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Ultrasonic Blood Flow Meter with Doppler Velocimetry

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Ultrasonic Blood Flow Meter with Doppler Velocimetry

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Abstract— **Ultrasonic blood flow meters are a non-invasive method to measure the velocity of blood. These flow meters are relatively expensive. The goal of this project was to produce a low-cost ultrasonic blood flow meter that utilizes the Doppler Effect. The flow meter constructed costs less than $300 dollars to build, which is less expensive than current flow meters used in the medical field. The flow meter transmits a frequency into the body and receives a Doppler shifted frequency back. This Doppler shifted frequency is proportional to velocity. The constructed flow meter produces an audio signal with this Doppler shifted frequency. The circuit used consisted of a transmitter, receiver, and frequency shifter. The frequency shifter eased the signal processing by shifting the signal up. Signal processing was done on the audio signal to produce velocity profiles of arterial blood flow. MATLAB was used to create spectrograms and low pass filters on the recorded audio signal. Many filters were tested as well as different methods to produce the spectrograms. Spectrogram plots mapped out the velocity profiles. Results showed that the velocity profiles had a roughly parabolic shape and that filters were necessary to reduce high frequency noise. Testing was done on multiple subjects and with different strain on the heart to determine the flow meter's performance under various conditions. Results are promising, ıt more testing is necessary to determine accuracy and safety.**

Keywords—Doppler Effect; ultrasonic flow meter; spectrogram

I. Introduction

Measuring and understanding flow of fluids has been an important concept. In 1972, Bernoulli introduced the idea that fluid flow conserves energy [1]. This was the start of being able to measure fluid flow. Another major breakthrough was when Doppler discovered that a source of sound emits a different frequency depending on if it moves toward or away from an object. This is the major concept behind ultrasonic flow meters. However, this idea was not utilized for flow meters until almost a century later [1].

Doppler or ultrasonic flow meters are used in industry to measure the velocity of fluid flow. The transducers of the meter are clamped onto the wall of the pipe. This ensures the emitted sound waves transmit to the flow [2]. Particles in the fluid cause the frequency shift, which is used to measure velocity. These ultrasonic flow meters are used to measure fluid velocities of liquids and gases. These meters have high accuracy, rapid response and they are unaffected by pressure, temperature and viscosity variations [2]. However, these ultrasonic flow meters are expensive.

Ultrasonic flow meters are also used in the medical field to measure blood. The first application of a Doppler ultrasonic ᶠ˜w meter for measuring blood flow was in 1959 [3]. This ..nology has been further developed because it is a non-invasive way to measure blood flow. Measuring flow is important for medical applications because it correlates with the concentration of nutrients in the cells. Without blood flow, a doctor may use blood pressure, which correlates to blood flow, or an electrocardiogram (ECG) signal, which correlates to blood pressure [4]. Blood flow is used to locate any obstructions in flow such as blood clots. It can also detect fatal diseases and monitor treatment techniques [5]. Invasive flow meters are not often used because they can cause blood clots. There are several methods to measure blood flow non-invasively other than using Doppler techniques. Electromagnetic flow meters measure blood flow instantaneously by using a magnetic field and inducing an electromagnetic force (emf) voltage.

Ultrasonic blood flow meters obtain blood flow continuously. There are many variations of the Doppler ultrasonic blood flow meter including: the transit-time flow meter, continuous-wave Doppler flow meter, pulsed Doppler, and laser Doppler blood flow meter [4]. A transit-time flow meter obtains velocity by measuring the time difference between when the transmitted sound is sent and then received. This allows the direction of flow to be measured; however, an invasive surgery is required [4]. Continuous-wave Doppler flow meters use piezoelectric transducers to transmit and receive the sound waves. Most of these devices transmit frequencies in the MHz range [4]. The transmitted sound waves are beamed through the skin and used to measure velocity of blood by detecting the Doppler shifted velocity. A pulsed Doppler flow meter acts like a radar. It excites the transmitter for a brief time and then waits for the received signal. The velocity is obtained from the Doppler shift from the varying delays, and this method requires only one transducer because the transmitter receives signals. However, the calculations for this method are more complicated [4]. Laser Doppler flow meters use lasers and the shift in light caused by red blood cells to determine flow [4]. Doppler flow meters use the Doppler Effect principle to obtain velocity of the blood flow.

Ultrasonic flow meters are an important device for medical applications. There is a major problem with this equipment, and that is the expense. The average cost of an ultrasonic flow meter is $4,000 due to the necessary frequency of the transmitted wave and the amount of accuracy built into the device [6]. This is a rather expensive device. The objective of the project is to construct an ultrasonic flow meter at a reduced cost and to develop signal processing techniques to display the velocity of arterial blood flow. The continuous-wave Doppler flow meter will be built and use a 400 KHz frequency for the source frequency. The flow meter will use piezoelectric transducers as the probes. The audio signal obtained will be recorded and then filtered in MATLAB to reduce noise and display velocity. The cost of the flow meter's total parts will be under $300 to ensure a reduced cost. The constructed flow meter will be accurate enough so that it could be used as research equipment for facilities with limited budgets. The major contribution of this project is developing a procedure in MATLAB to process audio signals to display spectrograms and velocity. This procedure could be applied to other flow meters that do not have the capability for display.

A product like this will benefit society by allowing ultrasonic flow meters to be more easily accessible to many institutions. Research institutions will benefit because they can have a tool to measure blood flow without using up the entire budget. This could allow new studies to occur and give experience in using devices like this to many people. This device could also be used in a hospital setting to give access to velocity profiles of patients' blood. The reduced price would hopefully reduce the cost of some testing used in the hospital. A device like this could also be used in athletics. This device gives easy access to velocity profiles of the blood, and can be used to monitor athletes during training. There are many benefits a less expensive ultrasonic blood flow meter can offer.

II. RELEVANT BACKGROUND

A. Doppler Effect

Ultrasonic waves have frequencies that are greater than audible frequencies. These waves are ideal for non-invasive sensing [2]. A moving object changes the frequency of sonic waves before and after it. The sonic waves are compressed in front of the object and spread out behind it. This frequency shift is known as the Doppler Effect [7]. Figure 1 shows how the Doppler Effect works [8].

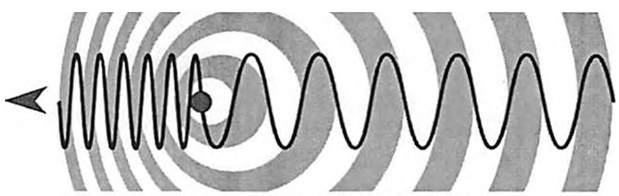

Figure 1: Doppler Effect [8]

Ultrasonic flow meters use this concept to obtain the Doppler frequency shift. These devices include a transmitter and receiver. In order for this technique to work, reflective material is needed so that the transmitted wave into the flow bounces back off the object and back into the receiver. The received wave has a shift in frequency due to the reaction with the reflected object. During this process, the source frequency is lowered twice. The first shift occurs when the transmitted wave hits the object and the second shift occurs when the resulting wave comes back to the receiver [4]. This can be seen in Figure 2 [9]. The angle of the transmitted ultrasonic wave and the flow is also a factor to the Doppler frequency shift [4]. The Doppler frequency can be calculated using the following equation:

$$f_d = \frac{2 f_0 u \cos\theta}{c} \tag{1}$$

where f_d is the Doppler frequency shift, f_0 is the source frequency, u is the velocity, θ is the angle factor, and c is the velocity of sound in the medium [4]. The Doppler frequency is proportional to the velocity of flow, as seen in Equation 1. Rearranging the terms gives the following equation:

$$u = \frac{f_d c}{2 f_0 \cos\theta} \tag{2}$$

The equation can be further simplified if the angle factor is assumed to be irrelevant [10]. In this study, this assumption was applied because there was no way to measure the angle of the transmitted wave to the blood vessel accurately. The following conversion factor relating velocity and the Doppler shifted velocity is:

$$u = \frac{f_d c}{2 f_0} \tag{3}$$

Equation 3 is the conversion factor used to change frequency to velocity. The Doppler shifted frequency is obtained from the received signal, and the source frequency is the frequency used to generate the transmitted ultrasonic waves. The velocity of ultrasound in human tissue is known to be in the range of 1540 m/s to 1600 m/s [10]. Equation 3 shows how velocity can be obtained from the Doppler Effect.

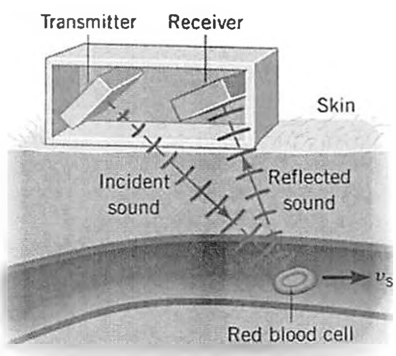

Figure 2: Ultrasonic flow meter using Doppler shift [9]

B. Piezoelectric Transducers

The transducers used in ultrasonic flow meters are to transmit and receive ultrasonic waves. These transducers are made from piezoelectric material. Piezoelectric transducers convert electric power to acoustic form [4]. The piezoelectric material is formed into discs and then surrounded by metal electrodes. These electrodes are driven by an oscillator, and this produces an up and down motion in the material. This motion creates longitudinal plane waves which will then propagate into the tissue [4]. The same principle is used to receive ultrasonic waves. Figure 3 shows how the transducers transmit and receive ultrasonic waves [11]. If there are any gaps between the transducer and tissue, it is necessary to fill them with a fluid or gel to prevent loss. This loss occurs because ultrasonic waves do not travel through air or gas well. The gel ensures the ultrasonic waves reach the tissue. Higher frequencies from a range of 2 and 10 MHz are generally used for these transducers to ensure the signal can reach the red blood cells and be reflected by them [10].

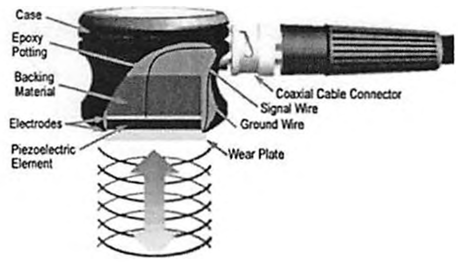

Figure 3: Piezoelectric transducers [11]

C. Fluid Dynamics

Fluid dynamics is an important topic for studying flow. There are many important concepts that are needed to understand how to interpret flow and how to predict flow. Fluid kinematics is the study of fluid motion. There are two main reference planes. The Lagrangian reference plane focuses on an individual particle in the flow. The Eulerian reference frame focuses on a region in flow and observes flow as it goes by. This reference frame utilizes a control volume as the region being studied [7]. The mass flow rate, which is mass per time, can be solved for by applying the Reynolds transport theorem to the conservation of mass. The result after simplification with the assumption of uniform-steady flow is:

$$\dot{m} = \rho V A \tag{4}$$

where $\dot{m}$ is the mass flow rate, ρ is the density of the fluid, V is the velocity of the fluid, and A is the area through which the flow is travelling [7]. Uniform flow implies that both the density and velocity of the fluid is constant over any area. Steady flow means that nothing in the flow is changing over time [7]. This mass flow rate equation is important because it shows basic behavior of fluid flows. Equation 4 illustrates that if the area of a flow is reduced and mass flow rate is held constant, then the velocity will increase. This situation is similar to what happens when a blood clot forms in a blood vessel. The area of the blood vessel is decreased, but the same amount of blood flows past this obstruction. This will increase the blood velocity. Therefore, flow meters can help detect blood clots and other obtrusions.

Fluid dynamics can also form a model for fluid flow in a blood vessel. A blood vessel can be simplified to a simple pipe system. There are two types of flow in a pipe system. Laminar flow is fully developed flow that is layered and ordered. Turbulent flow has velocity fluctuations and disordered motion. Viscosity is the internal resistance to flow or the relationship between shear stress and the time rate of strain. A no slip boundary condition exists when a fluid is touching a surface. This condition states that the fluid touching the surface must move at the speed of the surface. For a pipe, the edges are not moving. This means the velocity of the fluid touching the wall is not moving. As the fluid moves away from the wall, the viscosity is reduced, and the fluid moves faster. For a Newtonian fluid, shear stress has a linear profile because the coefficient of viscosity is constant [7]. Since the pipe system has two non-moving boundaries, the velocity profile of laminar flow is parabolic, seen in Figure 4 [12]. Assuming a parabolic velocity profile allows the maximum velocity method to be used. This method assumes the mean velocity is half the maximum velocity if the velocity profile is parabolic [13]. This is one method to obtain the mean velocity of a system, and this can be applied to blood flow.

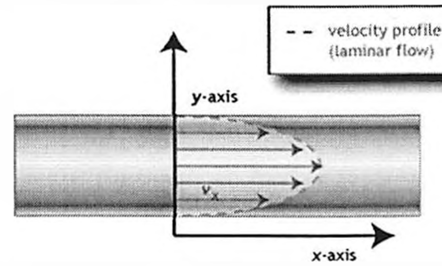

Figure 4: Velocity profile of laminar flow in pipe [12]

D. Arterial Blood Flow

Arterial flow is the blood flow in the arteries. This blood flow is similar to pipe flow, but there are also significant differences. Arterial flow pulses and is not a constant flow. This often corresponds to a rise in pitch from the audio produced in the flow meter followed by one or more smaller waves. This is caused from the under-damped flow found in arteries. The output of the flow meter often makes the velocity look like a full-wave rectified signal [4]. An example of how blood velocity over time in the aorta looks is in Figure 5 [14]. The velocity profile in arterial flow is not a perfect parabola, but it is similar to one. The range of blood velocity in the human body is known to be between 20 mm/s and 750 mm/s. Blood tends to flow faster in arterial flow. Arterial flow was measured in this study.

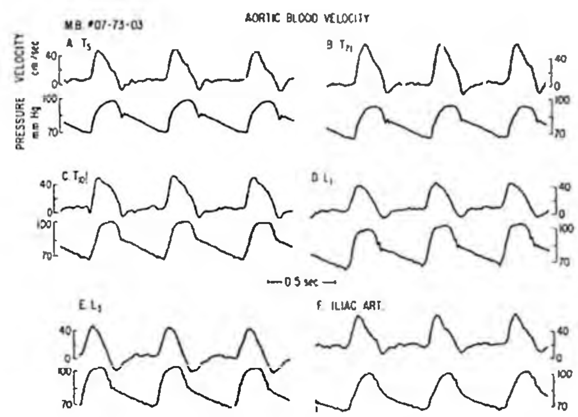

Figure 5: Velocity and pressure measurements in aorta [14]

E. Spectrograms

Spectrograms are a popular method for displaying the velocity of blood flow from ultrasonic blood flow meters. A spectrogram is a plot of frequency over time. The spectrogram is found by taking the Fourier transform (FT) of a small segment of data. The data is windowed or separated into sections. A FT is taken for each window [15]. However, to prevent any loss of information, the windows are overlapped with each other. The spectrogram also has a third component other than frequency and time. This third component is the strength of the signal. The strength of the signal is displayed by color intensity [16]. An example of a spectrogram is shown in Figure 6.

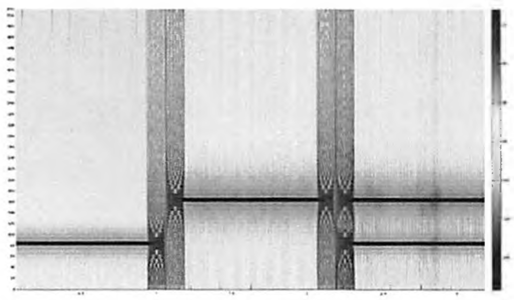

Figure 6: Spectrogram example [16]

Interpreting spectrograms is not difficult. In the case of Figure 6, the red color represents a strong signal. It can be seen that the first part of the signal until the time reaches 1, there is a signal with the frequency around 90 Hz. After that there is a signal with a frequency of 160 Hz until time reaches 2. After this, there are two signals, one with a 90 Hz frequency and one with a 160 Hz frequency. Spectrograms are used to display the velocity of blood in this study.

III. Description of Design

A. Circuit

The circuit for the ultrasonic blood flow meter has three main parts. The circuit construction was based off another design with a few modifications [17]. The whole circuit is displayed in Figure 7. The first part of the circuit is the transmitter. The circuit has a signal generator chip (XR-2206) that is connected to provide a 400 KHz signal. This signal is used as the source frequency. This is lower than typical ultrasonic frequencies for medical equipment, but this is to reduce the cost of the overall product. The lower frequency means that the ultrasonic waves cannot penetrate very deeply into the body, but the sound waves can still reach blood vessels close to the surface of the skin, such as arterial flow going to the heart. The 400 KHz signal is amplified before going to the transmitting transducer.

The next part of the circuit is the receiver and mixer. The receiving transducer sends its signal to an operational amplifier, where the signal's gain is increased. The signal from the receiver and the signal from the transducer are then mixed using a multiplier chip (AD633JN). Mixing the two signals is necessary because the receiving signal with the Doppler shift is inaudible. By mixing the two signals, or multiplying them, two signals are produced, as seen in Equation 4, where f_0 is the transmitted frequency and Δf is the Doppler shifted frequency.

$$\cos(f_0+\Delta f)\times\cos(f_0)=1/2\cos(2f_0+\Delta f)+1/2\cos(\Delta f) \quad (4)$$

One of these signals is a sinusoidal signal with the frequency that is the difference between the two signals, or the Doppler shifted frequency [17]. This is the signal we need to find the velocity. This new signal is also audible, and is outputted. This allows the user to hear and record the Doppler shifted frequency.

However, the Doppler shifted frequency is often low, usually under 400 Hz. This makes signal processing difficult because the frequency is centered at zero. The last part of the circuit is a frequency shifter. The frequency shifter generates a 500 Hz signal and then mixes this signal with the 400 KHz signal. This shift is done before it is mixed with the receiving signal. The 500 Hz shift allows the signals to center around 500 Hz instead of zero. This basically shifts everything up 500 Hz. This shift is beneficial because is shifts the Doppler frequency to a higher value which is easier to detect in the spectrograms [17]. It also raises the Doppler frequency above any low frequency noise, such as power line noise. This also makes the signal processing easier because the noise can be filtered out without distorting the signal.

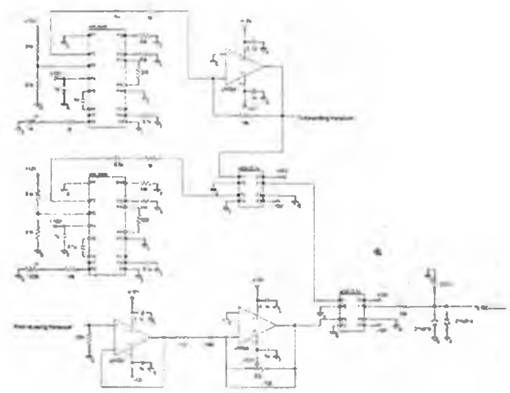

Figure 7: Schematic of ultrasonic blood flow meter

The circuit was first built on a breadboard for testing and debugging. An oscilloscope was used for debugging. The oscilloscope allowed for both the transmitted and received signals to be observed. Some of the components were modified to produce a better transmitted and received signal. Figure 8 shows the signals on the oscilloscope after finalization of the circuit. The yellow signal is being transmitted, and the blue signal is being received. Both probes were put together, so the received signal should match the transmitted signal.

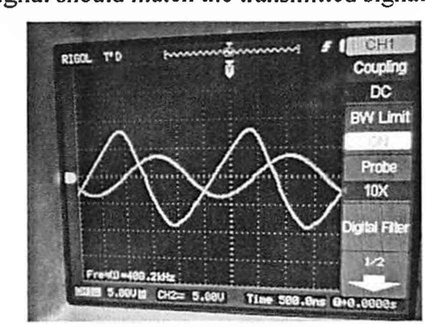

Figure 8: Transmitted (yellow) and received (blue) signals

Once the circuit was modified and working, the components for the circuit were then arranged to fit on a blank printed circuit board (PCB). Each component was soldered on this board and tested again to ensure that the circuit was working. The soldering was done so that all power and ground lines branched out and did not create any circles to prevent errors. The PCB board was also modified to fit three power terminals and three audio terminals. The circuit requires a +12V and -12V DC power as well as a ground. The circuit also has RCA terminals to connect the two transducers and an output audio signal. The finished product is shown in Figure 9.

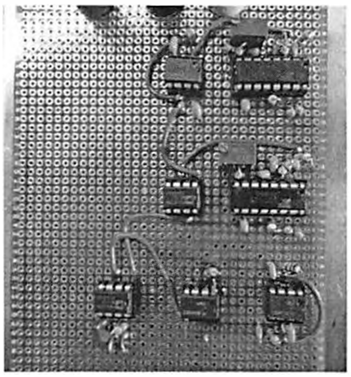

Figure 9: Finished soldered circuit

B. Probes and Housing Unit

Two probes were also constructed for the flow meter. One is for the transmitter and one is for the receiver. The probes have a piezoelectric transducer used for emitting or receiving ultrasonic waves. The probes are connected to a BNC cable to allow for maneuverability. The probes are secured to the BNC cable with solder, tape, and heat shrink to make sure the probe is durable. The BNC cable is then connected to a BNC to RCA adapter to allow it to be plugged into the RCA terminals in the PCB board. Figure 10 shows one of the finished constructed probes. A housing unit was also constructed for ease of use and portability, shown in Figure 11.

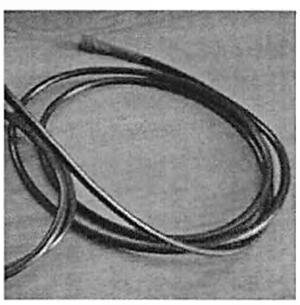

Figure 10: Finished transducer probe

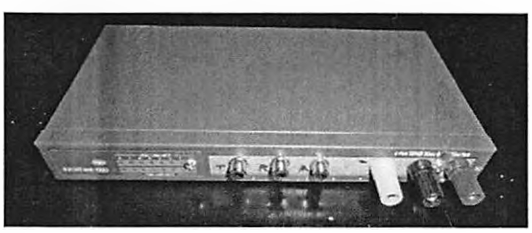

Figure 11: Final housing unit for ultrasonic flow meter

C. Signal Processing Design

The outputted audio signals needed to be processed in MATLAB. There were many steps and tests done to process these signals. Figure 12 shows the design process for the signal processing. The green boxes indicate the steps used. The red boxes indicate the steps tried and deemed inferior.

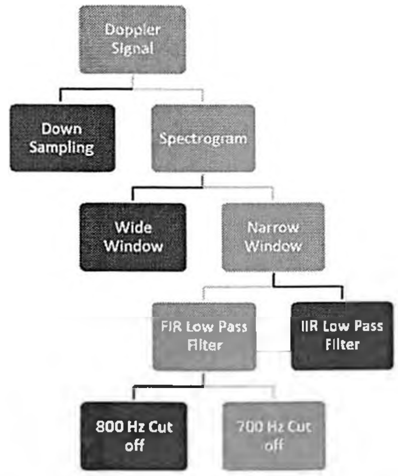

Figure 12: Signal processing design

The first step to the signal processing design was to determine if down sampling was possible. The sampling frequency was 44,100 Hz. This was originally thought to be high. Down sampling was implemented, but this process distorted the signal and many details were lost. The reason why this did not work was because the Doppler shifted frequency is time independent signal. Down sampling simply removed too many necessary details. Spectrograms were used to show the velocity profiles. Two different window lengths were tested to determine which method gave better results. A similar process was used to determine which low pass digital filter should be implemented as well as the corresponding cut off frequency for that filter.

IV. Measurement Methods

Once the ultrasonic flow meter was constructed, testing could be done to receive arterial flow from the heart. Gel was applied to both of the probes being used and the skin where the probes were being applied. This was done to ensure no air gaps would exist between the probes and the skin. The probes were placed below the left-sided ribs to obtain a signal from the heart. The subject of the test was also lying down on a bed to ease testing and to record a resting heart rate. All testing was done in the biomedical lab in the engineering building. The RCA output was connected to a set of speakers so that the tone could be heard. When the tone changed with time, this indicated that the heart signal had been located. When this was found, the speakers were connected directly to a laptop, and the resulting audio was recorded. The audio was recorded using free software called Audacity. This program allowed many recordings of the signal to be done with ease. The direct connection to a laptop ensured that no background noise infiltrated the signal. Once the audio signals were recorded, they could be imported into MATLAB to be processed. Figure 13 shows a generic set up for the flow meter. Figure 14 shows the set up as well as all the necessary connections, and Figure 15 shows the Audacity software.

Figure 13: Set up for ultrasonic flow meter testing

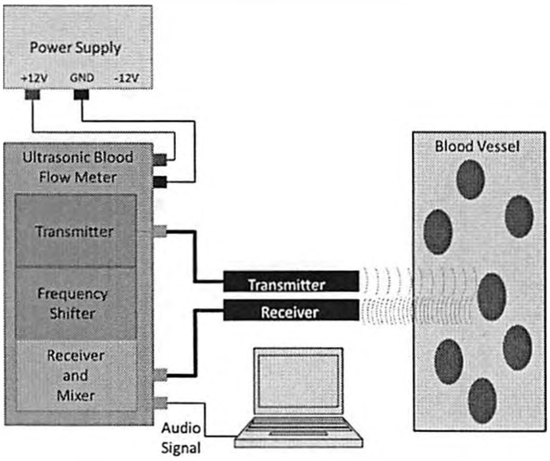

Figure 14: Flow meter connections and set up

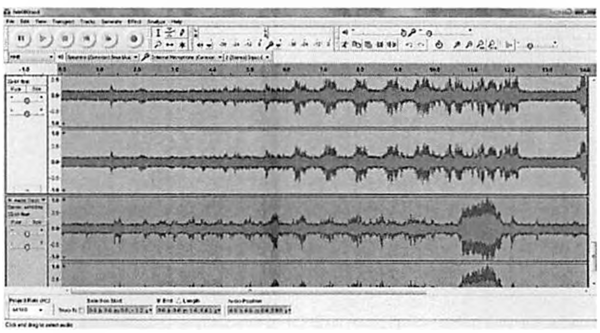

Figure 15: Example of recordings using Audacity software

V. MEASURED AND SIMULATED RESULTS

MATLAB was used for all of the signal processing. The recordings of the heart blood flow signals were imported into MATLAB and displayed. Figure 16 shows what one of these signals look like. There are oscillations in the signal. This corresponds to when the heart is beating.

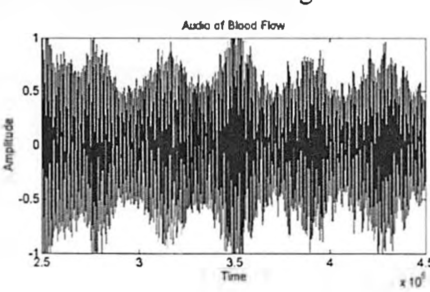

Figure 16: Audio signal of heart blood flow

Once the signals were in MATLAB, a spectrogram of the signal was obtained. The spectrogram window length was varied to determine the best results. Narrow and wide window lengths were programmed. Figure 17-18 show the results of this windowing respectively. The narrow length gave much more detail than the wide length. In fact, much of the velocity profile was lost due to the wide window length. Because the narrow window length had a higher resolution, this window length was chosen for all the spectrograms generated.

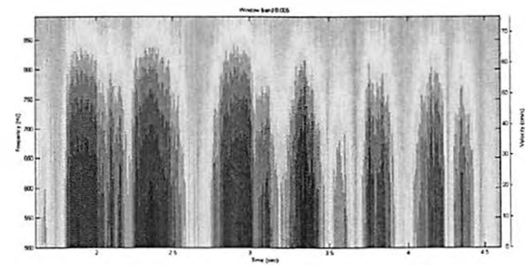

Figure 17: Narrow window length for spectrogram

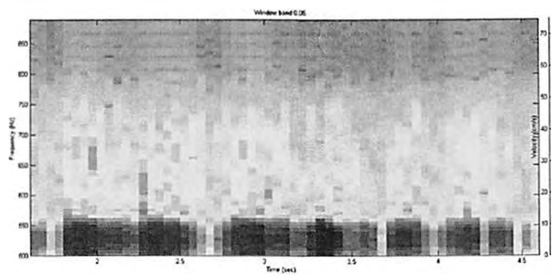

Figure 18: Wide window length for spectrogram

Spectrograms were used to analyze the signal and determine what filters were needed, seen in Figure 19. Because the sampling rate for the signal was 44100 Hz, the spectrogram went up to half of this frequency due to the Nyquist-Shannon sampling theorem. This theorem states that the sampling frequency must be twice the original frequency. It can be seen from the spectrogram that there is a lot of high frequency noise. It is also evident that the Doppler shift frequency is relatively low. Due to these observations, a low-pass filter was chosen to filter the signal.

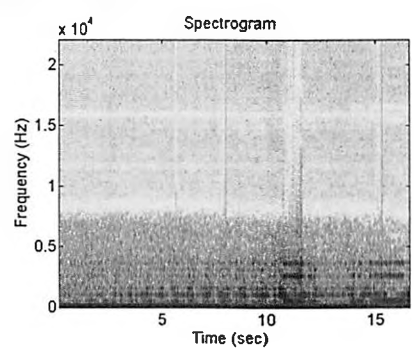

Figure 19: Spectrogram of signal

Several low-pass filters were designed. Two digital filters were tested to see which one gave a better result. Figure 20 shows the result after using an infinite impulse response filter

(IIR), and figure 21 shows the result after using a finite impulse response filter (FIR). The IIR filter had more noise, so the FIR filter was deemed the better one. The FIR filter was also chosen because it has better stability. Even though it has a higher order, the quality of the signal was considered more important.

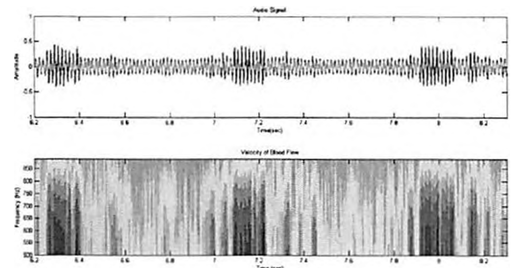

Figure 20: IIR filter results

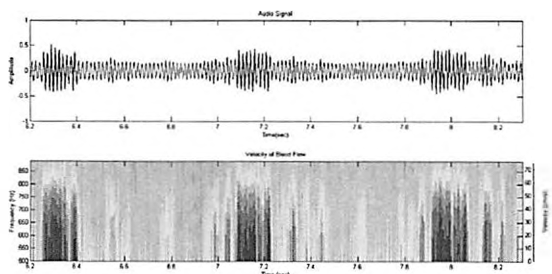

Figure 21: FIR filter results

Different cut off frequencies were also tested. One low-pass filter was designed to have a frequency cut off at 800 Hz, and another was designed to have a cut off frequency at 700 Hz. This was done to compare the two filters and determine which would give the best result. The velocity was also calculated using Equation 3. The velocity is displayed on the right hand y-axis. Figures 22-23 show the original signal and two filtered signals.

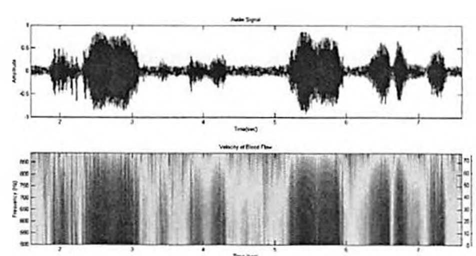

Figure 22: Filtered audio signal with 800 Hz cut off

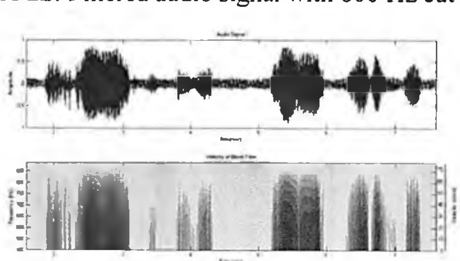

Figure 23: Filtered audio signal with 700 Hz cut off

The low-pass filter with a cut off frequency at 700 Hz was selected to analyze signals. This was selected because it better divided the shades between colors and filtered more of the noise between the heart beats. Figures 24-25 show two audio signals from different subjects filtered with the 700 Hz low pass-filter.

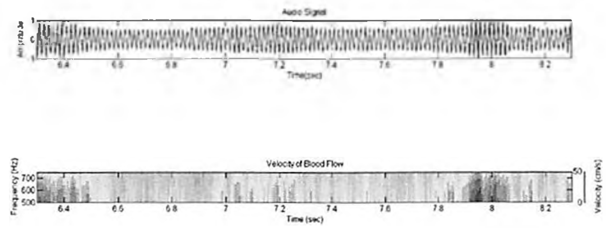

Figure 24: Heart rate signal from subject 1 and spectrogram

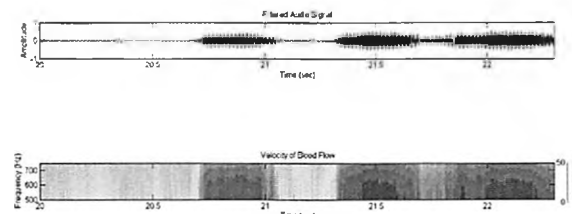

Figure 25: Heart rate signal from subject 2 and spectrogram

A final test was done to see if this signal processing method would work with a slightly different signal. The resting and recovery heart rate was recorded for a subject. Both of these signals were processed, and the results are shown in Figure 26-27. The resting heart rate shows a fairly regular beat with a similar trend with other recorded signals. The recovery heart rate shows a different velocity profile. The heart is beating faster and pumping more blood, as can be observed with the increase in the red color on the spectrogram. This result showed the ultrasonic flow meter is capable of obtaining signals from the heart under different conditions such as at rest and after stressful exercise.

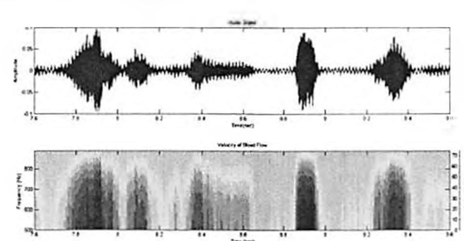

Figure 26: Resting heart rate

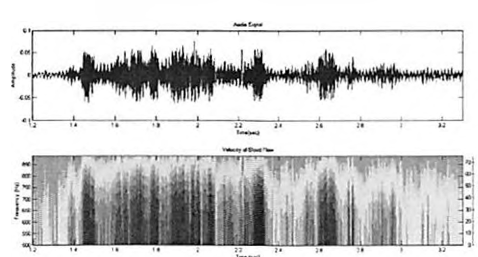

Figure 27: Recovery heart rate

The spectrograms show a roughly parabolic trend over time, similar to the one seen in Figure 5. The spectrograms show how velocity changes with time. The most concentrated parts are shown in red and correlate to a velocity around 30 cm/s. The spectrograms also show that when the heart pumps, an increase in magnitude occurs in the time domain. The spectrograms also show that the flow meter can detect arterial flow near the heart and display the velocity over time. The graphs also show that the code generated in MATLAB works for more than one subject, which helps show that it can be used universally without much calibration.

VI. CONCLUSIONS

The ultrasonic blood flow meter constructed for this project cost less than $300, including all of the parts and both transducer probes built. The flow meter was able to detect arterial flow and transmit an audio signal with the Doppler shift frequency (Figure 16). After some signal processing an acceptable low-pass filter was applied to the signals, after determining what techniques worked and did not work. The spectrogram plots were able to display the velocity of the blood flow as well as trends. A roughly parabolic shape was seen in the flow in the spectrograms as well as an increase in magnitude to the audio signal when the flow increased (Figures 22-23). These plots show that a less expensive flow meter can still obtain velocity trends in the blood with signal processing techniques.

While this ultrasonic flow meter shows promising results, a lot of future work is necessary. A better fixture for the probes : desirable. Currently both probes are used independently of each other. A contraption that will restrain them so they are always a certain distance apart would make sure they work together, and the user would only have to move one object instead of two. Another testing experiment should be conducted to make sure the flow meter is indeed reading the correct velocity. The current velocity profiles seem correct based on other research, but an actual test would be beneficial. A final recommendation would be to attempt real-time signal processing. This would give the user feedback right away instead of having a delay where the data must be processed.

VII. BUDGET

The ultrasonic blood flow meter developed for this project was under $300. A detailed breakdown of individual costs is shown in table 1. Table 1 shows both the cost of producing one flow meter unit and the cost per unit if one hundred were made. The costs include all of the components, wires, cables, and various other material needed for construction.

VIII. PROFESSIONAL AND ETHICAL PROBLEMS

This project dealt with testing on human beings. To ensure ethical methods were maintained, all testing was done on individual group members. No outside subjects were used in this study. To ensure safety for users, a housing unit was developed so there were no exposed wires or components. All results are reported truthfully. This project should not be used for actual data on any healthcare measurements because more testing is needed to determine accuracy and safety of the project.

Part	Quantity	Cost	Total Cost	Cost (100)	Total Cost (100)
IC					
XR-2206	2	7.95	15.9	6.75	13.5
356	3	0.99	2.97	0.65	1.95
8-pin socket	5	0.13	0.65	0.1	0.5
16-pin socket	2	0.19	0.38	0.12	0.24
AD633JN	2	6.95	13.9	5.75	11.5
Capacitors					
1 uF	7	0.39	2.73	0.25	1.75
0.001 uF	1	0.1	0.1	0.08	0.08
0.1 uF	4	0.08	0.32	0.06	0.24
68 pF	1	0.09	0.09	0.07	0.07
10 pF	1	0.06	0.06	0.04	0.04
0.01 uF	1	0.06	0.06	0.04	0.04
Resistors					
2k	1	0.04	0.04	0.04	0.04
1k pot	1	1.95	1.95	1.49	1.49
51k	9	0.04	0.36	0.04	0.36
200	2	0.04	0.08	0.04	0.08
1k	2	0.04	0.08	0.04	0.08
10k	3	0.04	0.12	0.04	0.12
100k pot	1	1.75	1.75	1.35	1.35
10M	1	0.04	0.04	0.04	0.04
510	1	0.04	0.04	0.04	0.04
Diodes					
n914	2	0.05	0.1	0.02	0.04
Audio					
RCA panel mount	3	0.85	2.55	0.69	2.07
RCA cable	1	1.95	1.95	1.59	1.59
Stereo Audio Auxiliary Cable	1	1.45	1.45	1.15	1.15
Transducers					
MA400A	2	39	78	39	78
BNC cable RCA to BNC female	2	3.95	7.9	2.95	5.9
Power					
Banana Cables	3	10.25	30.75	9.25	27.75
Power Supply	1	64.95	64.95	64.95	64.95
Banana Plugs	3	3.45	10.35	3.25	9.75
Other					
PCB board	1	12.95	12.95	11.49	11.49
Wire	5	1.59	7.95	1.19	5.95
Solder	1	8.95	8.95	7.25	7.25
Heat shrink	1	1.79	1.79	1.45	1.45
Housing Unit	1	19.95	19.95	16.95	16.95
Difference	23.41	Total Price	291.21	Total Price	267.8

Table 1: Budget of project

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The College of Engineering and Engineering Technology provided a work space and tools for this project. Dr. Martin Kocanda provided guidance and advice.

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University Honors Program

Capstone Approval Page

Capstone Title (print or type) Ultrasonic Blood Flow Meter with Doppler Velocity

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Department of (print or type) Electrical Engineering

Date of Approval (print or type) 5/10/13