ECE 435/535 Radar & Sonar Processing

Project Report:
Integrated Chain Home System

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Introduction

Objective

The main goal of this project was to implement the basic concepts of sonar and radar. Radar and sonar use radio and sound waves, respectively, to detect and locate targets. When a radar transmitter sends out a radio wave, a fraction of the transmitted power of the wave will be reflected from the target and this return signal is seen by the receiver. The time difference of arrival (TDoA) from when the pulse is sent, to when it is received can be used to calculate the distance of the target from the radar, as seen in the equation below [1].

$R = \frac{\Delta t \cdot v_p}{2}$, where v_p is the velocity of the wave.

Experimental Design

This project is a further exploration of ranging systems with radar. We used a Raspberry Pi and Matrix Voice as hardware and programmed with Python. The system can be seen in figure 1. A pulse train was created using Python and a bluetooth speaker was used to transmit this signal. The Matrix Voice was the receiver, and using Python, the received signal was filtered and cross correlated to obtain the TDoA. We used the data acquisition capabilities of these devices to collect data. We determined the theoretical capabilities of the system and then tested the performance in a controlled environment with known ranges.

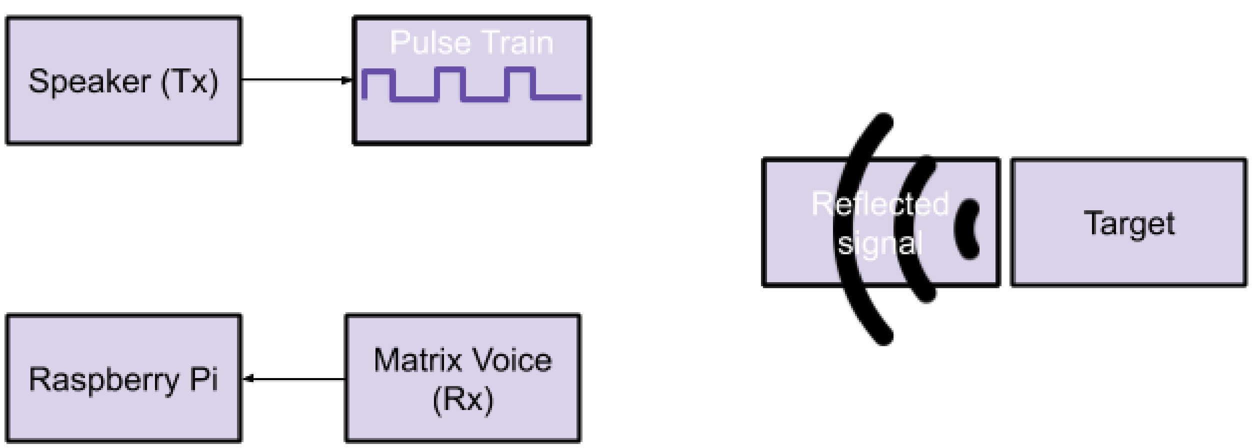

Figure 1: Basic diagram of radar system.

Method

The basic method of the radar system is to send a pulse train transmitted via bluetooth speaker, and the receiver, the Matrix Voice, detects the signal that is reflected back from the target as depicted by figure 1. The signal is then processed in the Raspberry Pi using Python. To process the input, the raw signal was enveloped, then gated and each pulse was stacked and summed together. The noise floor was then calculated by taking the average of the signal. The noise floor served as the threshold for relative reflection peaks; any pulse outside of the pulse train and above the noise floor is a potential reflection from the target.

To further reduce the noise and more accurately pinpoint a pulse, the pulse train was changed from a sine wave to an FM chirp and a 5th order butterworth filter was applied to the raw signal. Then, using the carrier frequency pulse (the pulse width) a kernel was created and cross-correlated with the filtered, gated and summed signal.

A peak detection function was created by stepping through the signal and comparing each amplitude to the samples directly adjacent. When an element was greater than the sample to its left, and to its right, and above the noise floor of the signal, the Using the corresponding sample numbers of the first pulse (the pulse train) and the reflected pulse, the time difference of arrival was calculated.

$R = (sample\ number) \cdot v_p/rate$, where rate = 44,100 samples/sec, v_p = 343m/sec

Data & Results

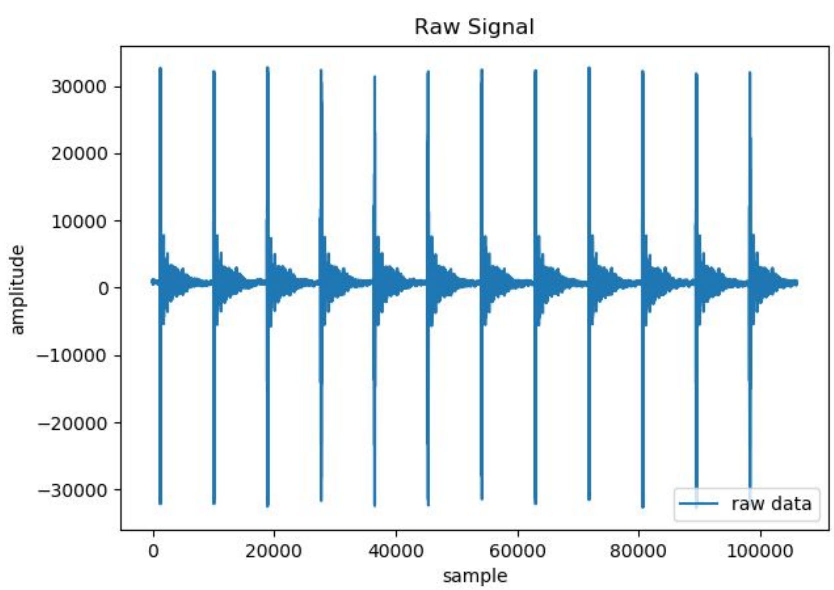

Figure 1: Raw recorded signal.

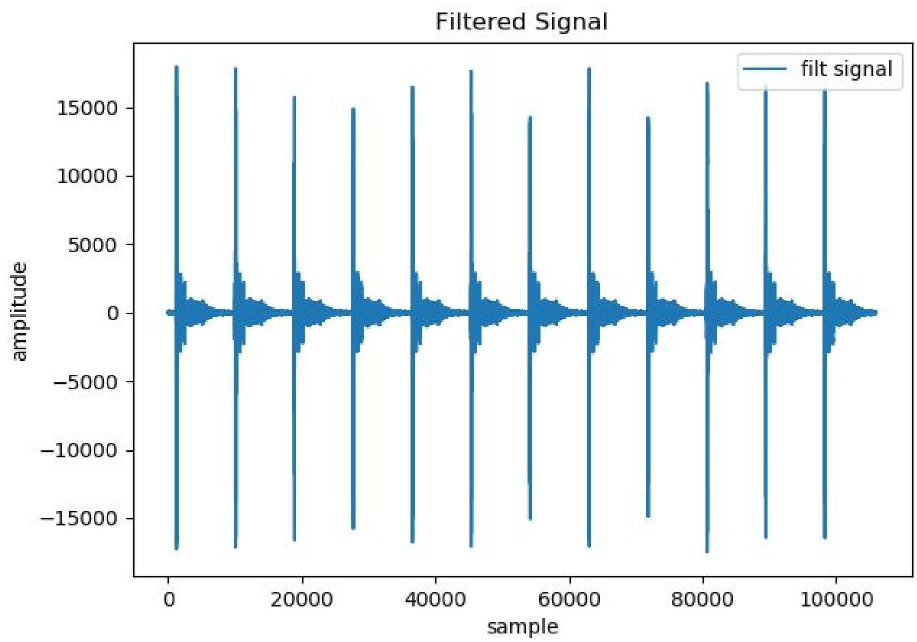

Figure 2: Recorded signal after 5th order butterworth filter.

A 5th order butterworth filter with a bandpass from 3.5k to 4.5k Hz, centered around 4kHz frequency was applied to the raw data. The fft of the data before and after the filter shows a much cleaner pulse around 4k Hz.

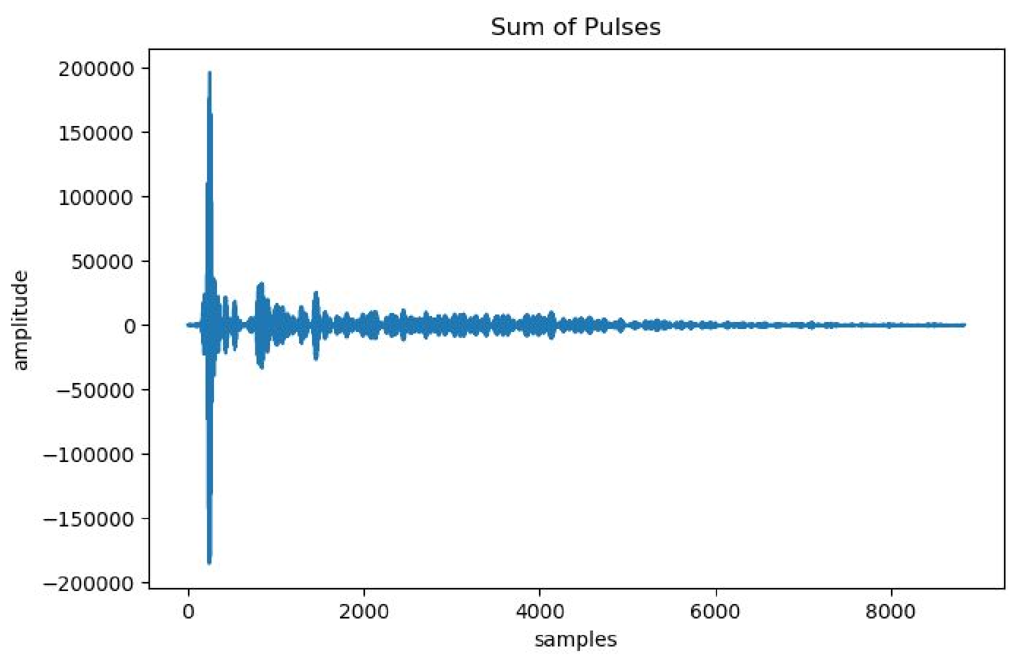

Figure 3: The sum of the pulses.

After the signal was filtered, the pulses were gated by their approximate PRI, rolled so that the transmitted pulses were at the same time, and summed together. This is the sum of 12 pulses.

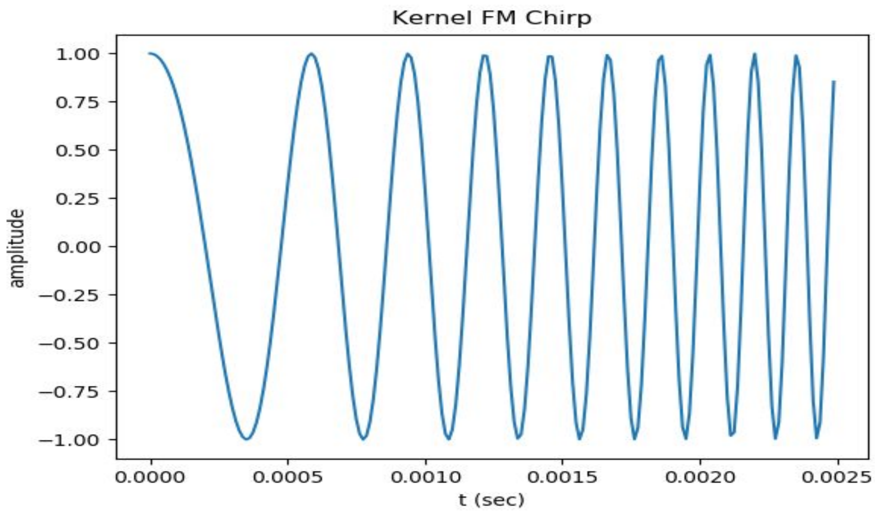

Figure 4: The kernel of the FM Chirp.

The kernel of the FM chirp is what each pulse width of the pulse train is made of. This FM chirp goes from 1k Hz to 7k Hz in 2.5ms.

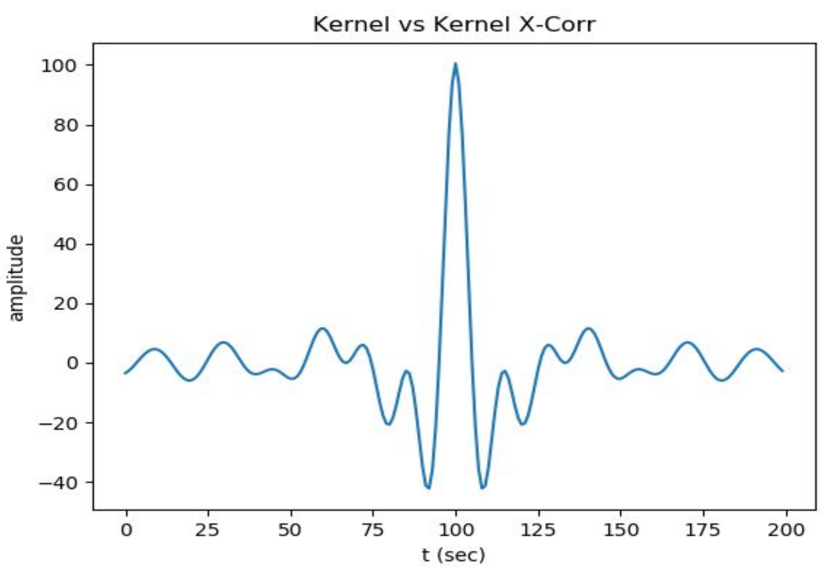

Figure 5: The kernel of the FM Chirp cross-correlated with itself.

This shows that when the FM chirp directly aligns with a signal that “looks” like itself, a high peak is made.

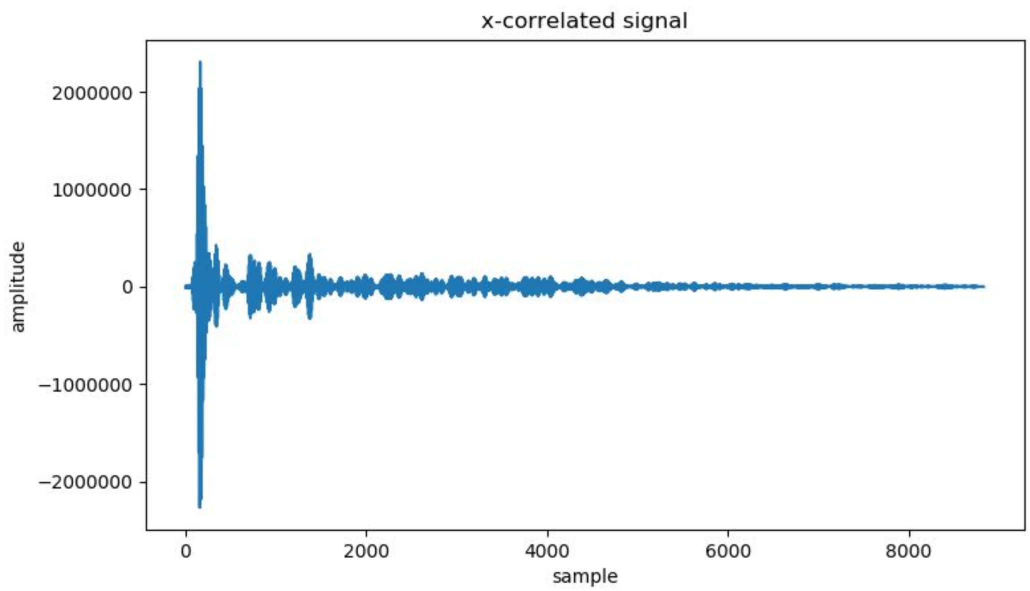

Figure 6: The output of the kernel of the FM Chirp cross-correlated with the summed signals.

With this output, we can begin to see where the reflected pulses are.

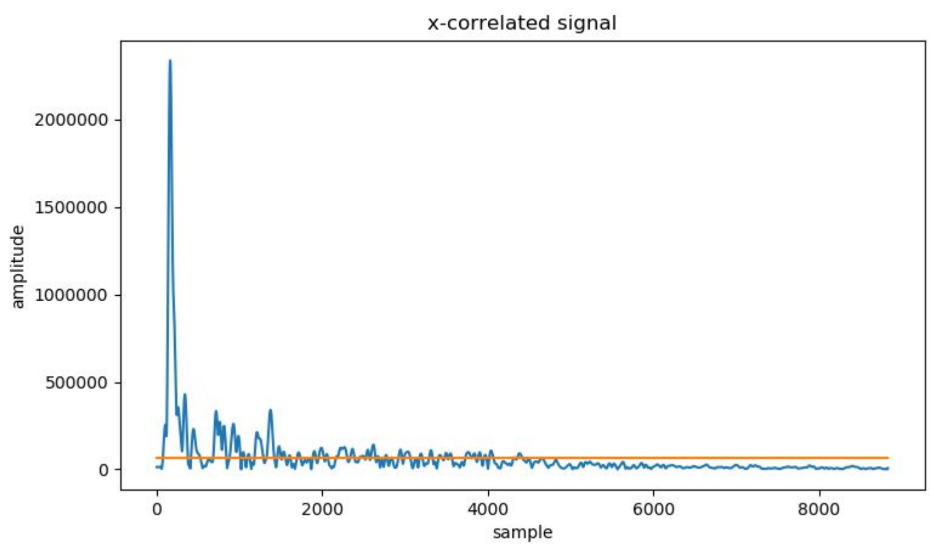

Figure 7: The cross-correlated signal from figure 6, enveloped (blue) and the noise floor of the signal (orange).

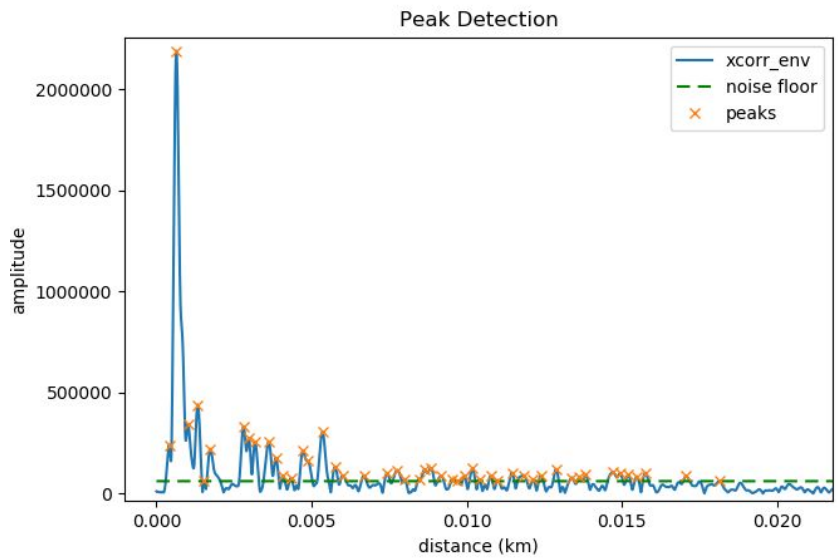

Figure 8: Peak detection above the noise floor was applied to the enveloped cross-correlated signal.

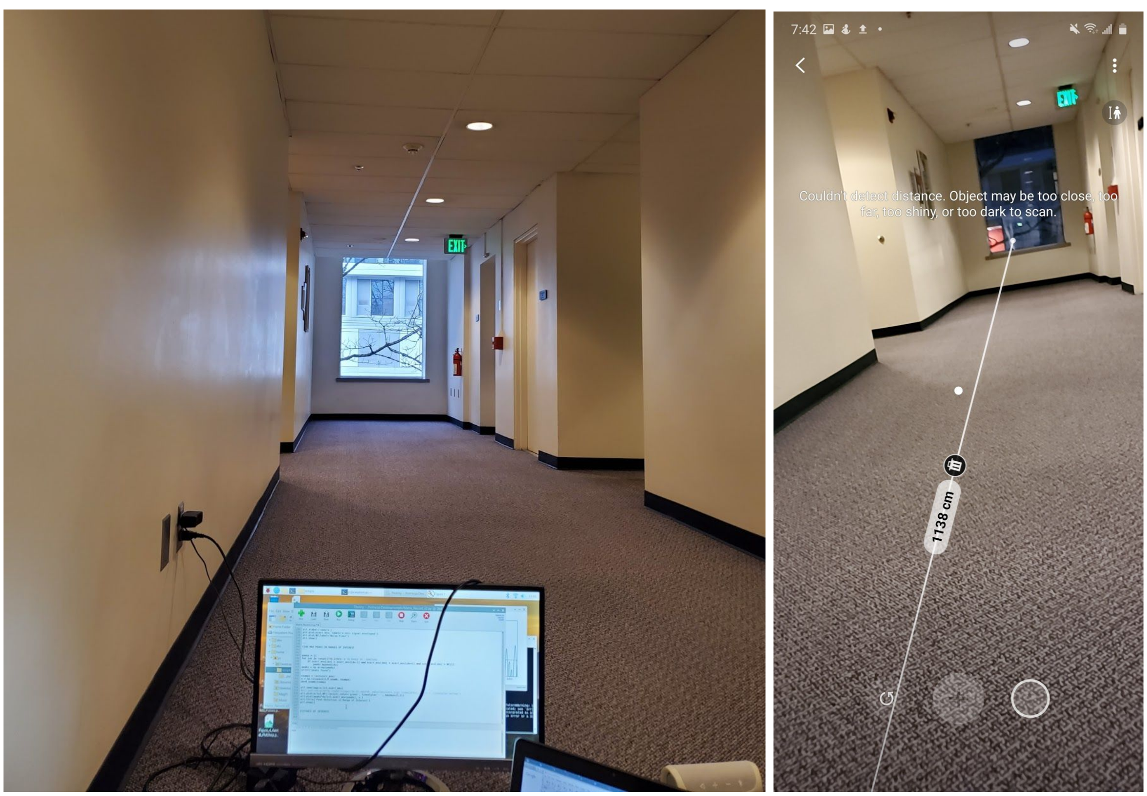

Figure 9: Test environment, distance from Matrix Voice (Rx) and bluetooth speaker (Tx) to target (window at end of hall).

The window at the end of the hall was approximately 11.4m away from the speaker and the Matrix Voice. The final calculated distance from our code was 15.6m. This is an approximate difference of ~4.2m. The other peaks in the signal are due to multipath, from the reflections from the foyers down the hall. This could have been reduced by utilizing more channels, to better gauge where the signal was coming from and only look at the window as a target. Another way to have increased accuracy would have been to add directionality with the speaker, by placing it in a cup/cone or something similar. This would have reduced the amount of signals bouncing off of other targets.

Conclusion

In this experiment, we have studied and mastered the basic concepts of sonar systems. Our results in experiments are consistent with what we have learned theoretically. Through calculation and comparison of the graphs, we can find the reflections in the graphs that match the pulses we generate. The image is not as intuitive as expected due to the following reasons: external environmental factors (such as noise, echos, obstacles, etc.), code (whether there is an opportunity for optimization), and the accuracy of the measuring instrument.

The biggest gain for us in this experiment was a preliminary understanding of the relevant knowledge of radar and sonar systems, which has brought us into a completely new field, which has given us a correct preliminary direction in this field. Programming with Python is indeed a challenge for us. We think that there is still a lot of code that can be modified in the experiment. These may make our results more similar to expectations.

References

[1] Ridenour, Louis Nicot. *Radar System Engineering*, Vol. 1 of *MIT Radiation Laboratory Series*. McGraw-Hill, New York, 1947.