Quality Assessment of Fiber Optic Pressure Sensors

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Introduction

Since the functional features of an artery can correlate to the risk of cardiovascular events, intra-arterial pressures can be utilized as a tool to gain more information about the condition of a vessel or even downstream structural features in the vasculature. Pressure waveforms contain information regarding peak systolic and diastolic pressures, as well as the elasticity and possibly even sites of reflection. Similarly, the pulse wave velocity can be indicative of the mechanical properties of the arterial system. Intravascular fiber optic pressure sensors are one tool that can be used to record continuous pressure readings, especially during interventional procedures.

Members of our team are currently obtaining FDA approval for a device that incorporates a fiber optic pressure sensor within a catheter. The sensors have been proven accurate for systolic and diastolic pressures. Additional important hemodynamic properties, such as arterial stiffness and resistance, might also be obtained with these sensors with further experimentation.

Objective

In order to effectively maximize the capabilities of the RJC pressure sensors (RJC Enterprises, Inc., Bothell, Washington), they must be tested to fully understand the magnitude of their capabilities. Specific tests were performed to analyze the behavior, precision, and accuracy in different scenarios.

Equipment

Figure 1. The Fiber Optic Measurement system that transmits the pressure data to the computer

Figure 2. A diagram of the fiber optic pressure sensor. The RJC fiber optic pressure sensors (RJC Enterprises, Inc., Bothell, Washington) utilizes a Fabry-Perot interferometer by reflecting light at different angles through a pressure sensitive diaphragm.

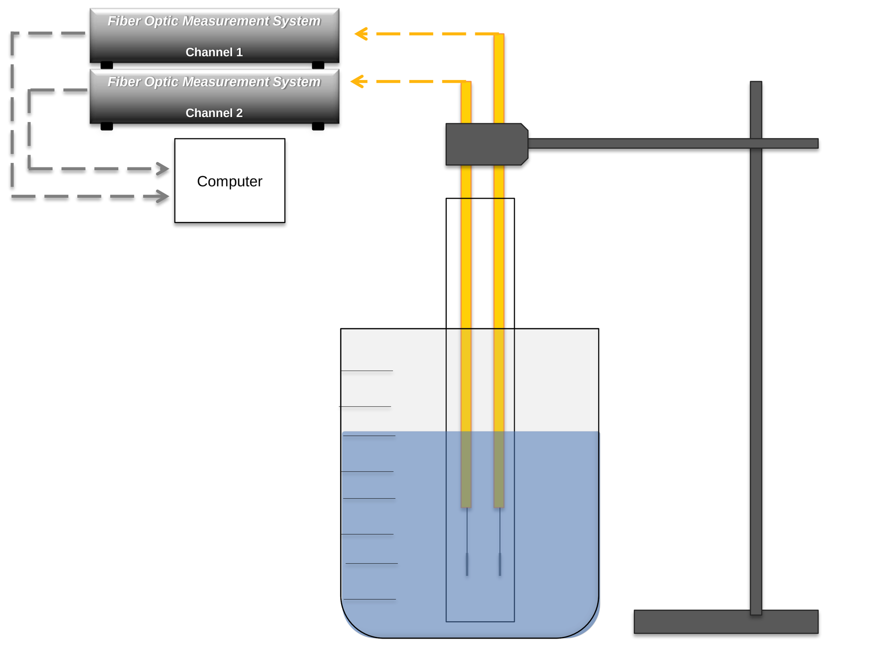


Figure 3. This figure displays the setup of how the sensors were immersed in different levels of water. The RJC fiber optic pressure sensors (RJC Enterprises, Inc., Bothell, Washington) transmitted the data to the Fiber Optic Measurement System (RJC Enterprises, Inc., Bothell, Washington), which transmits the data to the computer to be analyzed. The water level was changed to induce different pressure readings.

Methods

1. In vitro, four RJC fiber optic pressure sensors (RJC Enterprises, Inc., Bothell, Washington) were immersed into known depths of water systematically. The pressures ranged from 0 mmH_2O to 500 mmH_2O. The pressure measurements included 6 measurements at low pressures (under 100 mmH_2O) and 1 measurement at 500 mmH_2O. Each pressure reading was approximately 10 seconds and the sensor recorded pressure measurements at a frequency of 1000 Hz.

2. At each pressure reading, the variation and behavior of each individual sensor was recorded. In addition, the discrepancy between two simultaneous measuring sensors and the theoretical pressure value was calculated.

3. The Fiber Optic Measurement System was also tested to ensure that it was not causing a bias on the measurements.

4. Various methods of calibrating the sensor were performed to investigate if the calibration method contributed to the accuracy and precision of the pressure readings. Methods of calibration included immersing the sensor in less than 1 mmH_2O and air drying the sensor prior to calibration.

Results

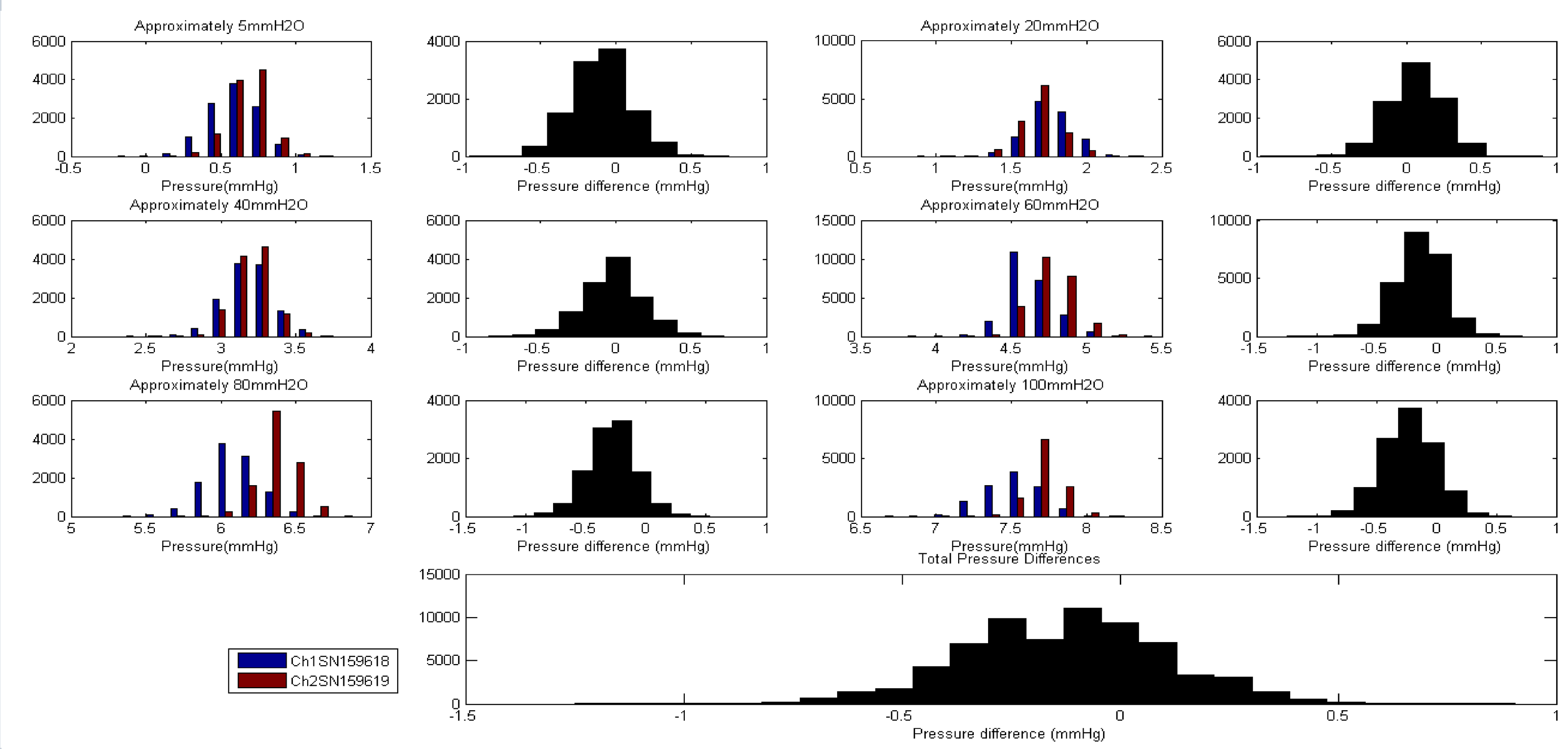


Figure 4. The red and blue histograms display the pressure values collected by two of the sensors over 6 pressure measurements (5 mmH_2O, 20 mmH_2O, 40 mmH_2O, 60 mmH_2O, 80 mmH_2O, and 100 mmH_2O). The smaller black histograms show the pressure difference between the two sensors. The bottom black histogram shows the accumulation of the pressure difference over the 6 measurements.

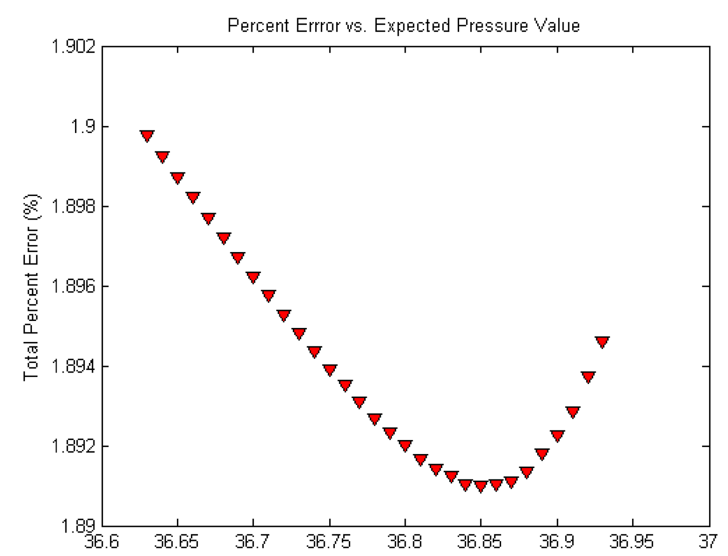


Figure 5. This plot shows the relationship between the averaged percent errors versus the expected pressure value for the 12 trials performed at approximately 50 cm of H_2O. Each data point is the average percent error for each pressure reading compared to the expected pressure value. The expected pressure values are calculated from 500 ± 2 mmH_2O (36.7780 ± 0.1471 mmHg).

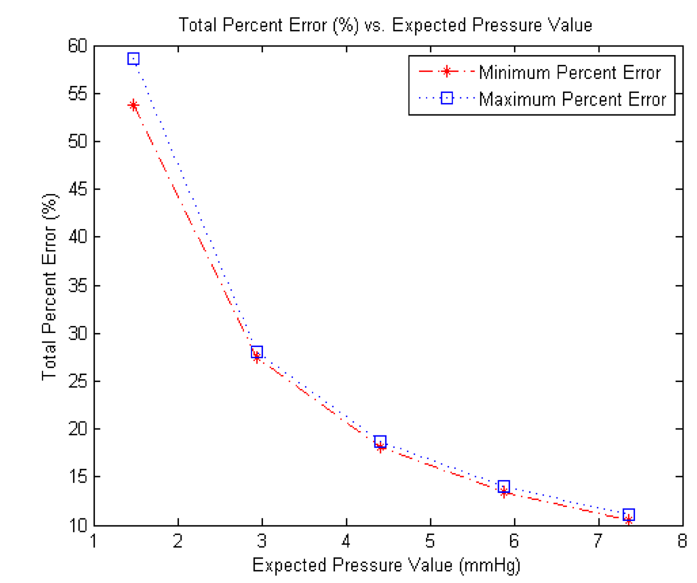
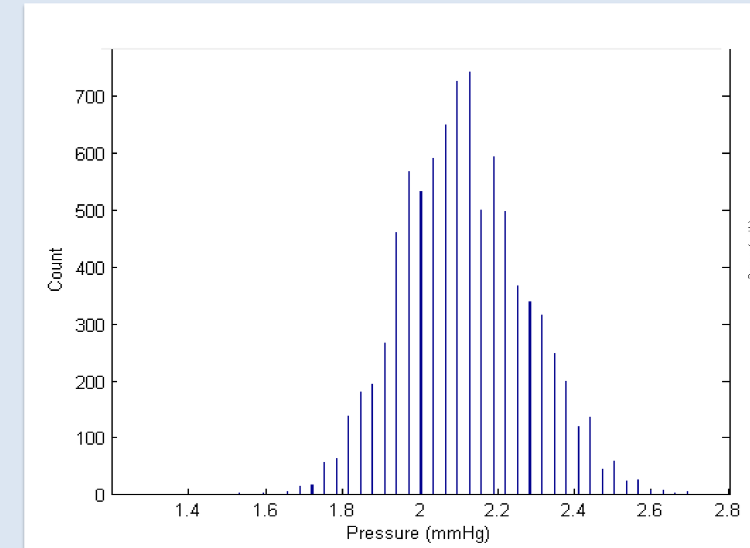


Figure 6. This plot shows the minimum and maximum percent error from five separate depths (20 mmH_2O, 40 mmH_2O, 60 mmH_2O, 80 mmH_2O, and 100 mmH_2O).



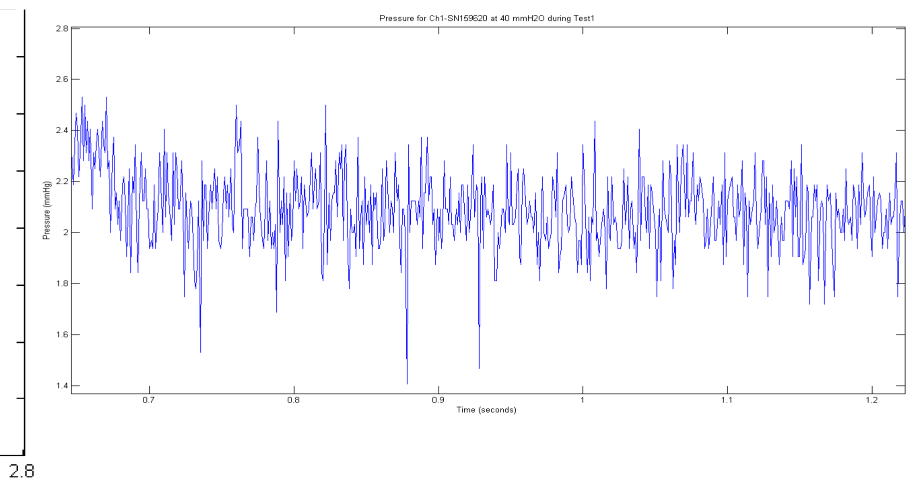


Figure 7. (above left) This histogram shows the pressure values from Channel 1 and Sensor SN159620 at 40 mmH_2O. The variation is displayed in Figure 8 (above right). The bin number was set to equal 13750, which is the number of values that the sensor could have collected during the sample (1.3438 mmHg to 2.7188 mmHg).

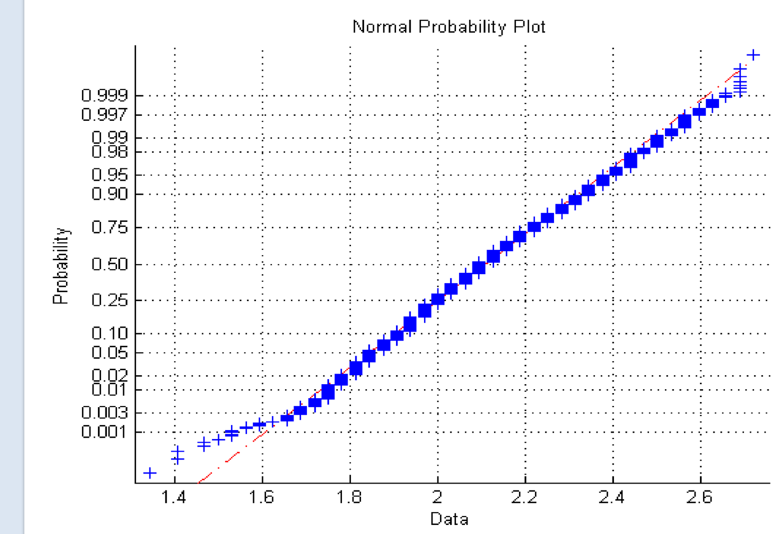


Figure 9. (left) This figure is a normal probability plot for the pressure data collected by Channel 1 and Sensor SN159620 placed at 40 mmH_2O. This data set is representative of the other sensor recordings. From Figure 8 and Figure 9, the data does not follow a normal distribution at extreme low and high pressure values.

- The sensors were found to have the capability of giving instantaneous pressure values with a precision of 0.03 mmHg. This value was calculated by pooling the data into a histogram with the amount of bins equal to the number of samples. The pressure values recorded by the sensor had a limited precision of 0.03 mmHg.
- The standard deviation of one pressure sensor at a constant pressure for 10 seconds was 0.15mmHg.
- The average difference between two sensors' pressure values that were calibrated simultaneously was 0.66 mmHg.
- The accuracy of the sensors decreased at higher pressures.
  - At a pressure of 37 mmHg, the accuracy of the sensors was approximately 1.9%.
- Pressures recorded in a constant pressure setting have a normal distribution within a finite range.
- The method of calibration is still a possible contributing factor to any lack of accuracy. Calibrating the sensor in 1 mmH_2O caused the mean difference in the two simultaneously recording pressure sensors to be 0.43 ± 0.41 mmHg compared to 0.99 ± 0.69 mmHg when the sensors were carefully air dried with a heat blow dryer.
- The Fiber Optic Measurement Systems itself did not have a bias on the measurements outputted.

Conclusion

This data will be important for all future experiments and measurements that involve the RJC fiber optic pressure sensors (RJC Enterprises, Inc., Bothell, Washington). With a complete understanding of quantitatively how the sensors behave, it will be feasible to analyze results of future pressure measurements.

In the future, the pressure sensors should be evaluated in with non constant pressure values. Theories of signal processing will be useful in using the pressure waveforms to determine information about the arterial system. This technology will allow for precise arterial pressure values and other physiologic properties to be obtained intra-operatively.

References and Acknowledgements

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