Hemodynamic Analysis System

Sarah Czaplewski[1] Megan Jones[1] Sara Schmitz[1] William Zuleger[1]

Advisor: Mitchell Tyler, M.S., P.E.[1]

Client: Naomi Chesler, PhD[1]

[1]Department of Biomedical Engineering – University of Wisconsin-Madison

Project Motivation

- Interested in calculation of pulmonary vascular impedance (PVZ)
- PVZ calculated by synchronized blood pressure and flow analyses
- Data used as indicator of pulmonary hypertension and to determine arterial stiffness and locate blood vessel defects
- Current device for this is inadequate
  - Cost: $30,000
  - Must be used with outdated laptop
  - Overanalyzes data so not user flexible

Background

Pulmonary Hypertension

- Pressure in pulmonary arteries exceeding 25 mmHg
- Leads to insufficient oxygen levels (hypoxia)
- Doppler echocardiography and right heart catheterization used together to diagnose and monitor

Right Heart Catheterization

- Used to obtain pressure data
- Catheter inserted into major vein, threaded through the heart and into the pulmonary artery

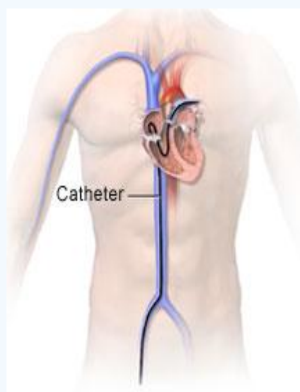

Figure 1: Insertion of catheter to pulmonary artery.

Doppler Echocardiography

- Used to obtain data of blood flow and velocity
- How it works
  - Transducer emits at known frequency
  - Signal reflected off blood vessel is shifted
  - Signal then returned to transducer
- Returned frequency shifted due to motion of blood

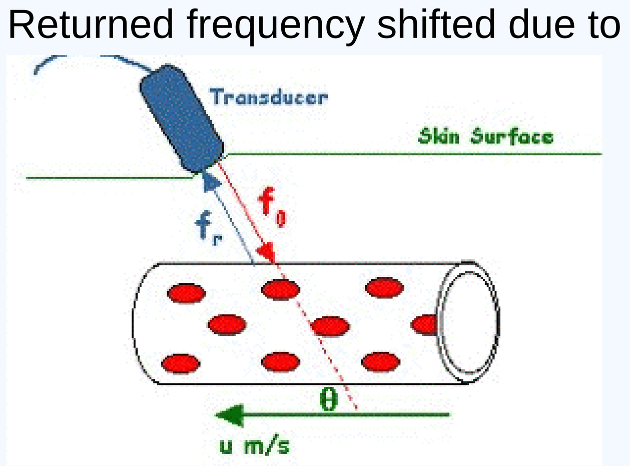

Figure 2: Diagram demonstrating use of Doppler Ultrasound.

$$f_d = \frac{2 f_0 v \cos\vartheta}{c}$$

Figure 3: Equation relating emitted and reflected frequencies used to calculate blood velocity.

Objectives

Design Requirements

- Simultaneous capture of ultrasonic audio and pressure signals
- Synchronization of these signals in time
- Storage of acquired data to text file
- Calculation of blood flow no less then 20 data points per cardiac cycle
- Provide simple user interface
- Cost less then $1000
- Able to operate twice per week for 5 years in a lab environment
- Weigh less than 5 lb and occupy less than one cubic foot
- Professional appearance

Semester Objective

- Proof of concept due to high cost of components
- Demonstrate key objectives are feasible
  - Signal collection
  - Synchronization
  - Data storage (blood flow and pressure)

Development and Testing

Justification of Design

- Heart catheterization not feasible for initial testing
- Generated sine wave as imitated pressure
- Echo machine required technician and equipment reservation
- Collection of ultrasound from radial artery
  - Accessible equipment
  - Signal easily acquired
- Mini Dopplex 8 MHz ultrasound transducer
- National Instruments myDAQ for signal collection
  - Audio and voltage analog inputs
  - Output of signals directly to LabVIEW
- Signal processing and storage to text file in LabVIEW
- Calculation of blood flow and pressure conversion in Matlab

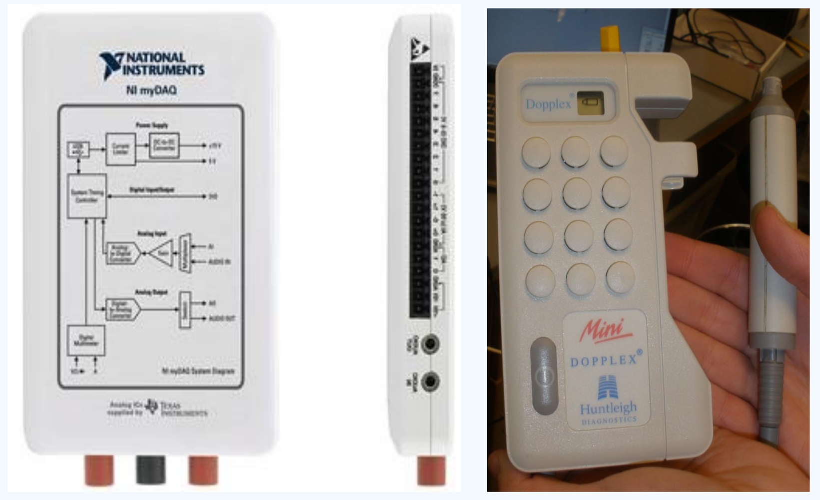

Figure 4: NI myDAQ (left) and Mini Dopplex (right).

Signal Acquisition

- Synchronous collection of ultrasound and sine wave through stereo audio input
  - Split 3.5mm dual audio cable
  - Ultrasound using left channel
  - Voltage signal using right channel
- Signal acquisition in LabVIEW
  - Sampled signals at 50 kHz to meet Nyquist criteria for audio
  - 5th order high-pass Butterworth filter for audio with a cutoff of 200 Hz
  - Graphical display of signals as they are acquired
  - Storage of data to a text file with columns for time, ultrasound, and "pressure"

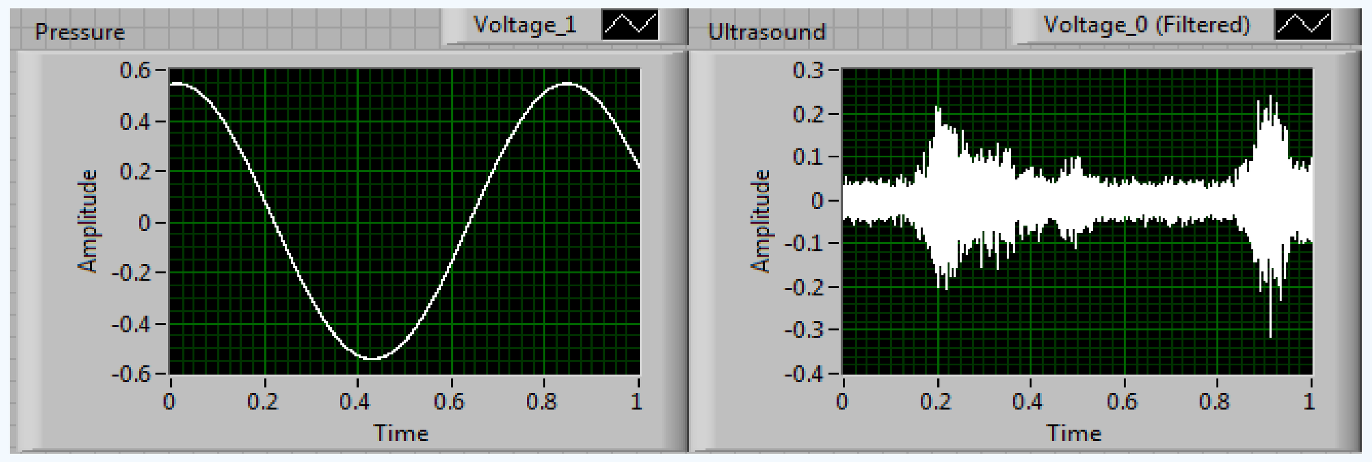

Figure 5: Waveforms generated by simultaneous acquisition of ultrasound and voltage signals using the NI my DAQ.

Signal Analysis

- Preliminary Matlab code for calculation of blood flow
  - Broke ultrasound data points into segments
  - Performed FFT and determined max frequency of each segment
  - Used frequency to calculate blood velocity
  - Multiplied velocity by average radial artery area to find flow
- Averaged "pressure" and time over each segment
- Reduction in total number of data points per second
  - From 50k to 50
  - Desirable for analysis
- Results for blood flow too high
- Flow error most likely due to low quality audio signal

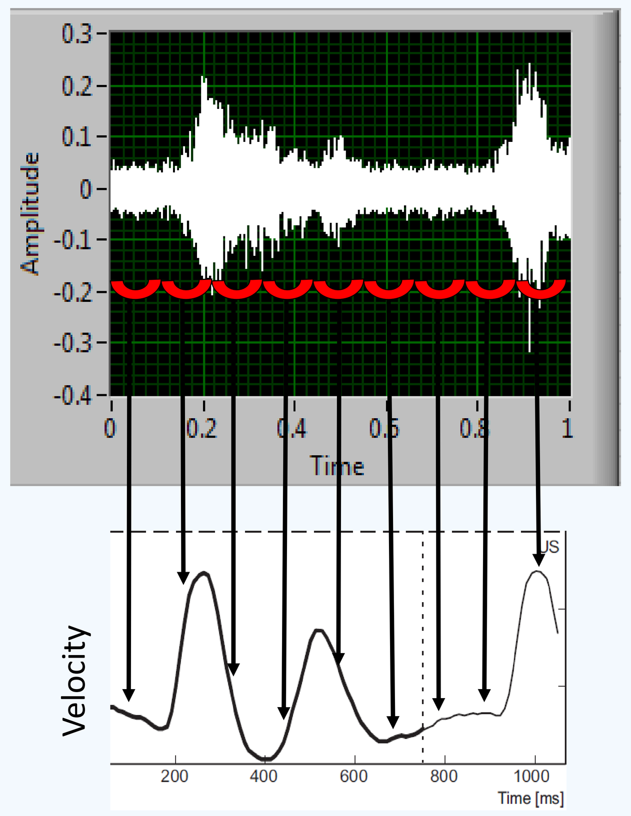

Figure 6: Schematic diagram of method used to determine blood velocity for the stored audio data.

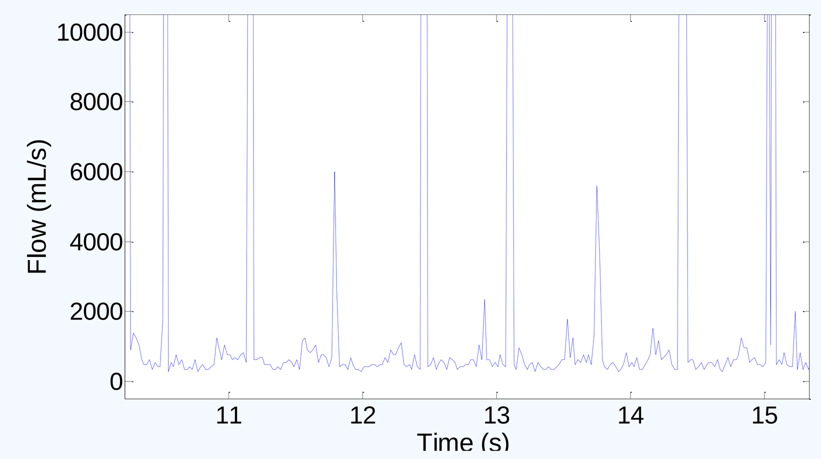

Figure 7: Plot of blood flow calculation results.

Key Accomplishments

- Synchronous collection of ultrasound and "pressure" signals
- Storage of acquired data to text file
- Solid foundation for blood flow calculation
- Demonstrated that proposed methods are feasible

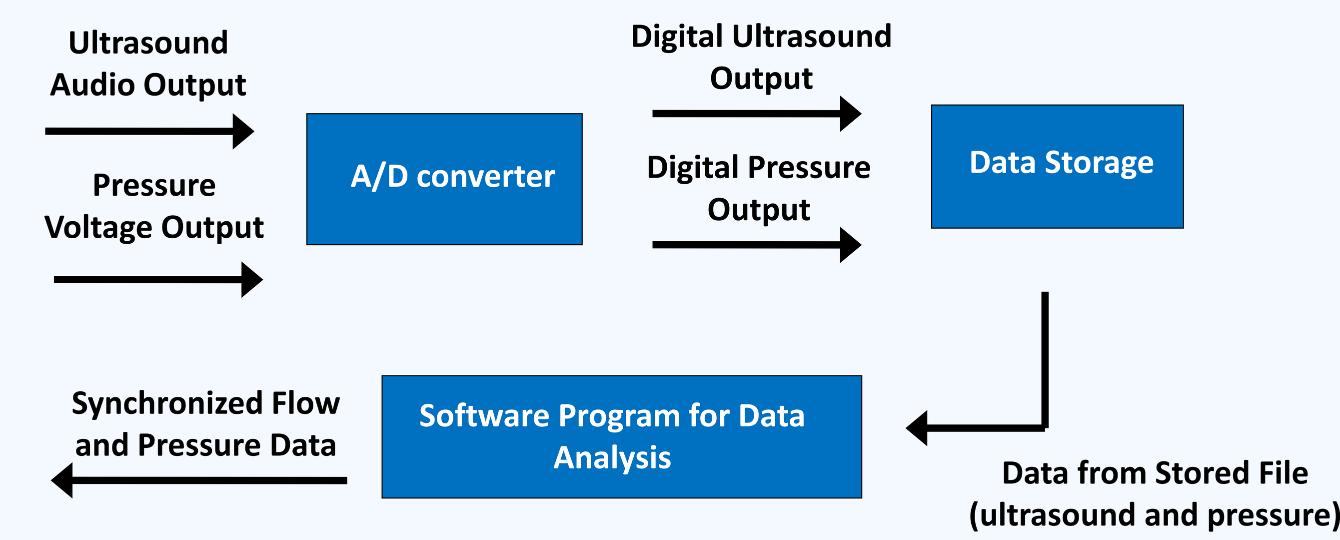

Figure 8: System diagram demonstrating accomplishments of the developed system.

Future Work

- Optimize Matlab code for calculation of blood flow
- Test calculation of blood flow with signal from actual echo machine
- Develop method to acquire true pressure data
- Have client perform PVZ calculation from stored data
- Order more sophisticated data acquisition device
  - PC oscilloscope
  - National Instruments DAQ
- Test final system with Doppler echo machine and right heart catheter

Figure 9: Example of PC oscilloscope.

References

Arcasoy, Selim. "Echocardiographic Assessment of Pulmonary Hypertension in Patients with Advanced Lung Disease." American Journal of Critical Care Medicine 167. (2003): 735-740. Web. 18 Oct 2010.

Herr, M., et al. "A real-time device for converting Doppler ultrasound signals into fluid flow velocity." *Am J Physiol Heart Circ Physiol.*2010(298): 1626 – 1632.

Nabili, Siamak. "Pulmonary Hypertension." Medicine Net. Web. 18 Oct 2010. <http://www.medicinenet.com/pulmonary_hypertension/article.htm>.

"PropScope." *Parallax Inc.* 2010. Web. 28 Nov 2010. <http://www.parallax.com/StoreSearchResults/tabid/768/List/0/SortField/4/ProductID/586/Default.aspx?txtSearch=PC+Oscilloscope>

"Pulmonary Hypertension." American Heart Association, 26/07/2010. Web. 18 Oct 2010. <http://www.heart.org/HEARTORG/Conditions/CongenitalHeartDefects/TheImpactofCongenitalHeartDefects/Pulmonary-Hypertension_UCM_307044_Article.jsp>.

Shung, Kirk. Diagnostic Ultrasound: Imaging and Blood Flow Measurements . New York: CRC Press, 2006. Print.

Tabima, Diana, et al. The effects of chronic hypoxia on pulmonary input, characteristic impedance and wave reflections: A comparison between time and frequency domain methods. 2010. Print.

Acknowledgements

- Mitchell Tyler, MS, PE
- Naomi Chesler, PhD
- Tom Yen, PhD
- Tim Hacker, PhD
- Amit Nimunkar, PhD
- Tim Hall, PhD
- Amrish Chourasia, PhD candidate
- William Sethares, PhD