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EVALUATION OF A PRESSURE SENSOR FOR A TSUNAMI WARNING SYSTEM

INTRODUCTION

The goal of this project is to develop a low-cost tsunami warning system for use in impoverished regions where tsunamis pose a threat. This paper details the design process of a pressure sensor used for tsunami detection. We begin by first considering the desired sensor parameter and range of depth in which the experiment will be conducted. The signal conditioning circuit is incorporated following the pressure sensor selection. The concept of the experiment used to collect and analyze the data necessary for tsunami prediction is presented in detail. Paper provides a discussion of the possible modification and improvements to the finalized pressure sensor model as a platform for future applications of this work. Finally, conclusion provides the overview of the pressure sensor design and gives insight for the continuation of this project for the next semester.

PRESSURE SENSOR SELECTION

Sensor Parameters

The desired sensor parameters for a pressure sensor in a tsunami warning system are repeatability and linearity. Repeatability refers to the closeness of agreement among a number of consecutive measurements of the same variable. Repeatability serves to reduce the possibility of a tsunami warning being a false alarm. Linearity is a measure of how well the transducer output increase linearly with increasing pressure. Linearity eliminates the need for a complicated set of algorithms to calculate the dynamic pressure from the pressure recorded by the sensor.

Pressure range

In order to pick the right sensor, it was first necessary to calculate the range of pressures the sensor will be deployed in. The initial bench test was done in a still water tank with a depth of 3 feet. The calculation of the pressure range was as follows:

$$P = \rho gh = \left(1000 \frac{\text{kg}}{\text{m}^3}\right) \left(9.81 \frac{\text{m}}{\text{s}^2}\right) (0.9144\text{m}) = 8.96 \times 10^3 \text{ Pa} = 1.30 \text{ psi}$$

At 3 feet (0.9144m) of water, the pressure is 1.30psi. Given this pressure range, we sourced for a pressure sensor available in our laboratory that was functional over a similar range. A strain gage pressure sensor with a range of 0 – 13psi fit our needs best. This pressure sensor which requires a supply of 13 – 28VDC is internally conditioned to give an output range of 0 – 10 VDC.

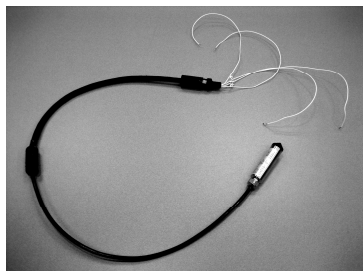


Fig.2.1: Photo of Pressure Sensor.

Although this output range is large enough, the output will subsequently be attached to a signal conditioning circuit to improve the resolution of the sensor as required. A Rabbit 3400 series microprocessor will be used in the analog-to-digital conversion of the signal conditioning circuit. Over the range of 0 – 13psi, the 12-bit Rabbit processor will provide an output voltage resolution of: $\Delta V = \frac{10}{2^{12} - 1} = 0.024V / count$

Bench Test

The selected pressure sensor was waterproofed and attached to a meter stick for an initial bench test. In order to protect the sensor, the inputs and outputs of the sensor were carefully monitored to prevent the apparatus from short-circuiting. The pressure sensor was then connected to the signal conditioning circuit. The signal from the sensor was put through a Single Supply CMOS (MCP 601) Op-Amp buffer in order to prevent the current from being loaded down by the Rabbit’s Analog-to-Digital Converter. All power supplies to the signal conditioning circuit, including the sensor, were commonly grounded in order to remove any floating voltage bias. The layout of the MCP 601 is detailed below along with a picture of the experimental set-up.

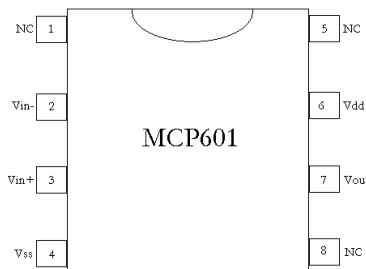


Fig.2.2: Sketch of Single Supply CMOS (MCP 601).

The sensor apparatus was lowered into the tank and measurements were taken as the apparatus was raised slowly out of the tank. The following graphs depict the linear regression and application curve performed on the collected data.

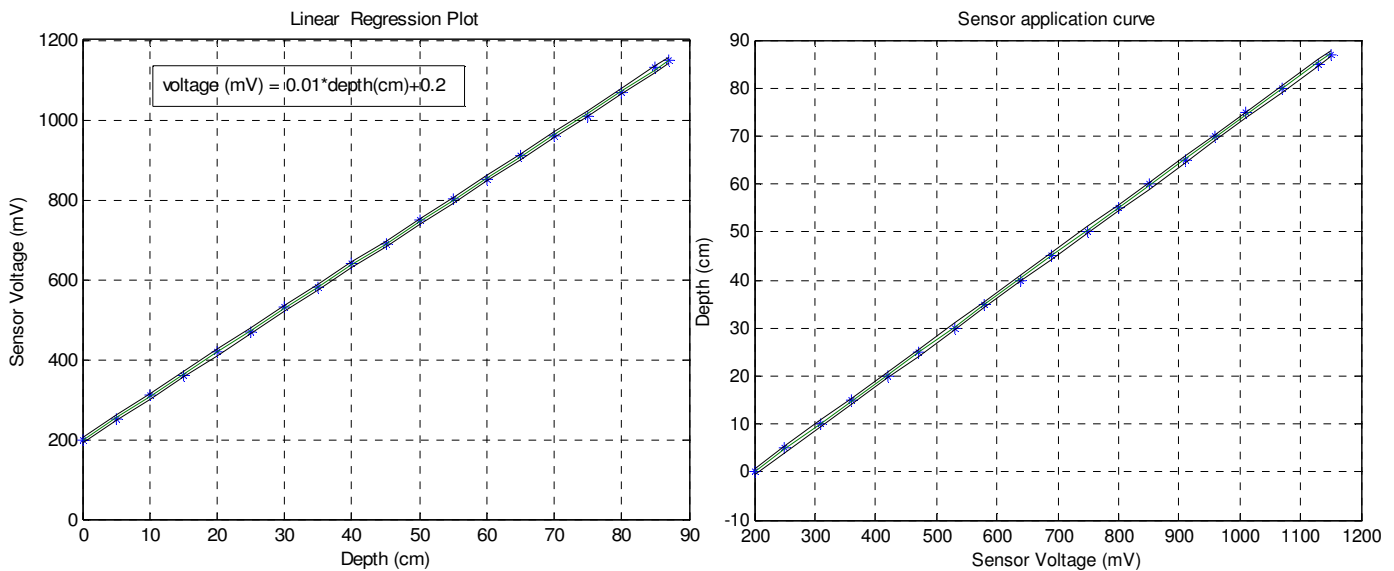


Fig.2.3: Linear Regression Plot and Application Curve

The narrow width of the 95% prediction interval on the linear regression plot shows that the voltage output of the sensor is approximately linear with depth and that the 95% uncertainty of this result is low (less than 1mV).

DATA COLLECTION & ANALYSIS

Concept of experiment

When a shallow water wave passes by, the changes in the sensor voltage reading indicate a change of pressure. To a large extent, the change of pressure is due to the change of static pressure caused by the sinusoidal pattern of the wave height. However, a less significant factor that causes the change in pressure is derived from the dynamic pressure that is generated by the shallow water wave as it passes and “feels” the sensor. Our goal is to condition the sensor to detect the dynamic pressure as the wave passes by. We can achieve this by increasing the gain on the signal conditioning circuit to increase the voltage resolution so as to better detect slight changes in voltage readings. The Dynamic C code used to collect the voltage readings was written for time efficiency in order to improve the time resolution of the voltage readings.

Wave tank experiment

A bench test was first performed using a pail of water to simulate the underwater environment. The bench test validated the operability of the Dynamic C code that was written to make voltage sensor readings, measure the time taken in between the reading and output the data into a MATLAB-compatible file.

The sensor was attached to a rigid metal body that was clamped onto the edge of the wave tank. The picture of the experimental set-up is shown below.

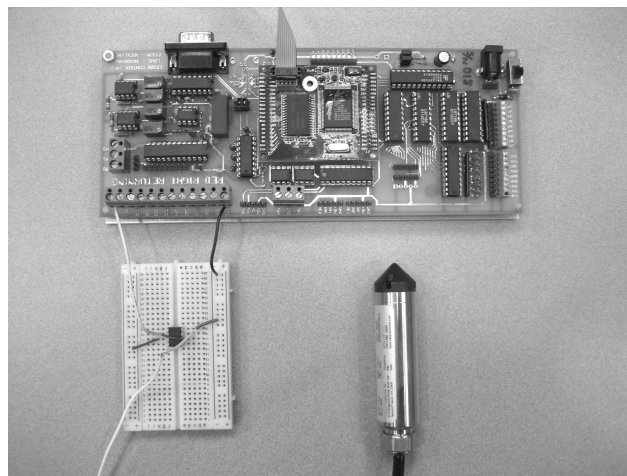


Fig.3.1: Photo of Experimental Set-up.

Using this set-up, the depth of the sensor was found to be 80.0 cm. The wave generator was configured to send a shallow water wave with wave height of 5.0 cm of period of 1s, 3s and 5s in three separate experiments in order to find the effect of the

period on the sensor voltage results. From the results, it was evident that more noise is present in the data for the smaller periods. As a result, the data for the experiment with period of 1s was omitted from the data analysis process. The results from the other two experiments depicted a sinusoidal pattern for the sensor voltage over time. These results were then outputted into MATLAB for data analysis.

MATLAB data analysis

The MATLAB code was designed to first collect 300 voltage readings from the sensor through the Analog-to-Digital Converter on the Rabbit 3000 Microprocessor, and then to perform an average function on the voltage measurements in order to reduce uncertainty and best profile the voltage changes that take place during one waveform. The time at which each voltage reading was taken was also recorded and the same averaging process is performed on the time measurements. The 300 voltage readings will profile multiple periods of the waveform. Hence, the 300 measurements will be divided into groups of voltages profiling the voltage changes that take place in a single waveform. The groups of voltages, which should be of the same size, will be stacked together. At each point of the waveform where the sensor voltage was sampled, the respective voltage readings were collected and averaged. The following matrix is produced to provide further explanation for the first average function:

$$\begin{bmatrix} V_{1,1} & V_{1,2} & V_{1,3} & K & V_{1,Y} \\ V_{2,1} & V_{2,2} & V_{2,3} & K & V_{2,Y} \\ V_{3,1} & V_{3,2} & V_{3,3} & K & V_{3,Y} \\ M & M & M & M & M \\ V_{x,1} & V_{x,2} & V_{x,3} & K & V_{x,Y} \end{bmatrix}$$

Each element in the matrix is designated as $V_{x,y}$ where x is the waveform number and y and point in waveform in which the voltage was sampled. X is the total number of waveforms that were found in the 300 measurements and Y is the total number of sample points taken in one waveform. The voltage values in each column are then averaged to produce a single row vector profiling the voltage changes in a single superimposed waveform. The resulting averaged single waveform for period of 5s is shown below.

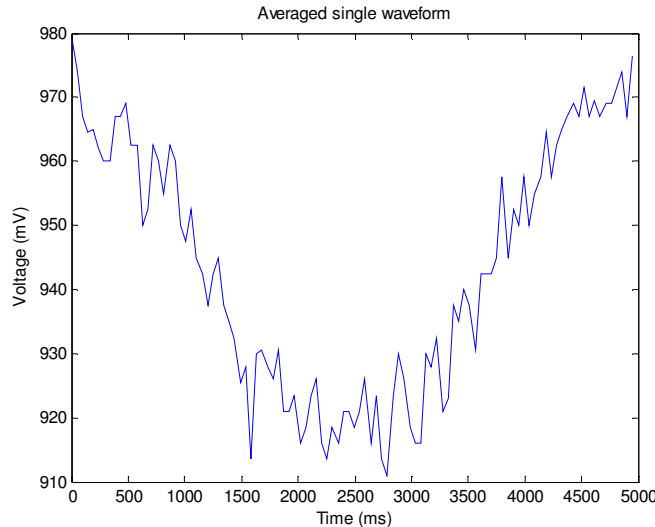


Fig.3.2: Averaged Single Waveform

Since the time vector is related to the depth by a sinusoidal function, another MATLAB code was written to do that function and perform a fourth order curve fit for the voltage v.s. depth data. The resulting 4th order curve fit plot is shown below.

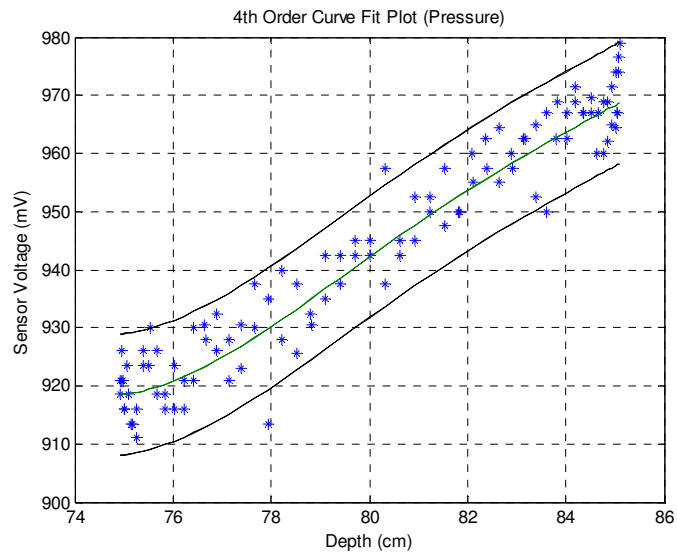


Fig.3.3: 4th Order Curve Fit for Pressure Data.

In order to extract the dynamic pressure data from the overall pressure data (static + dynamic pressure), the static pressure was subtracted from the overall pressure data. The linear function derived for the static pressure was found by taking sensor voltage measurements under static conditions from a depth of 75 cm to a depth of 85 cm. A 4th order curve fit was then performed on the dynamic pressure v.s. depth data. The plot is shown below.

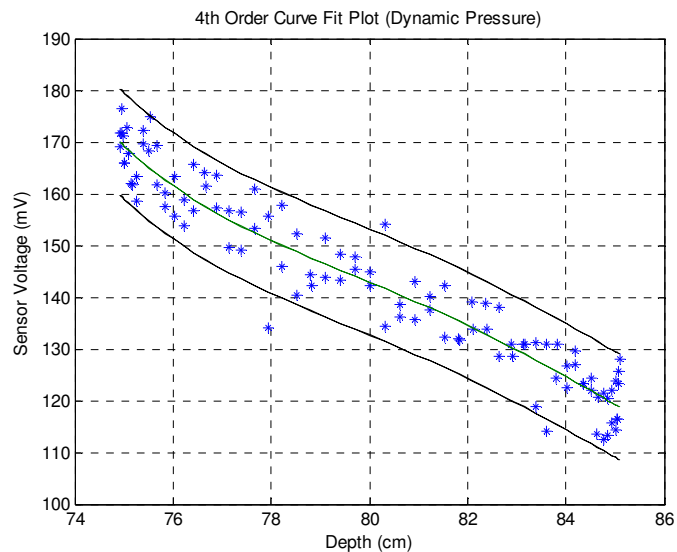


Fig.3.4: 4th Order Curve Fit for Dynamic Pressure Data.

MODIFICATIONS AND IMPROVEMENTS

From Fig 3.4, it is evident that the granulation for the dynamic pressure results (approximately 0.11 – 0.18V) is too small and might be masked by noise created by sea state and underwater current. As such, the signal conditioning circuit will be modified to provide a gain 10X larger than the current set gain. A similar pressure sensor will be ordered with specifications closer to what the wave tank is able to achieve in order to augment the sensor's output voltage resolution.

CONCLUSION

The goal of the project was to design a sensor – signal conditioning circuit that was capable of extracting dynamic pressure data from a passing shallow water wave generated in a wave tank. The experiment was successful in accomplishing that goal. The minimum value of the dynamic pressure voltage reading found in this experiment is 110mV. This value correlates to a pressure equivalent to 11 cm of water depth according to the sensor application curve. Since the maximum depth the sensor was approximately 85 cm (depth of sensor = 80 cm, maximum wave height = 5.0 cm), an 11 cm spike in water depth pressure reading will be significant in detecting the shallow water wave. In the next semester, a network of sensors will perform an algorithm to ascertain whether the spike in pressure readings relates to a tsunami or simply environmental noise in the pressure readings. A adaptive filter can be used to update the expected anomalies in pressure readings due to sea state so that a new threshold can be set to detect the presence of a shallow water wave passing by. A communication system will also be incorporated to equip the tsunami warning system with online reporting capability.