Blockage Detection in Cerebrospinal Fluid Shunt Systems through Interferometry

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ABSTRACT

Hydrocephalus is a condition where an accumulation of cerebrospinal fluid (CSF) gives rise to an increased cranial pressure. Excess fluid can be discharged through the use of a surgically placed ventriculoperitoneal (VP) shunt to relieve this condition.[1] VP shunts are prone to proximal and distal blockages of the catheter. Previous studies have shown that micron displacements occurring inside the shunt are proportional to different flow conditions.[2] This study investigates an optical method, interferometry, to detect these displacements. A Michelson Interferometer was constructed and was able to detect distinct differences in fluid flow for normal flow, proximal blockage, and distal blockage conditions.

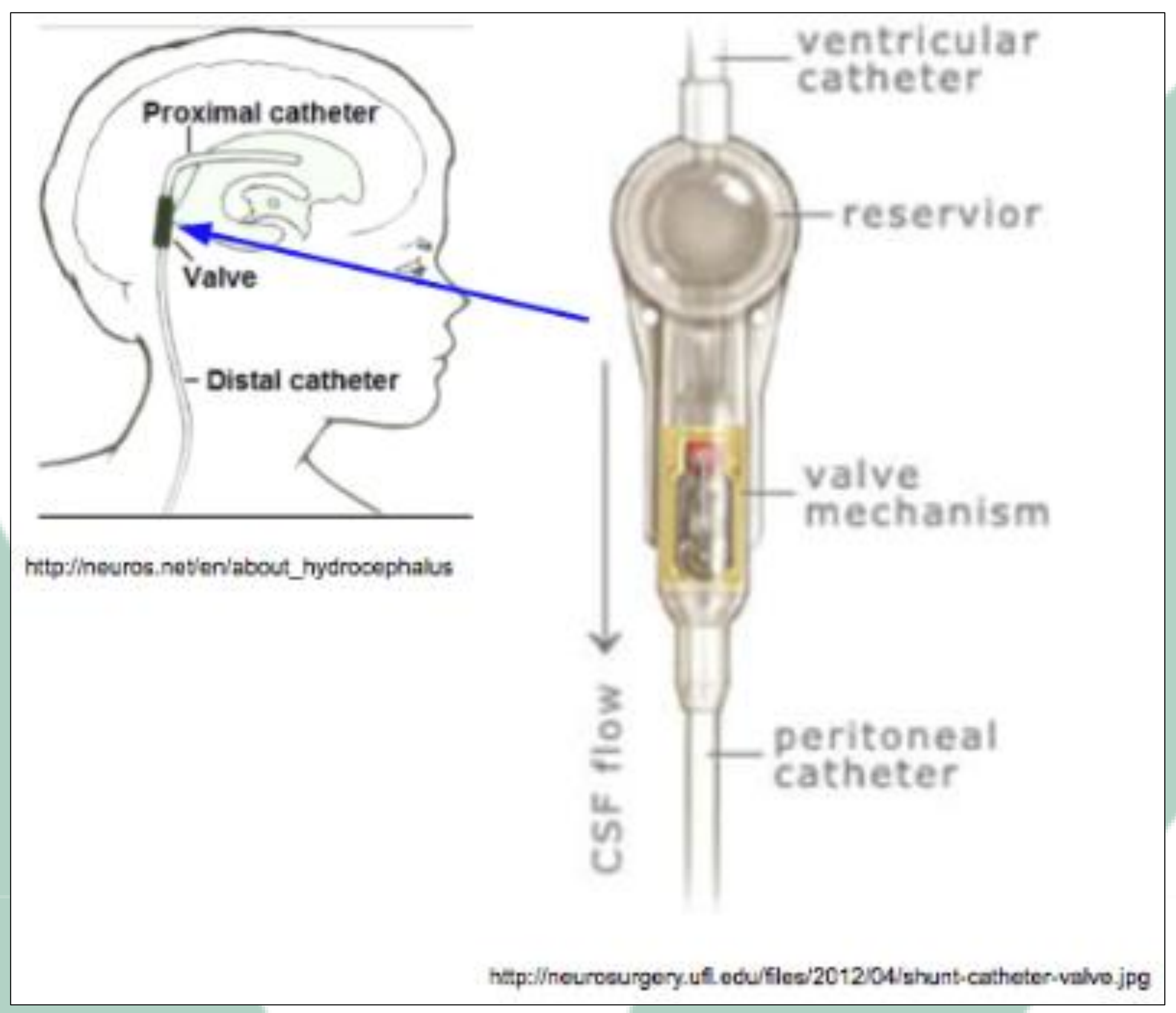

Figure 1: A VP shunt is surgically implanted near the proximal ventricle. Excess CSF is drained at ~20 ml/hr. The VP shunt draws fluid out of the ventricles and is drained into the peritoneum body cavity through the distal catheter.

INTRODUCTION

- VP shunt tends to be blocked proximally and distally
- CSF has pulsatile nature driven by cardiac cycle
- CSF flow causes shunt reservoir oscillation at ~2.4 micron displacements [2]
- Shunt blockage detection methods tend to be invasive and/or expensive

RESEARCH QUESTION

Can interferometry be used to detect micro displacements inside the reservoir, relative to different flow conditions: Proximal Blockage, Distal Blockage, and Normal Flow?

METHODOLOGY

- Test feasibility with Laser Doppler Imager
- Construct a Michelson Interferometer and optimize with piezo-chip to detect ~2.4 micron displacements
- Construct a Test Bed to deliver fluid to VP shunt at ~0.9 Hz pulses
- Detect differences in shunt reservoir displacement for normal flow, proximal blockage, and distal blockage conditions
- Perform peak analysis on displacement behavior to see statistically significant changes

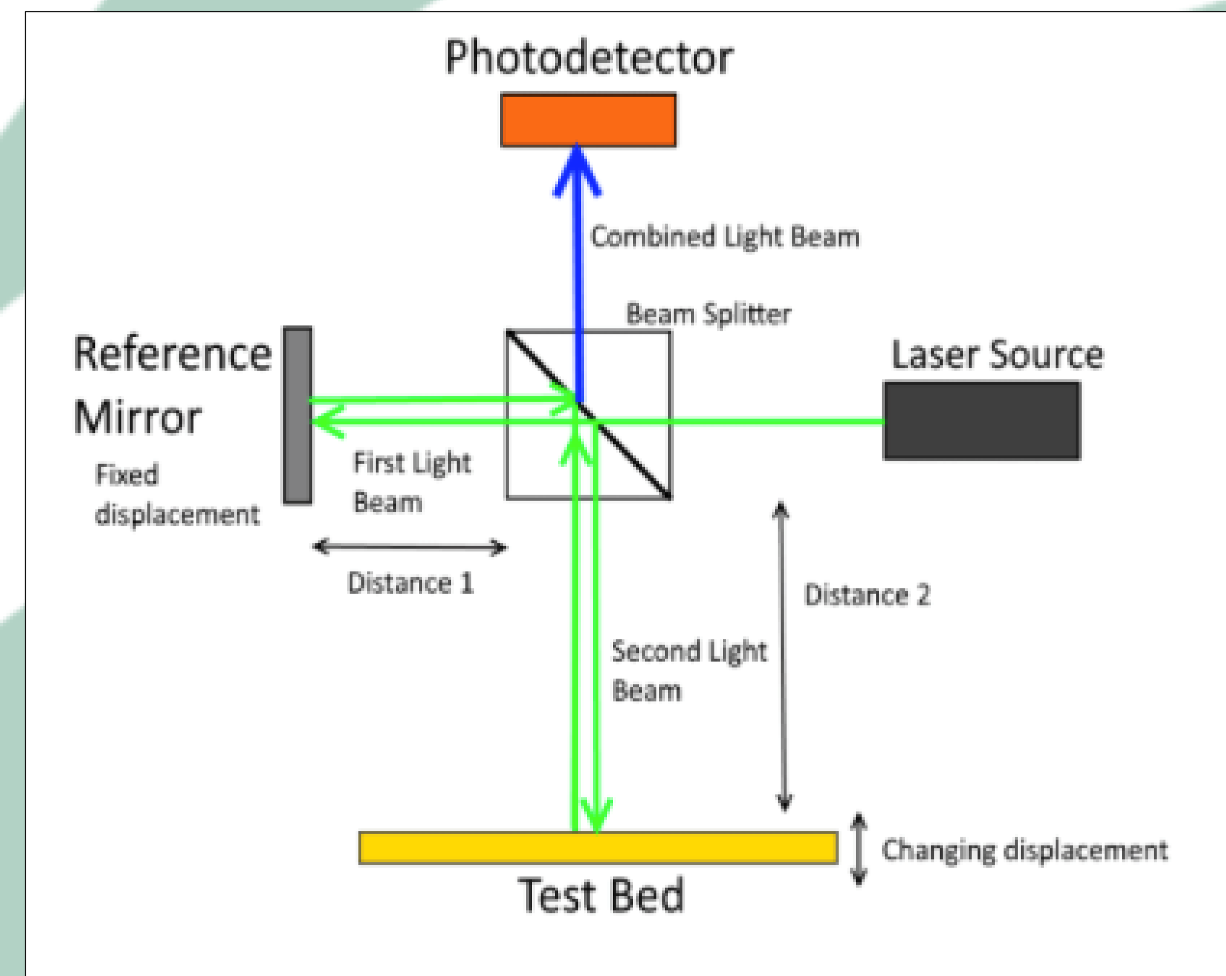

Figure 2: Diagram of the Michelson Interferometer system. Laser source is 4.5 mW collimated green laser. Beam splitter splits laser beam at 50:50 ratio towards test bed and reference mirror. Test bed oscillation causes phase shift in second light beam, resulting in interference change. Photodetector translates light intensity from interference to voltage.

RESULTS

Normal Flow

- Shows a periodic nature
- Has an average of ~0.26 V with a variance of ~0.0067

Proximal Blockage

- Shows a significant drop in peak voltage
- Has an average of ~0.02 V with a negligible variance

Distal Blockage

- Shows irregular behavior in peak voltage
- Has an average of ~0.28 V with a variance of ~0.0089

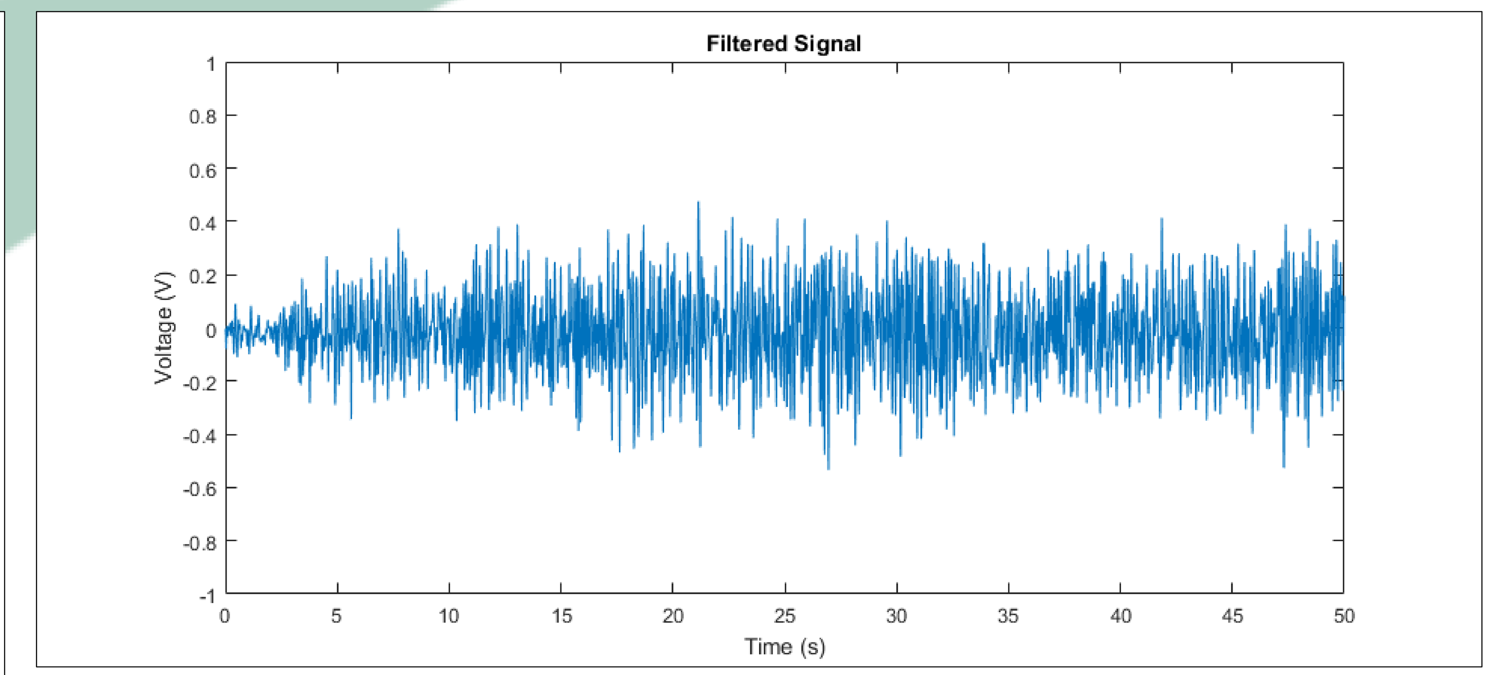

Figure 5: Filtered signal of **normal flow** condition. Peak voltage of ~0.3 V shows periodic nature at ~0.9 Hz.

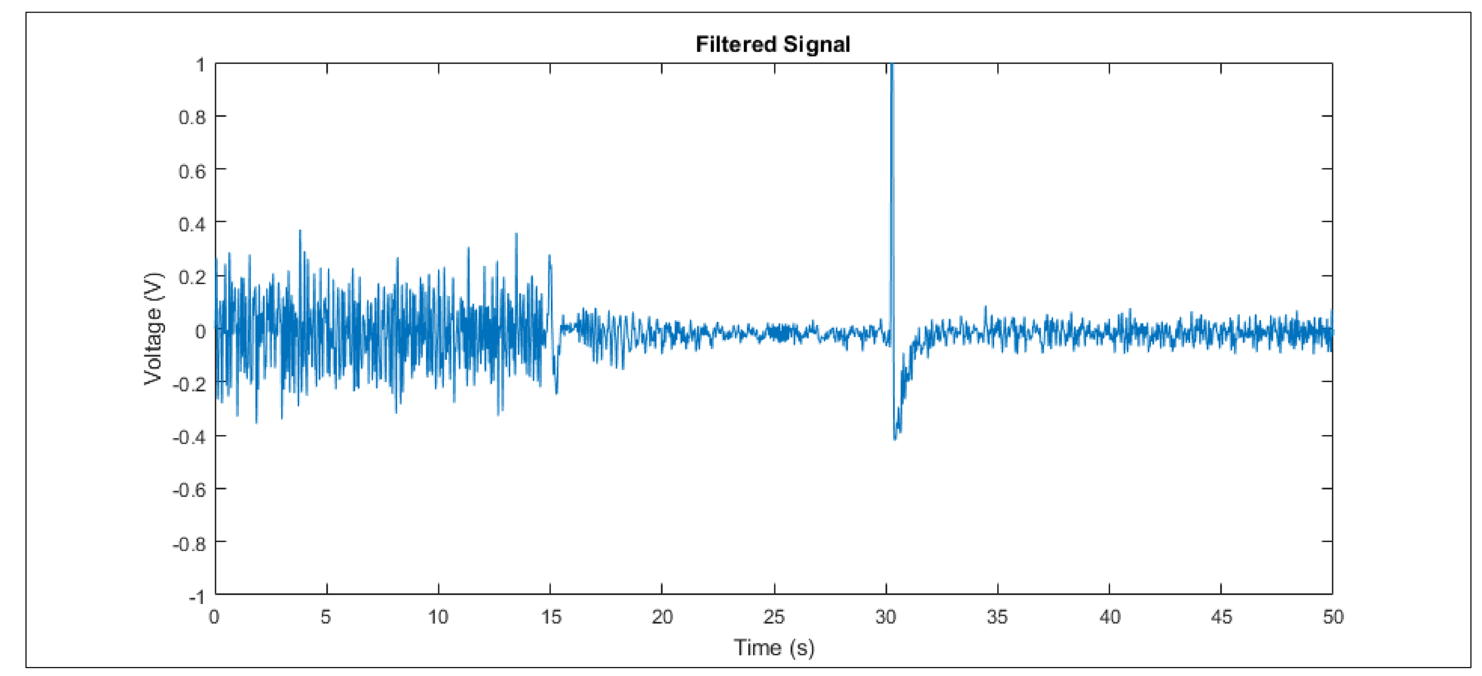

Figure 6: Filtered signal of **proximal blockage** condition. Induced proximal blockage at 15 seconds. Unblocked at 30 seconds. Instant drop in peak voltage at 15 seconds.

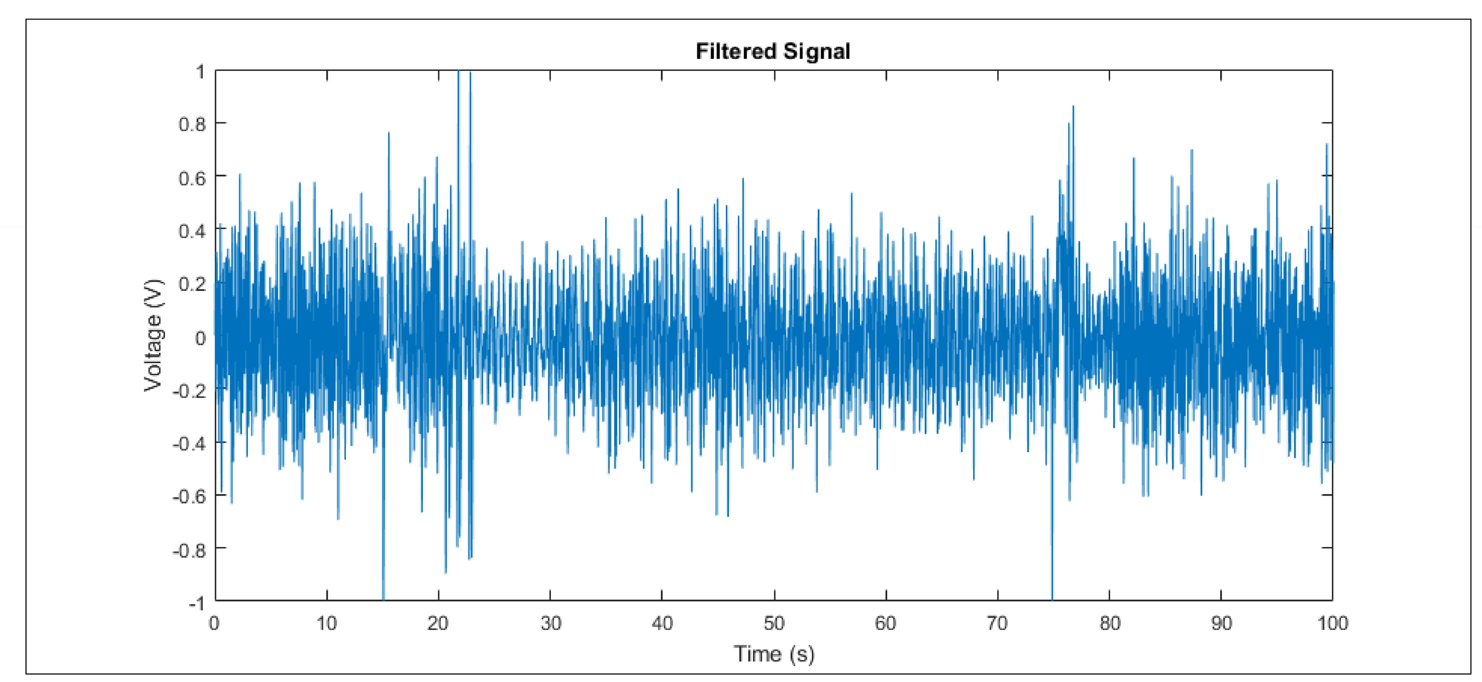

Figure 7: Filtered signal of **distal blockage** condition. Induced distal blockage at 20 seconds. Unblocked at 75 seconds. Irregular behavior in peak voltage during blockage.

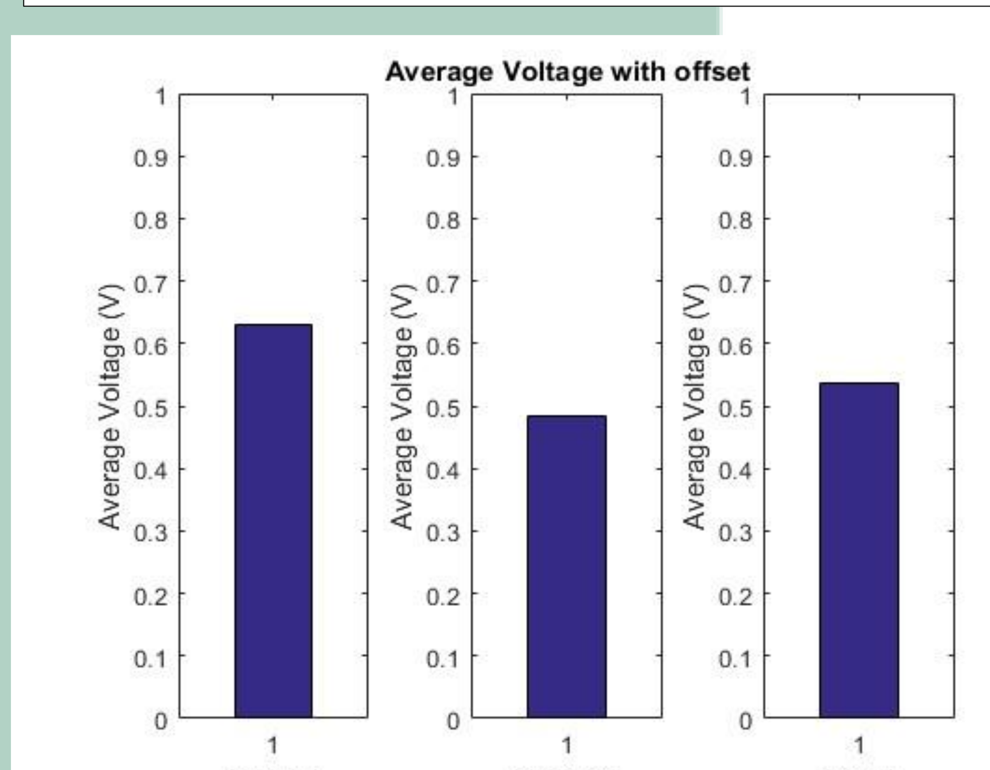

Figure 3: bar graph showing average voltage for each flow condition. Flow preserved in shunt reservoir in distal blockage, causing similar values in voltage to normal flow.

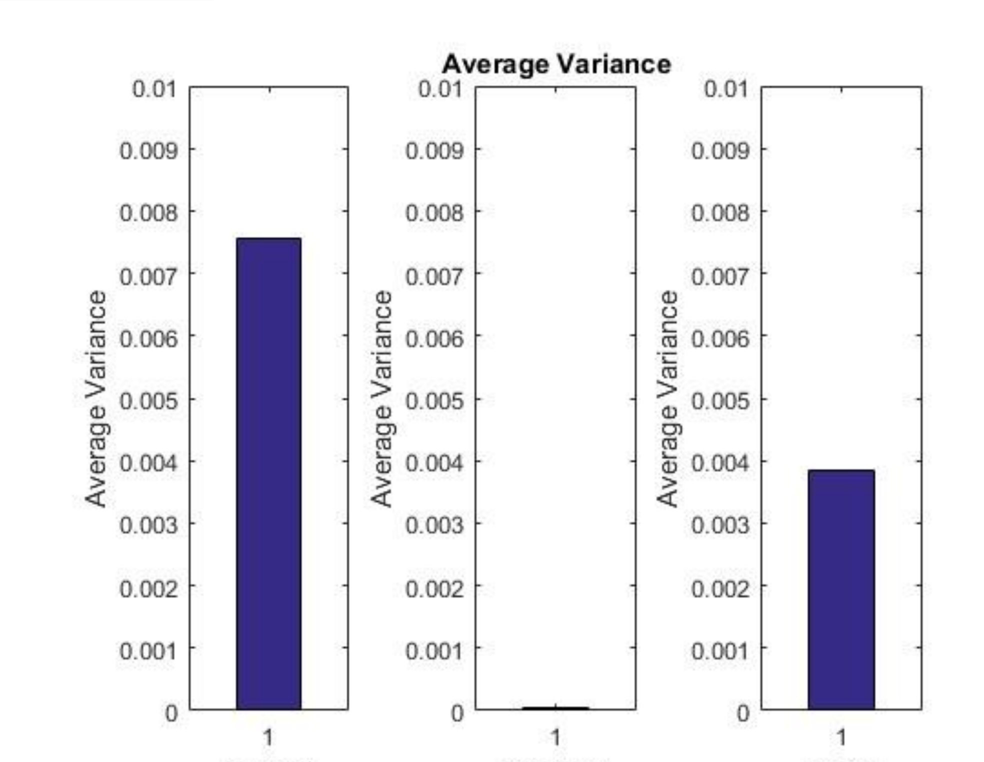

Figure 4: bar graph showing variance for each flow condition. Distal blockage shows higher variance due to irregular behavior in peak voltage.

DISCUSSION/CONCLUSION

- Interferometer can detect displacements up to 0.4 microns under ideal conditions
- Interferometer can show distinct differences in flow conditions
- VP shunt flow rate is not at physiological conditions
- Not tested with artificial skin

ACKNOWLEDGEMENTS

We would like to acknowledge Dr. Deepu George for his guidance with the building of the Michelson Interferometer. Additional acknowledgments to Nima Aklhaghi, April Aralar and Matthew Bird for helping us understand shunt systems.

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[1] Allanch, Simon. (2010). "Treatment of Hydrocephalus." Accessed: http://hydropcephalus.allanch.dk/sources."

[2] Aralar, April., Bird, Matthew., Graham, Robert., Koo, Beomseo., Shenai, Mahesh., Chitnis, Parag., Sikdar, Siddhartha. (2016) . "Ultrasound Characterization of Interface Oscillation as a Proxy for Ventriculoperitoneal Shunt Function." Department of Bioengineering, George Mason University. Fairfax, VA.