membrane for pressure between -30 mmHg and 100 mmHg. If the membrane deflection exceeds this value, then the membrane will be subjected to forces that may change its mechanical properties. The expected deflection of the membrane under such pressure is .125 μm for -30 mmHg and .415 μm for 100 mmHg (Figure 10). This is less than the 15 mm maximum deflection.

With the coils glued to the cellulose acetate and both coils being soldered together with one wire, the other wire was left open for the 1.0 pF capacitor. This 1.0 pF capacitor is covered in glue to keep it water tight. The spacer is made of the same material as the capsule which has a 3.1 mm outside diameter and a 2.8 inside diameter hollowed out. The sensor is glued to the end of the capsule.

User Interface

In order to detect this resonant frequency and translate it into ICP the interrogating device with external circuit sweeps through frequencies, powering the internal tank circuit through inductive effects. When the external circuit reaches the resonant frequency of the internal sensor maximum power is drawn from the external circuit. This is seen as a peak in voltage from the sawtooth waveform on an oscilloscope (Figure 11). An increase in ICP pushes the coils together thus decreasing the distance between them which increases the capacitance and decreases the

resonant frequency of the internal sensor (Figure 12). This change in resonant frequency is represented as a shift to the right of the resonant frequency peak.

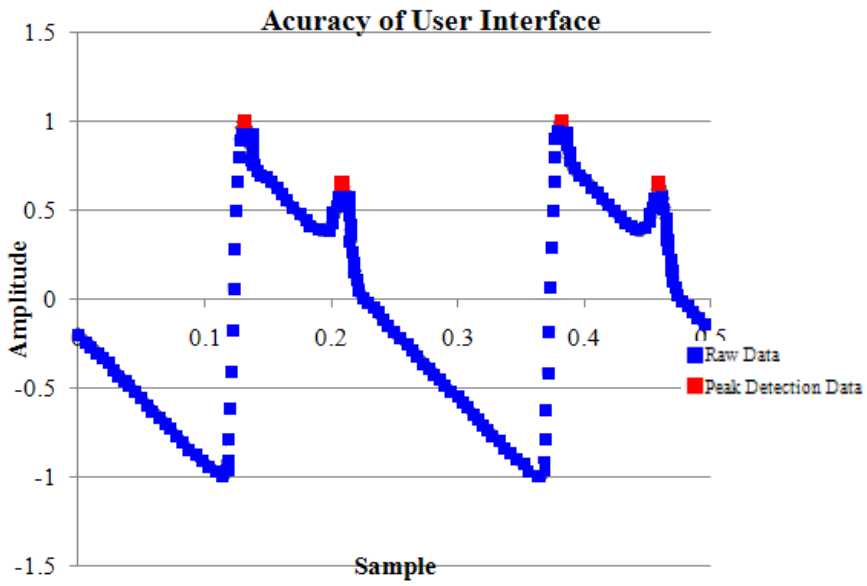

Figure 11: The frequency sweep of the external circuit starts at .12 and ends at .38 then repeats itself. The resonant frequency of the tank circuit can be seen as a peak in the amplitude around .2. The SD for the peak detection points have a y-value of no more than 0.005386314 and an x-value of no more than 0.000467873.

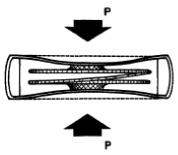

Figure 12: Membrane deflection from ICP will change the distance between the coils

The resonant frequency produced by the tank circuit is translated into pressure through an algorithm created in LabVIEW 8.2. This algorithm calculates the exact locations of each peak on the graph. By subtracting the distance of the resonant frequency peak from the start of the frequency sweep the distance between these two can be determined. This distance can then be translated into ICP based on our testing data. Pressure versus distance of these two peaks was calculated with the phantom tester.

Testing

When the ICP device is assembled and operational it will be placed in our phantom tester which creates pressures in a similar manner within the skull (Figure 13). The sensor will sit at

the bottom of the column of water. While filling up the column, pressure will be calculated based on the height of the water according to the pressure vs. depth equation (Figure 14). The distance of the peaks will also be recorded which correspond to the pressure. These data points will then be plotted and the line of best fit will be determined to relate the pressure and distance of the peaks.

Figure 13: Phantom Tester

$$p = \rho g h$$

ρ = density of water
p = Pressure
g = gravity
h = height of water

Figure 14: Pressure equation

Figure 15: Hand wound coils on the left photolithography on the right

Future Work

There are some modifications that can be made to improve the design and make it more marketable. One modification would be the use of photolithography to fabricate the coils instead of hand-winding them. Hand-winding the coil was a very delicate process. Because the wire is so thin, it was very susceptible to breaking if not handled with care. This method produced various coil sizes because it was very hard to be consistent from coil to coil. Hand-wound coils

also results in uneven shaping of the coils (Figure 15). This influences the amount of capacitance when the coils are placed near each other due to the magnetic flux also being uneven.

Photolithography uses chemical reactions involving acid and light to form grooves into silicon. The silicon is then hit with gold molecules. The excess gold is removed, leaving gold filled grooves in the shape of a coil. This method would make coil fabrication more reliable, repeatable, and mass producible. It also provides for a much more even coil which will have a higher capacitance than the hand wound coils.

Another modification would be the use of saline solution in our testing chamber instead of water because saline better represents the environment inside the body. The use of saline solution replaces the 1.0 pF capacitor which is temporarily soldered onto the prototype, because the composition of the saline solution completes the circuitry of our sensor. This allows the resonant frequency of our signal to be within a range where it can be observed for analysis.

References

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Appendix

Product Design Specifications:

Intracranial Pressure Sensor

Team Roles:

Team Leader: Brad Lindevig
Communications: Evan Flink
BWIG: Luke Juckett
BSAC: Nick Shiley

Last Update: May 5, 2010

Function: Shunt failure in hydrocephalus patients is difficult to detect. The current pressure sensor system is complex and bulky. Other detection methods can be inaccurate. Our client needs a more simple, inexpensive, and reliable implantable intracranial pressure monitor for patient care. The first step to developing this product is to design it on a large scale. A large prototype exists and our goal this semester is to design a user friendly interface to read the ICP pressure accurately.

Client Requirements:

• Must not interfere with sensor telemetry

• Must apply proper range of pressure (-30 to 100 mmHg)

• Must apply constant pressure over a long period of time

• Must be able to apply a known and accurate pressure

• Must be able to test drift-stability

• Testing protocol must be standardized and accurate

• 3mm max width, 15mm max depth

• Interface must show ICP pressure and the pulse rate

Design Requirements:

1. Physical and Operational Characteristics

a. Performance Requirements: The interface must be real-time and give accurate positive and negative ICP pressure readings. It also must give a pulse rate in real-time.

b. Safety: It must be accurate; otherwise false readings could lead to unnecessary surgery.

c. Accuracy and Reliability: The interface must be real-time that must be in close proximity to the actual pressure. The accuracy of the device will be improved continuously throughout the semester.

d. Life in Service: Components should have a life span of 20 years.

e. Shelf Life: Storing the product will have no effect on its ability to perform.

f. Operating Environment: This device will be used in a traditional lab setting, but should be operable anywhere, including patients' homes.

g. Ergonomics: There should be a low learning curve, but interpretation should be done by licensed professionals.

h. Size: The sensing device should be a maximum of 3mm in diameter and 15mm in depth. The interface has no size requirement.

i. Weight: Not applicable

j. Materials: Not applicable

k. Aesthetics, Appearance, and Finish: The interface system should look professional, yet easy to interpret ICP pressure.

2. Product Characteristics

a. Quantity: Our team will be developing one computer program.

b. Production Cost: The cost should be reasonable in comparison with technologies and materials used. The interface should cost less than $500.

3. Miscellaneous

a. Standards and Specifications: Electrical components should be compatible with data scanner device and inductive power source.

b. Customer: The client would like an interface that can show the ICP pressure, the change in resonant frequency from the sensing device, and the pulse of the patient.

c. Patient-related concerns: The final product will require multiple patient related concerns, including: out-growing device, infection, replacement or recalibration of device, comfort, and interaction on daily use. However, this product has no interaction with the patient.

d. Competition: Currently there are other devices on the market that have the same relative use. However, these devices are inaccurate and prone to failure.