Lab Report Experiment Two

Sergio Gutiérrez,* Tomás Carrasco,† and Samuil Belyovski‡
Radar & Remote Sensing , Lund University
(Dated: March 2019)

The report analyses the usage of a basic frequency modulated continuos wave (FMCW) radar to measure range and velocity components of objects in close proximity. A simple FMCW radar constructed from pre-fabricated components and operated with a Raspberry Pi platform is used. Initially the radar is operated as a continuous wave Doppler radar to analyse the Doppler shift phenomenon observed when a rotating hand-held fan is positioned in proximity to the radar. I and Q signals are used to detect the direction of motion and create graphs of the resultant time and frequency domain data captured by the radar. Additionally the radar is operated in full FMCW configuration which is used to determine the velocity and range of objects moving within the radar's view and create further time and frequency domain graphs. The raw radar data from the experiments conducted is analysed and used to discuss the theoretical aspects of SNR, Doppler shift resolution and range resolution under different conditions. Furthermore a discussion of possible improvements and system speedup using alternative implementations is conducted.

I. INTRODUCTION

The radar used in this analysis operates on a continuous wave (CW) principle as opposed to the more 'conventional' pulsed method of measurement. The pivotal operating principal behind CW radar is the constant emission of electromagnetic radiation which is used to track the instantaneous rate-of-change of an object's range by measuring the Doppler shift of the object as it moves across a distance [1]. The Doppler effect is observed when a wave source sees a continuous change of position relative to the observer and is described as a change in the apparent wave frequency as the range between the source and observer is altered [2].

CW Doppler directly measures the Doppler shift of an object. CW Doppler radar emits a signal of constant frequency and amplitude, as such the echoed return signal will either be identical to that of the emitted one, indicating a stationary source, or will be shifted by a given frequency, known as the Doppler frequency [3]. The rate-of-change of the source's range relative to the radar position is determined by observing the Doppler frequency and corresponding wavelength with constant propagation speed. Since frequency is inversely proportional to wavelength, an upward shift in frequency is observed when the object is moving in the direction of propagation and vice-versa [4].

This frequency shift in real-time is indicative of the rate of change of the echo source and is the defining principle of CW Doppler radar operation. Additionally to CW Doppler radar, frequency modulated continuous wave radar (FMCW) is also used in this analysis. The defining characteristic of FMCW radar as compared to CW radar is the ability to measure the distance between the wave source and the transmitter, achieved through the technique of frequency modulation [5]. A FMCW radar emits a signal with a periodically varying frequency as opposed to a constant frequency as in CW Doppler radar which results in the echoing signal returning with a varying delay [6]. The corresponding distance measurement is achieved by comparing the characteristics of the received echo to that of a control signal, most commonly the transmitted signal [7]. Overall these working principles of CW Doppler and FMCW radar form the core of the theoretical aspects analysed in this investigation.

II. METHOD

The method used to conduct the experiments was heavily reliant on manipulation of the Raspberry Pi module through use of the Python language.

For the first set of experiments regarding CW Doppler radar, a provided script consisting of an infinite loop designed to read and combine the analog voltage levels from the I and Q pins into a single value was used. Once initialised, a small fan was held in front of the radar whilst rotating and a graph of the raw time domain data gathered by the radar was captured. Following this, the experiment was repeated and a new graph obtained by stripping off the DC level. A graph of the frequency domain data was then obtained by manipulation of the Python script and the theoretical SNR of the radar module estimated using information from the provided data sheet, after which the rotation frequency of the fan was calculated.

The code was then manipulated to include timing controls to measure the time taken for the measurement loop, signal processing using FFT and output components respectively, the results of which were analysed using three different N values, where N is the number of

†
‡

consecutive measurements taken by the script. Doppler shift was then further analysed by recording the radar data collected when an object, in this case a human hand, moved towards and away from the radar during the recording period, the results of which were compared to that of the rotating fan.

For the second component of the experiment, regarding FMCW radar, a supplied python code was once again initialised to the radar module and used to capture both raw time domain data and time domain data with DC level stripped off, as with the previous section. In addition to this, an estimation of the radar SNR along with the collected frequency domain data was used to achieve an estimation for the distance between the radar module and the ceiling of the room. Timing controls were then once again inserted into the code so as to achieve measurements for up and down-chirp, signal processing and output components. Velocity components were then introduced into the experiment in the form of a hand wave in front of the radar and the up and down-chirp signal symmetry analysed.
The final section of the experiment involved initialising the radar module with an equivalent code in the C language and comparing the speed of the two codes.

III. RESULTS

A. Experiment 1: CW Doppler Radar

For the first part of this experiment we are going to study a basic implementation of a radar system that uses a fixed frequency to detect a Doppler shift signal. Before going on with the experiment, we are going to calculate the signal-to-noise ratio (SNR) of this radar. The SNR formula is:

$$SNR = \frac{P_r}{P_n} \tag{1}$$

Where P_r is the received power and P_n is the thermal noise power. Then we have the radar range equation and the thermal noise power equation:

$$P_r = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 R^4} \tag{2}$$

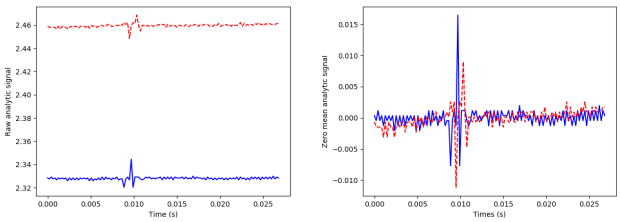
$$P_n = kT_0FB \tag{3}$$

Where P_t is the power transmitted, G_t and G_r are the gain of the transmitting and receiving antenna, respectively, λ is the carrier wavelength, σ is the radar cross-section, R is the range to the target, k is the Boltzmann's constant (1.38E-23 Ws/K), T_0 is the standard temperature (290 K), F is the noise figure of the receiver and, lastly, B is the instantaneous receiver bandwidth. Putting it all together, we get:

$$SNR = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 R^4 k T_0 F B} \tag{4}$$

We can solve this equation in order of R to get the maximum range. From the data sheet, $P_t G_t$ = 15 dBm = 0.0316 W, G_r can be calculated from $32000/(\theta_3\phi_3)$, where $\theta_3 = 45^o$ and $\phi_3 = 38^o$, getting G_r = 18.7. Then λ = c/f = 0.0125 m, with c being the light speed and f = 24 GHz. Lastly, we know that $\sigma = 1\ m^2$, F = 12 dB, B = 500 MHz and the SNR = 25. Using this values, we get that the maximum range is around 14.8 m.

Now that we know that maximum range, we can start the experiment. From this implementation we can detect the direction of motion if it's toward or away from the sensor by the I and Q signals. First we capture the raw time domain data, as shown in Fig.1a from which we can see the distinctive I and Q signals which still include the DC level off set.



(a) DC level and ramp (b) No DC level and ramp

FIG. 1: Time domain raw data single frequency Doppler signal

Now if we strip of the DC level (as seen in Fig,1b)we can see the real expected I and Q signal that can be used as input for our a_n coefficients. Further more find out Doppler frequencies by applying the Fourier transform to this coefficients. This signal contains all the information of a rotating fan at a constant speed, but since the wings of the fan have a finite length this must contain a large amount of velocity components.

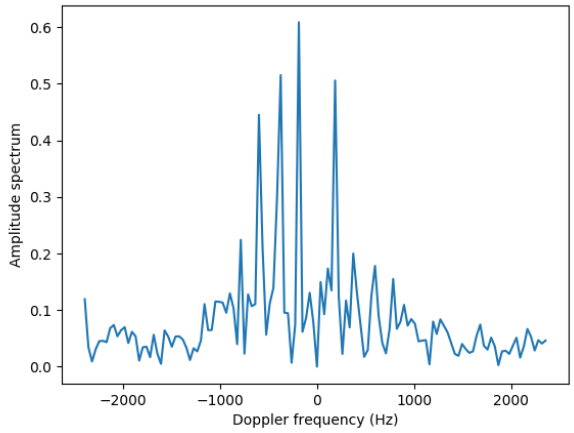


FIG. 2: Doppler frequencies component of a periodic signal form the fan.

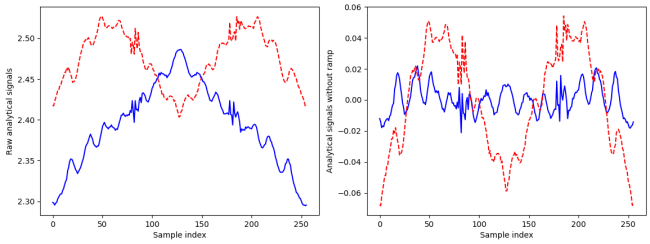
From the Doppler signal we can try to get an estimate of the rotation speed of the fan, as shown in Fig.2 there is a periodic signal which give us information about the periodic motion of the fan when one if the wings is moving towards the radar. From Fourier Transform theory we know that a comb in frequency is also a comb in time, with this we know that if we find the spacing in frequency we can determine the half the period of one rotation in time since we have to rotating blades. From the data in Fig.2 a spacing of approximately 220 Hz which gives a rotation period of 10 ms, thus giving an RPM of approximately 6000 which is reasonable considering the size and speed of rotation.

An interesting effect for this radar system is that it allows us sense if the object is moving towards or away from us. This can be determined by the sign of the frequencies components of the Doppler signal, when the frequencies are negative the target is moving away from the sensor, thus when they are positive the target is moving towards the sensor.

A way to improve the response time of this radar system is to decouple the data acquisition and the visualisation, because what makes this system significantly slower is that before doing the next sweep it plots the last detected signal and this takes longer than the sensing cycle thus making it much slower reducing its accuracy.For the timing control changes the data collected contains the same information for both the case of CW Doppler radar and FMCW Radar, so we only analysis the result for FMWC case since its the more interesting.

B. Experiment 2: FMCW Radar

Bellow there are two graphs that show the time domain raw data, but there is a difference between both of them. The first graph shows the signal overlayed on a DC level of about 2V and a ramp function corresponding to the tuning voltage, while the second graph shows the signal without them.



(a) DC level and ramp (b) No DC level and ramp

FIG. 3: Time domain raw data of the radar system.

Once the DC level and ramp have been stripped off, we can compute the Fourier transformation of both signals and extract the dominant frequencies in each signal.

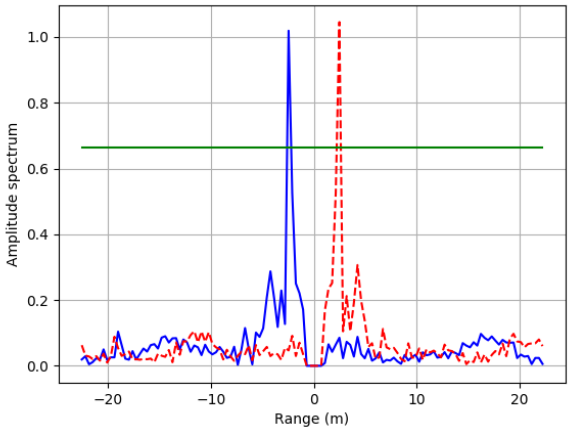


FIG. 4: Frequency domain data

From what can be seen in FIG.3, the distance between the radar and the ceiling is around 2m, because its range where both peaks are formed.

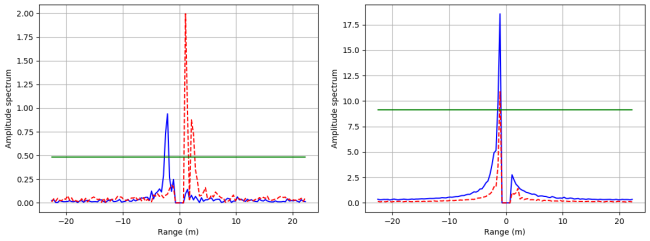
For the next task, the measurement of the times for each phase of the experiment, we made various measurements with each possible settings and, to simplify, we made a table with each average time, that can be found as Table.I.

TABLE I: Time table for each part of the experiment

N		128	256	512
Upper	Liveplot	0,043866889	0,043866889	0,167130154
	Text	0,038820385	0,057598455	0,14463025
Lower	Liveplot	0,048195222	0,048195222	0,170178462
	Text	0,039259974	0,058932091	0,12928725
FTT	Liveplot	0,003224833	0,003224833	0,003513692
	Text	0,002572795	0,001813136	0,00274725
Output	Liveplot	0,545424944	0,545424944	0,546187231
	Text	0,001106128	0,000799545	0,00107525

"Upper" represents the upper-chirp sweep time, while "Lower" the down-chirp sweep time. "FTT" represents the signal processing with the ramp extraction and FTT time and, lastly, output means the output display time, writing text on the screen for the "Text" mode or plotting for the "Liveplot" mode.

For the last part of this experiment, we add a velocity component in the form of waving our hand towards and away from the radar. From what we could observe, when we moved our hand towards the radar, a positive shift would occur and a peak to right appeared. In the same way, if we moved our hand away from the radar, a negative shift would occur and a peak to the left appeared.



(a) Positive shift (b) Negative shift

FIG. 5: Time domain raw data

C. Experiment 3: Porting to C

This experiment consisted on doing the same thing as the previous one, but this time using a C program, instead of a python one.

Using the times from Table 1, we can calculate the total time that the python program used in each different situation. The best time for both the "Liveplot" and "Text" mode occurred when N was equal to 128, 0.641 seconds and 0.082 seconds, respectively. To calculate the time used for the C program, we ran the program multiple times and got an average of 0.029 seconds. This means that the C program is around 22 times faster then the python one, in the "Liveplot" mode and around 3 times faster in the "Text" mode.

After analysing these results, we concluded that the bottle-neck of this system is graph plotting itself. Because the same program is responsible for getting the data and analyse it, plotting the graph consumes a big amount of time compared to just printing the results, like in the C program or the python program in "Text" mode.

IV. ANALYSIS AND DISCUSSION

From this simple system we can see the power behind the Doppler shifted sensing. Even thought its a relatively simple and cheap radar system by changing the way we analyse the acquired data it can become a very robust system. This sensor is not very sensitive or accurate since threw out the experiment we got a range detection that was large than expected but it was still reasonably close to what was expected. we could improve significantly the speed of detection thus improving its sensitivity to changes in the target speed if one modifies the signal processing by decoupling the data acquisition and the visualisation since most of the time spent in one data collection cycle was spent plotting.

Its worth noting that we where able to sense distance movement towards and away from the sensor and changes in speed just by modifying the signal processing, which is quite impressive when you think that the soul purpose of radar system used was to open and close doors automatically and for a low price.

[1] Sciencedirect.com. (2019). Continuous Wave Radar - an overview — ScienceDirect Topics. [online] Available at: https://www.sciencedirect.com/topics/engineering/continuous-wave-radar [Accessed 22 Feb. 2019].

[2] "The Doppler Effect", Physicsclassroom.com, 2019. [Online]. Available: https://www.physicsclassroom.com/class/waves/Lesson-3/ The-Doppler-Effect. [Accessed: 22- Feb- 2019].

[3] "Radar Basics", Radartutorial.eu, 2019. [Online]. Available: http://www.radartutorial.eu/02.basics/ Continuous
[4] "Continuous Wave Radar", Fas.org, 2019. [Online]. Available: https://fas.org/man/dod-101/navy/docs/es310/cwradar/cwradar.htm. [Accessed: 22- Feb- 2019].
[5] Iist.ac.in, 2019. [Online]. Available: https://www.iist.ac.in/sites/default/files/ people/IN14204/Lecture
[6] "Frequency Modulation", Fas.org, 2019. [Online]. Available: https://fas.org/man/dod-101/navy/docs/es310/FM.htm. [Accessed: 22- Feb- 2019].
[7] "Radar Basics", Radartutorial.eu, 2019. [Online]. Available: http://www.radartutorial.eu/ 02.basics/Frequency
[8] Optoelectronics and optical communication (FFFN25), "Diode Laser", Laboratory guide 2018.