Helios

Capstone I - Specification Report

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Prepared by:

Justin Chin
Sunny Mei
Miguel Dominguez
Ichwan Palongengi

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1. Introduction

a. We want to show that using a Laser Doppler Vibrometer (LDV), we can remotely obtain audio signals from distant objects that are hidden. The LDV measures the vibration of a surface of an object by analyzing the reflected laser beam. We will be developing an algorithm to handle the data received from the LDV to reproduce comprehensible audio similar to the original source. Our main reason for this system is to better understand the LDV and how well can someone use this technology to listen in on supposedly private conversations. From our discoveries, we hope to show what limitations and capabilities the LDV has so that people are more aware of the their environment when conducting confidential conversations. Also, engineers would be able to design buildings better so that an external adversary cannot listen in on conversations based off the vibrations of windows in that building.

b. This project has the benefits of being extended to using voice identification to determine who is speaking, and how many voices. For our purposes, we will be determining the accuracy based on varied distance and surface material.

2. Background

a. There are methods and research very similar to our system whereas the focus is on remote sensing. The main ones we are going to discuss are the typical surveillance equipments, MIT, Microsoft, & Adobe Research, and LDV Audio Research perform by various institutions.

b. Typical Surveillance Equipments

   i. These are the things you usually see in movies.

      - Parabolic Microphones

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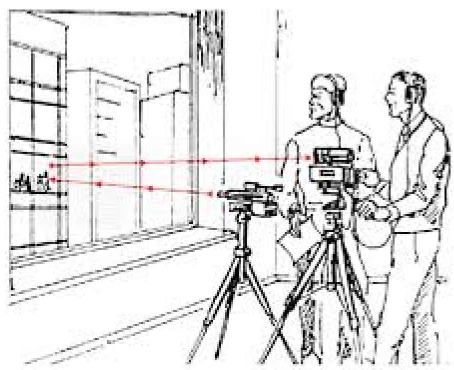
- Severely affected by noise and wind.
- Limited Range.

● Laser Microphone



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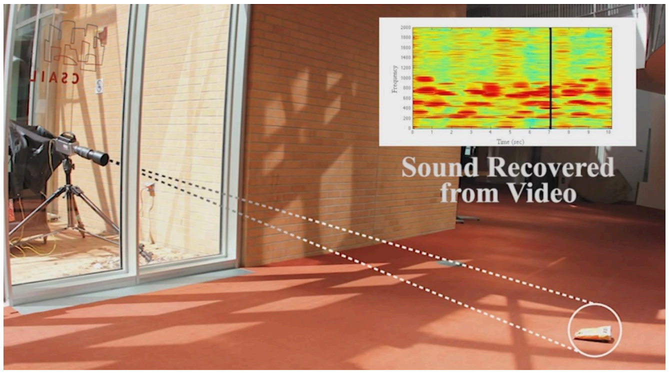
- Requires a receiver to intercept the window reflected beam sent by the laser transmitter.
    i. The longer the distance, the higher the degree matters in reflection.

c. MIT, Microsoft, & Adobe Research

i. 

ii. Developed a computer algorithm capable of analyzing miniscule vibrations on an object's surface and recreate a complete audio signal

iii. Requires a vibrational medium that is not so heavy in order to turn it into a microphone.

iv. Experiments were only 15 ft away

d. LDV Long Range Audio Research

  i. BAE & CCNY

  - Only looked at 50-100 feet (15-30 meters), we will extend this.
  - Performed in limited background noise environments.
  - Utilized only one or two simple signal enhancement techniques.
    - Volume Scaling
    - Band-pass filtering.

3. System Description

a. We aim to build a system capable of detecting audio signals covered or hidden by different surfaces. It is our objective to turn audio vibrations into meaningful elements or components for humans. To reach such system, we start by implementing a simple experiment that will be a building block for what we aim. We list instruments and materials essential to our project. As well, we analyze early results for our initial experiment. We talk about the features that compose the initial and future systems. Finally, we mention techniques and algorithms to be applied to our data and system and future experiments to be executed.

b. Instruments & Materials

i. Single Point Vibrometer OFV-505 Sensor Head, Vibrometer Controller, Matlab

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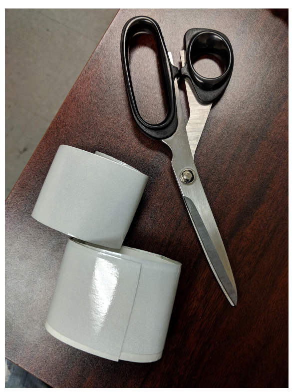
ii. 3M Reflective Tape, Scissors, Measuring Tape, Samsung Galaxy S5

- 


iii. Containers: Metal, Plastic, Cardboard

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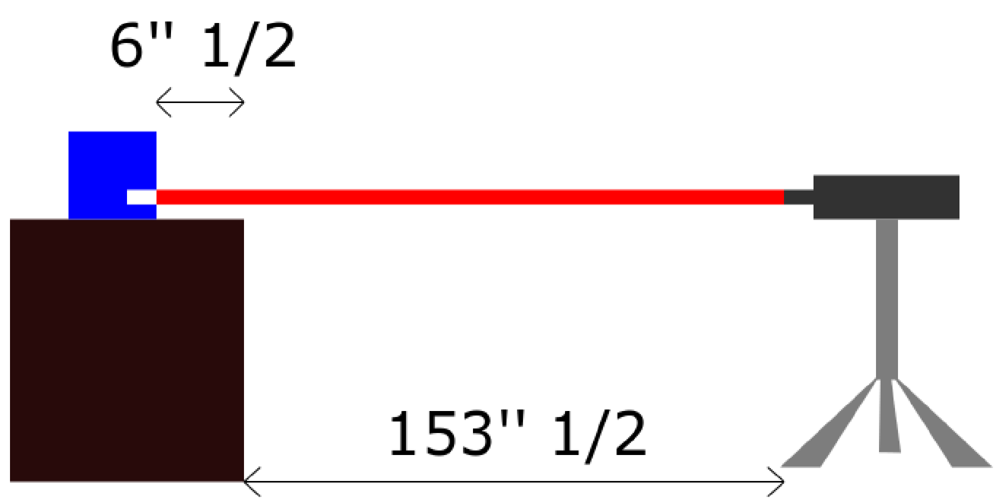
c. Initial Experiment

i. Setup: For our initial experiments we use the LDV, a cellphone that will generate the vibrations and three different types of containers. We pick a sound file that will be played repeatedly by the cellphone device. The container with the cellphone inside is placed on top of a black metal drawer. Outside the container, a small rectangular reflective tape is placed. The LDV laser is turned on and it is adjusted to point to the reflective tape. It is necessary to autofocus the laser from the Vibrometer Controller. The laser can be seen as a red dot on the tape, at this moment we can already observe the waves in Matlab. Any sound in the room alters the resulting waves. Using Matlab, we record the waves produced by the vibrating container.

ii. The picture below depicts our initial experiment. The container is blue and it has a small white reflective tape on its surface. The laser is the horizontal red line. To the right we have the LDV laser.



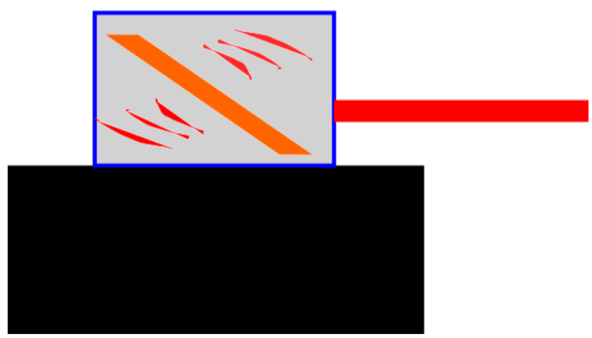
iii. Measurements to consider for initial experiment.

- Distance from black drawer to leg of LDV is 153’’ ½

- Distance from container to edge of black drawer is 6” ½
- Total: 160 inches (4.06 meters)
- Cellphone device plays sound file at three different scales 5, 10 and 15
- Reflective tape is placed on container surface, must be clean and contain no bubbles.
- Records take 30 seconds to collect vibration data.

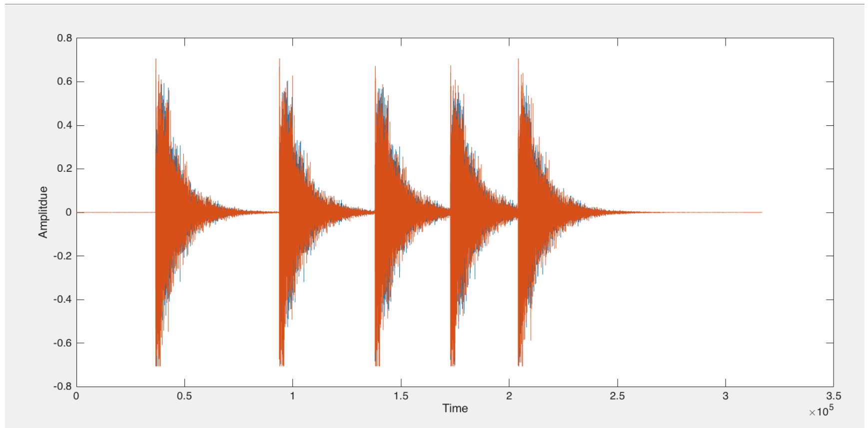
iv. Inside Container: The device that plays the sound file is shown below in orange color. The thick red line is the laser that will catch the vibrations on the container surface. The sound is displayed as red irregular segments inside the blue rectangle that resonate inside it.

Orange device inside container

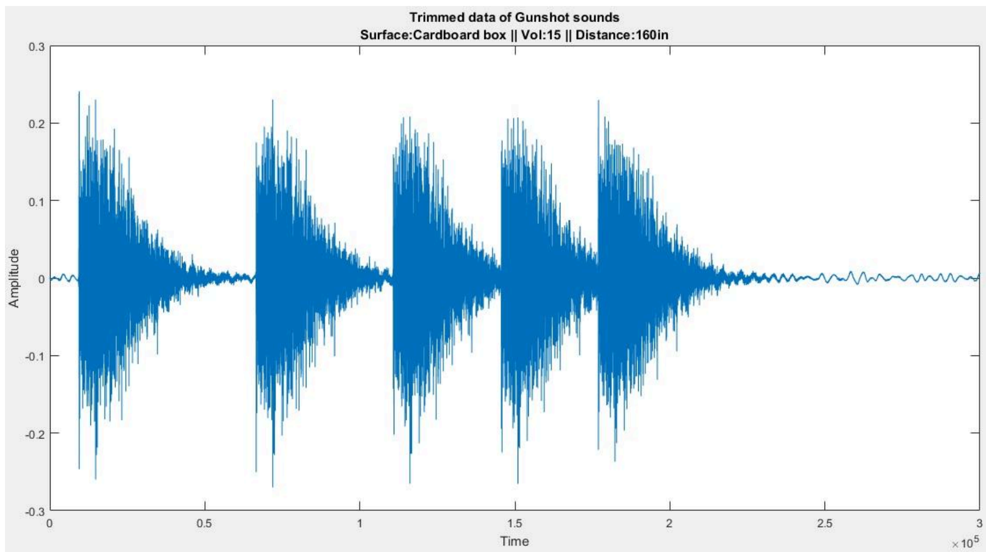


v. Experiment

- Shouting, Normal Talking, Whispering.
- Input Gun Sound (High Amplitude & Distinct)

- 

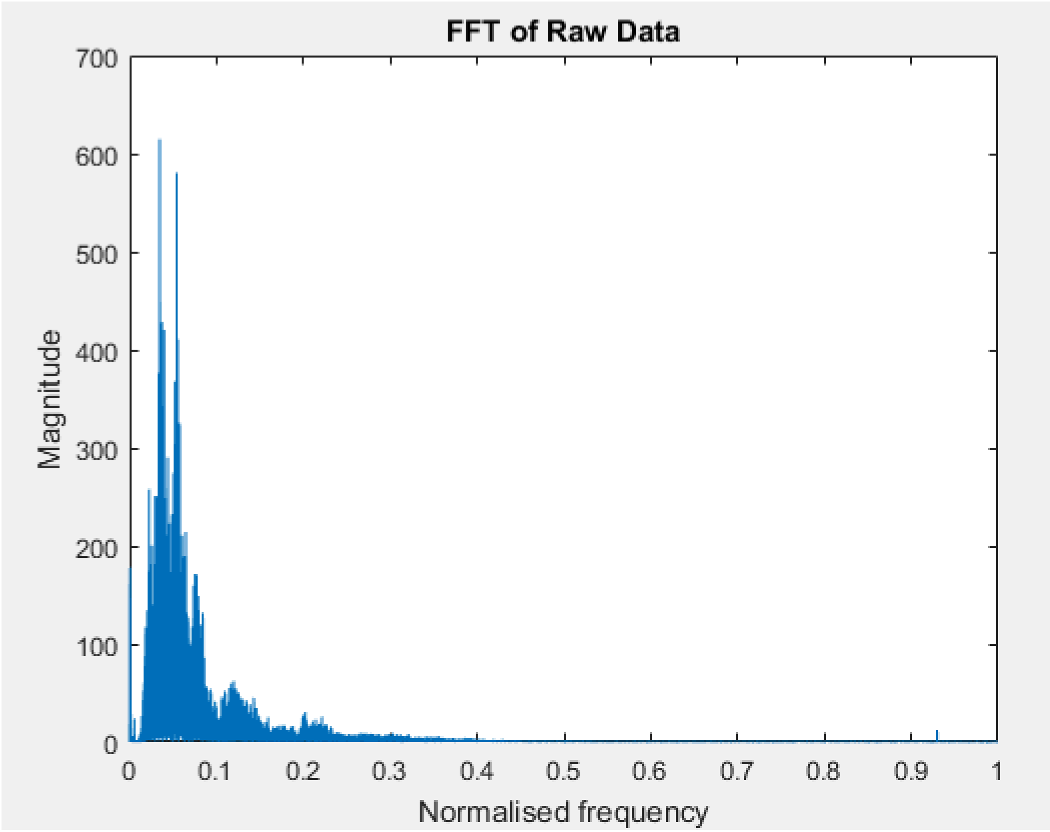
- Received data from LDV



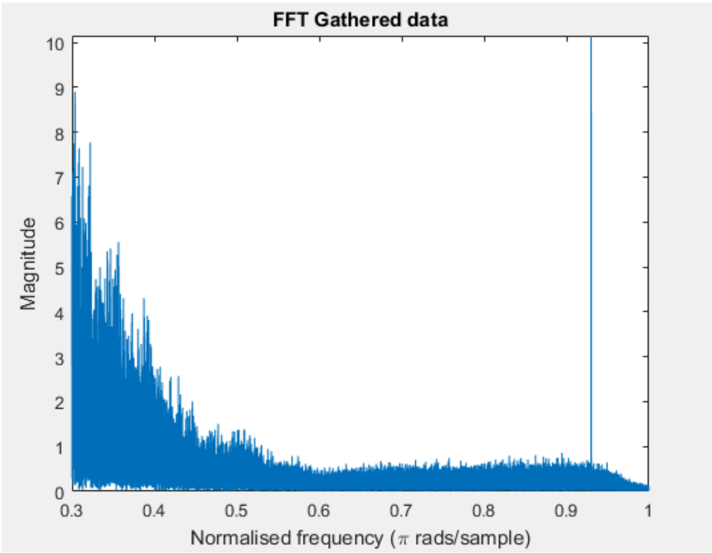
How our data looks on graph. This is our results.

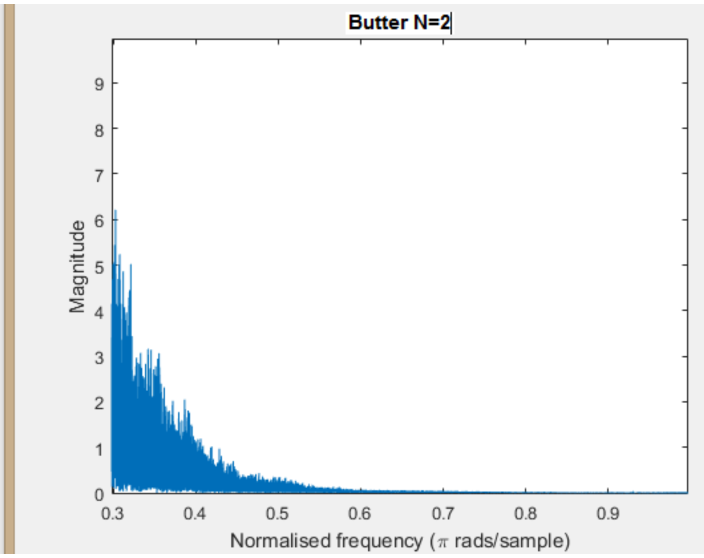
- Filtered Data

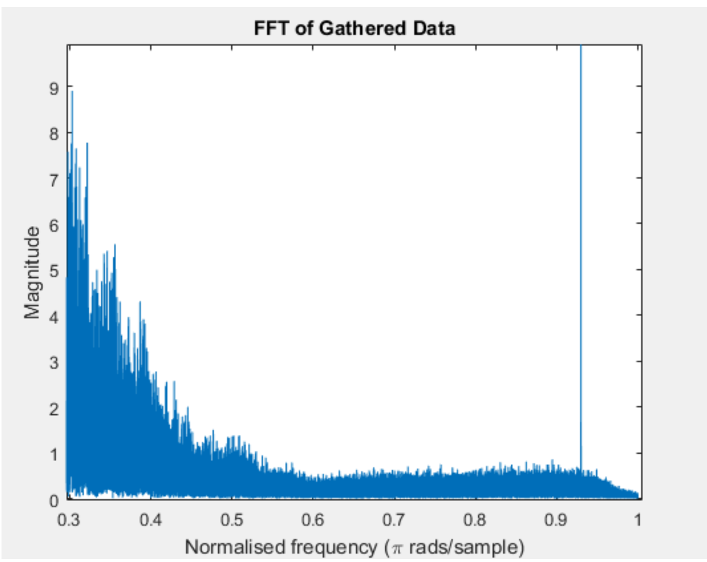
    - Using a built in function in Matlab, we applied Butterworth filter to our data. The function has 3 parameters
        i. n= the order in which we want our filter to be. Higher order will apply a stronger reduction when our data gets near the cutoff point.
        ii. nw=the cutoff point. Any data near this point, will be affected by the filter.
        iii. The type of filter we want. The default is “low”. By setting the filter setting to “low”, anything above the cutoff point will be affected. “High” settings, does the opposite. “Stop” setting can pick an interval between your data.
- FFT
    - FFT transform our gathered data into frequency.
    - We will determine the cutoff point based on the FFT.

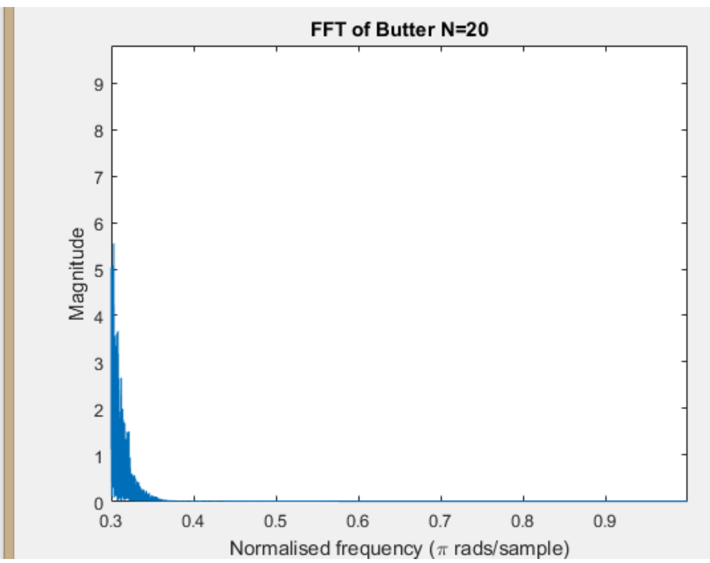


Judging from this, it seems like our data is concentrated around 0.3 and below. So our thoughts were 0.3 is a good cutoff point for the butter filter.

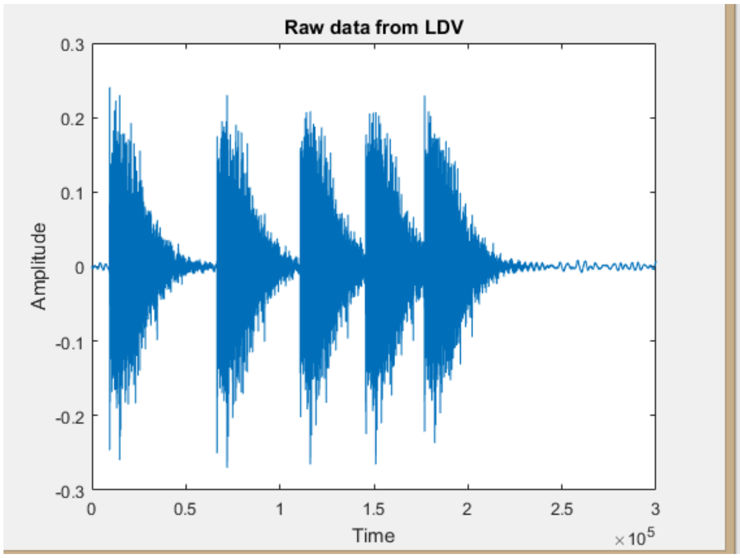


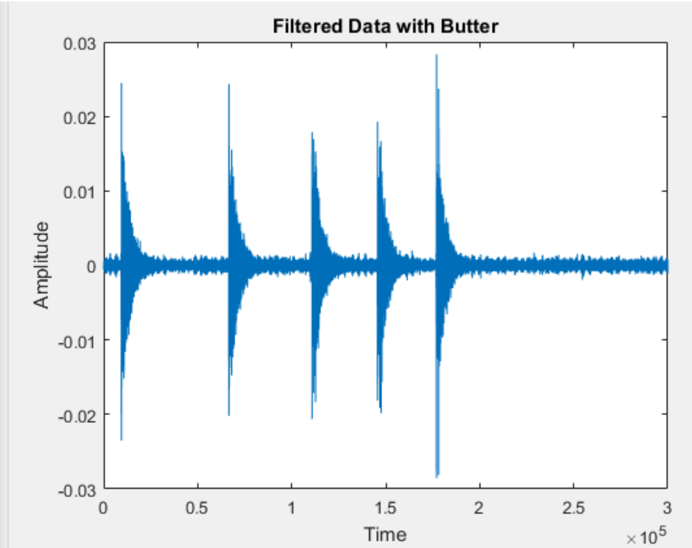




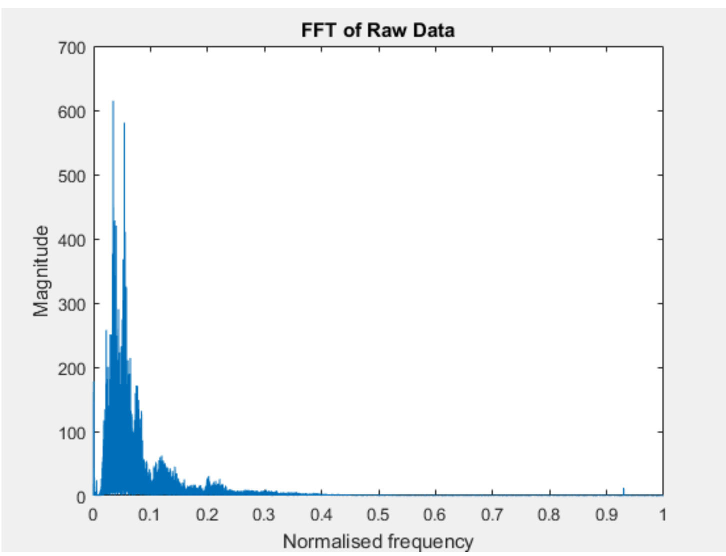


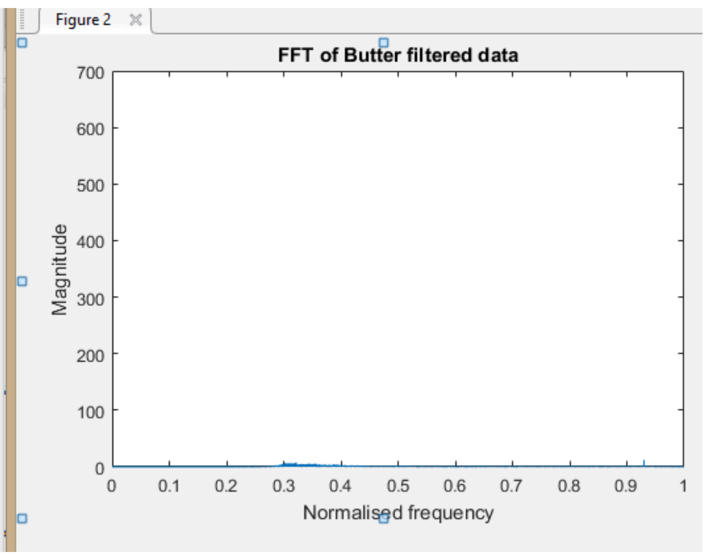
The graphs shows the FFT of the gathered data vs the FFT of the filtered data. In this case, butter N coefficient was changed while the cutoff point was fixed to 0.3. This is done with the settings of “low”. If this was done with “high” settings, we would filter out the gunshot sounds instead, but we can still faintly hear small pin like taps that resembles the gunshot sounds. Let’s look at this with settings set to high.



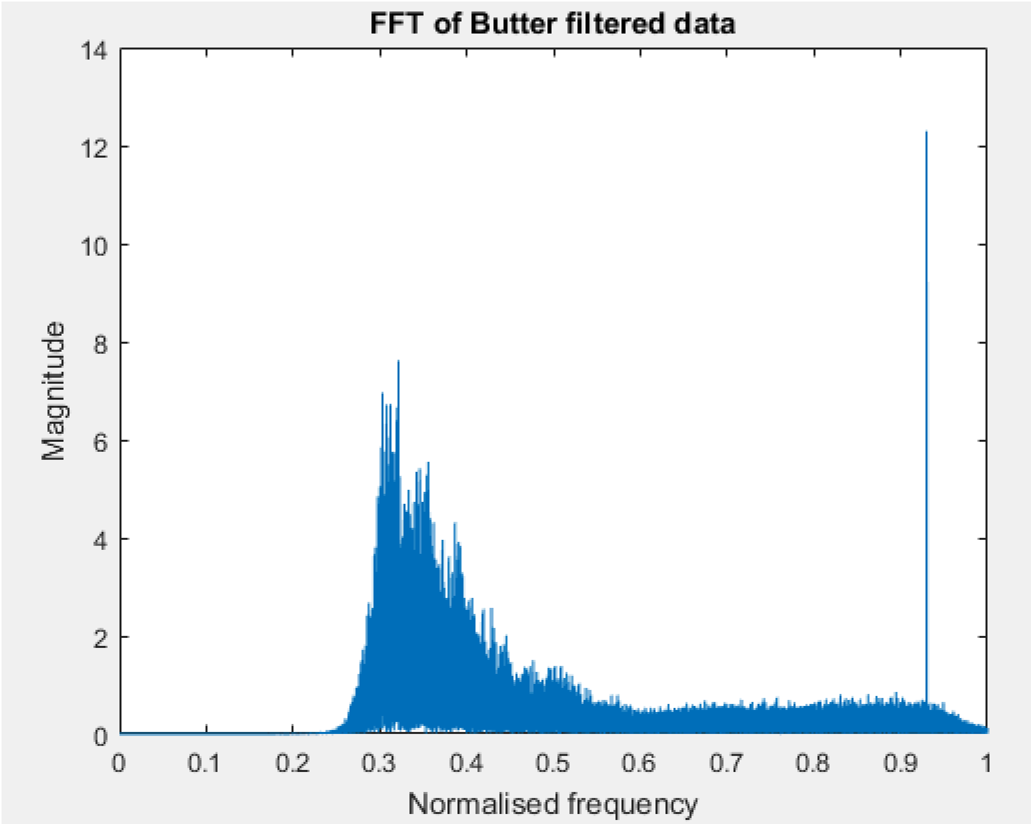


Just by looking at the sound waves, you can see a reduce in the gunshot sounds. Compared with the filtering of the background noise which contribute less.





Closer look on the right graph.



We can still hear faint gunshot sounds when played. So our guess is that somewhere between .3 to .5 maybe also hold faint gunshot sounds.

4. Member Responsibilities

a. Justin Chin

i. Project Manager

b. Sunny Mei

i. Technical Lead

c. Miguel Dominguez

i. Developer

d. Ichwan Palongengi

i. Database Administrator

e. Professor Wei

i. Sponsor - LDV
   - Provides the resources for the project.

5. Conclusion

a. There are many obstacles that we will face in the development of this project, especially in the matter of research resources. As a matter of fact, this is the first time for many of us to come across the aforementioned filtering and denoising algorithms.
   i. In order to find the best combination of algorithms, we will utilize and conduct more research on the algorithms listed above and see how well they perform.
   ii. It is very plausible that a combination of those algorithms will be able to provide us with the desired result.
   iii. We will also keep researching about additional algorithms that might have eluded us thus far.

b. The current technology stack that we are using right now is based on Matlab, a proprietary software. This might present a problem for us since we need to renew the license to use it at some point during the lifetime of the project.
    i. We might want to start using Python and its relevant packages to do our analysis since they are open-source projects.
c. At the moment, the light wavelength that we are using to conduct the experiment is in the visible range which can make it *very* obvious for the eavesdropping targets to realize that they are being observed.
    i. If it is possible, we might want to work with an LDV that operate outside the visible light range (i.e. X-Ray or Infrared)
d. A non-stationary target will add further noise to our experiment since the LDV is unable to maintain a lock on it's target.
    i. We will work with stationary targets.
e. Performance of the LDV depends on the properties (reflectiveness, size, distance from LDV) of the target surface
    i. To increase reflectiveness, we will apply the reflective tape to all target surfaces.
    ii. Note that in a real life situation, we may not be able to attach a retroreflective tape. Idea is to perhaps be able to shoot a retroreflective bullet on to the target surface.

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