University of Ottawa

Faculty of Engineering

Electrical and Computer Engineering

Digital Signal Processing (ELG5376)

Project Report

Submission

On

"LMCW Automotive Radars"

Under the Guidance

Dr. Martin Bouchard

Submitted by

Karthik Panyam

300257927

TABLE OF CONTENT

1. OBJECTIVE

A LMCW automotive RADAR is implemented by applying some of the concepts learned during the class sessions such as spectral analysis (Fourier transform, FFTs) to obtain practical hands-on learning of the DSP concepts. Two targets along with the range, velocity and angle of approach information were detected by using a 3D FFT and mixed beat frequencies.

2. INTRODUCTION

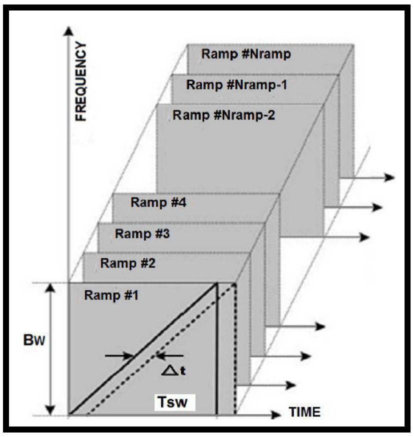
RADAR, short for radio detection and ranging, is used to detect objects. Presently, as safety standards are increasing, RADARs have started to appear even in automobiles to detect other cars, passengers etc. This is one of the steps to autonomous vehicles. The RADARs used in automotives is generally, FMCW RADAR, that is Frequency Modulated Continuous Wave Radar. In our case, we use a similar radar that is a LMCW which is short for Linear frequency Modulated Continuous Waveform radar.

A single transmitter and multiple receivers along with high speed A/D converters are used to make up this system. A Phase Lock Loop (PLL) is used to generate a signal f(t) = k.t where 'k' is the chirp rate. The signal processing part of the system performs the computations to obtain the range, doppler and the azimuth [1]. A 3D FFT is performed to compute the mentioned parameters. This is then plotted to give a visual understanding of the two targets.

3. ARCHITECTURE

The RADAR project was simulated using MATLAB, and thus a synthetic signal used to mimic the received signal by the transmitters. This design firstly used a cosine function to generate the synthetic signal, but since this signal was generating 'peaks' in the negative frequencies too which was undesirable. To circumvent this issue, a complex exponential version was used to measure the radial range, doppler and the azimuth for each of the two targets that were detected.

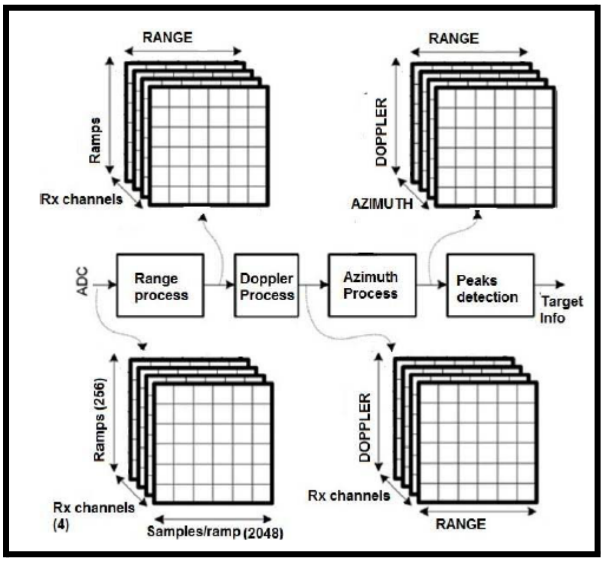
Since chirp signals are used, the frequency-time plot of such a signal rises linearly with time as shown below in Fig(1). They are in the form of a sawtooth wave, with each tooth representing a single chirp. The back scatter of these transmitted signals will have a delay attached to them. The target at distance D will cause a frequency shift between the Tx and the Rx signal and measuring these delays can yield us the range and doppler information. As for the angle of arrival, each of the Mr receiving antennae are spaced out at Da. From these, and the equation provided in paper[1], the azimuth angle can be determined.



Firstly, the code starts off to define the parameters of the carrier frequency, speed of light, carrier wavelength. Along with these, the maximum velocity and distance and the velocity and distance resolution. The number of the antenna is also initialized.

From the above initialized parameters, the chirp parameters are calculated by using the equations that are provided in papers [1] - [3], and also from the PDF provided by Prof. Bouchard. That is, the chirp bandwidth, number of chirps, the modulation index and the maximum beat frequency are all computed.

Following the sampling theorem, the sampling frequency is calculated as twice the max beat frequency and also the sampling period. The number of samples per chirp is calculated by the ratio of the maximum distance to be detected to the distance resolution.
As mentioned above, a complex exponential signal was used in order to avoid the “mirror images” that were generated by the negative frequencies. This was then put into a nested for loop to create a 3D data cube which had the dimensions (chirps X no. of sample per chirp X no. of antenna). Fig. 2.



To this 3D data a consecutive 1D FFT was performed three times, one in each of the three dimensions. Firstly a 1D FFT was performed along the range axis i.e., along the samples per chirp dimension after which another FFT along the chirp channel was performed. This was done considering the first antenna or in other words, the first channel or the first page. This FFT matrix is a complex valued matrix having dimension (chirps X no. of sample per chirp). Two peaks were calculated by using sort. The row of the two peaks correspond to the distance of the two targets while the column information corresponds to the velocity information. The magnitude in that particular row and column will be the highest after performing the FFT while the other areas will have minimal value.

Now the Range - Doppler 2D plot is plotted and from this showing two reddish spots on the otherwise blue plot. It shows the corresponding radial distance with its respective speed for both the targets. From this we can also plot slices for the range and velocity individually. Next, we compute the 3rd FFT in the antenna dimension. But to reduce the computations we apply the FFT only in the two places where the two peaks were generated. So now this will be a Mr point FFT at two points. Since this is in the dimension of the antenna, and the antenna have a fixed distance between them, the difference between the signals received for each of the antenna, we can extract the angle i.e., the azimuth information. Plotting the magnitude of this gives the angle information in visual form. If the range and angle information is only required, i.e., there is no need for the velocity information, only a single chirp can be considered along all the antennae. This corresponds to the bottom plane of the 3D cube. Plotting this, gives a visual representation of the targets with only the range and angle information.

Similarly, if only the speed and angle information is required, all the chirps along all the antennas for a single sample per chirp should be considered. This will provide the speed and angle information leaving the range.

4. Simulation and Result

The parameters considered are:

Parameters	Values
Carrier Freq.	10 GHz
Maximum Distance	300 m

Distance Resolution	0.3 m
Maximum Velocity	300 Kmph
Velocity Resolution	1.4 Kmph
Number of Antenna	16

Target information:

Parameters	**Target 1**	**Target 2**
Distance	100 m	200 m
Velocity	-50 kmph (approaching)	75 kmph (going away)
Angle (Degrees)	45	-45

The graphs for the above values are simulated and the plots are shown below.

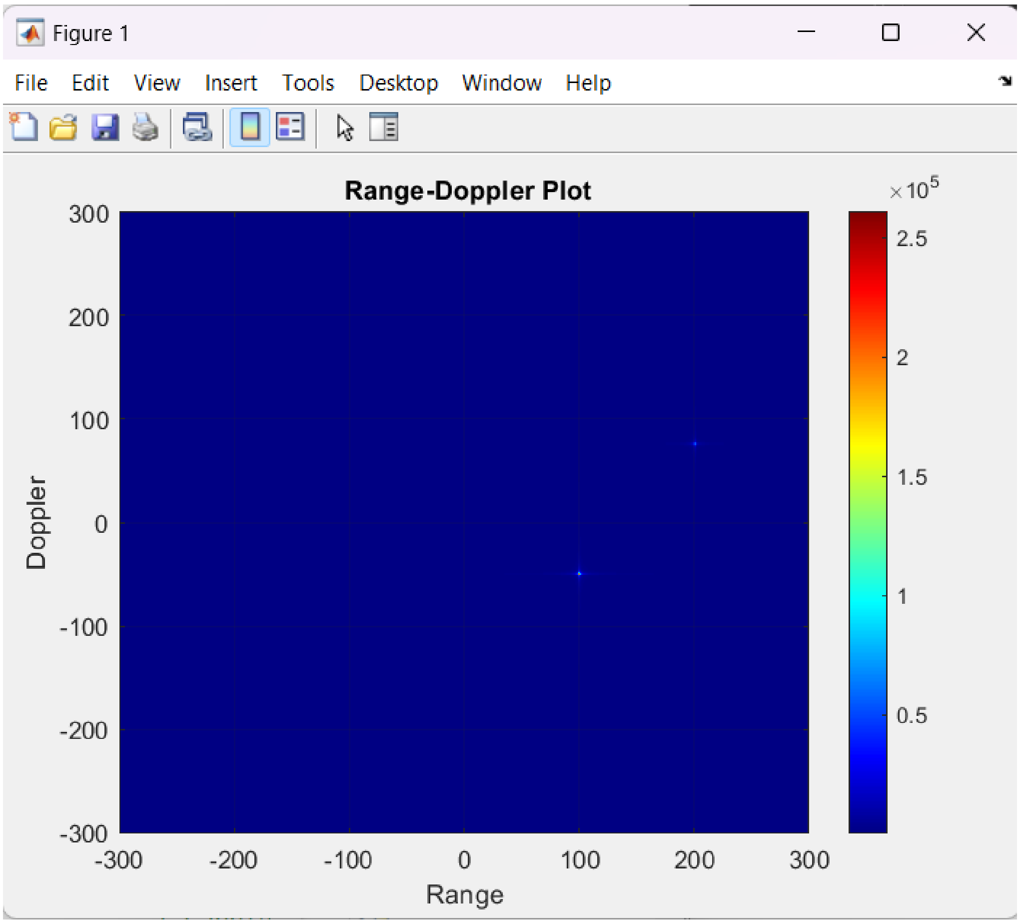


Fig. 3 Range Doppler plot

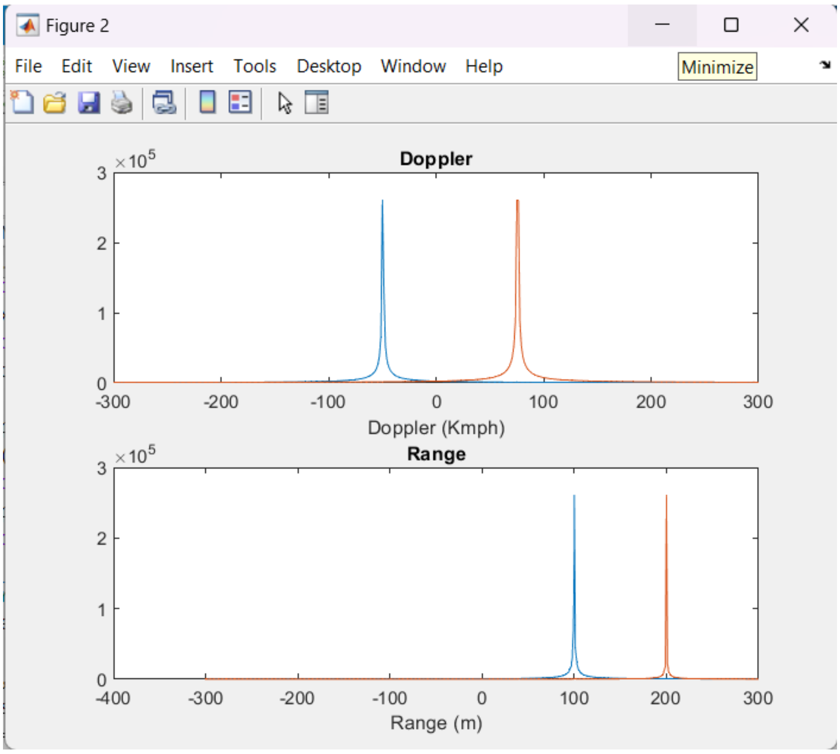


Fig. 4 Range and Doppler 1 D slices

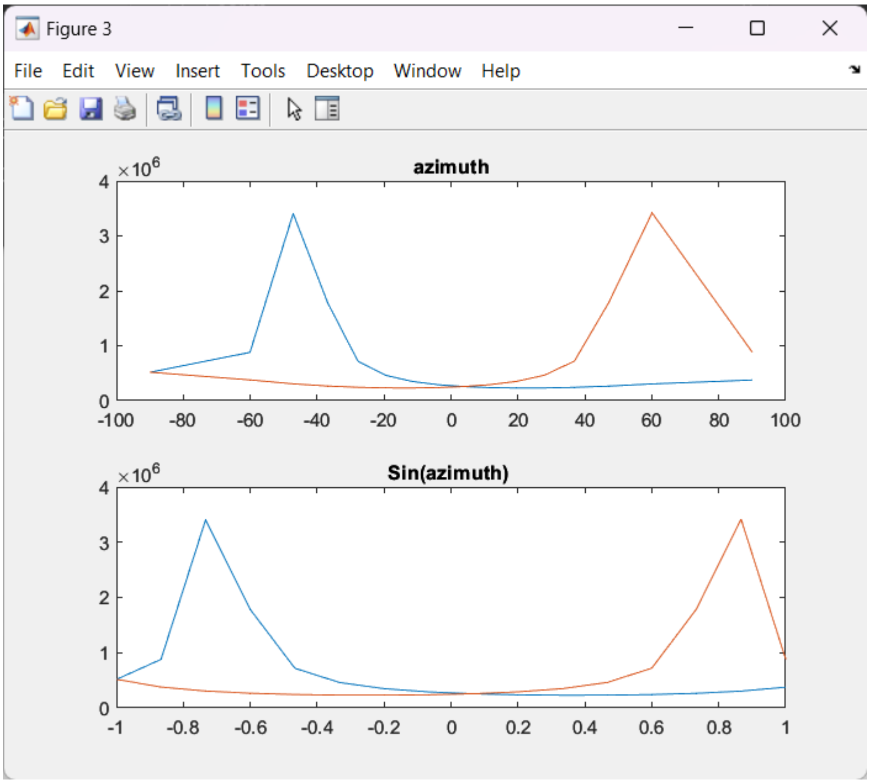


Fig. 5 Azimuth and Sine(Azimuth)

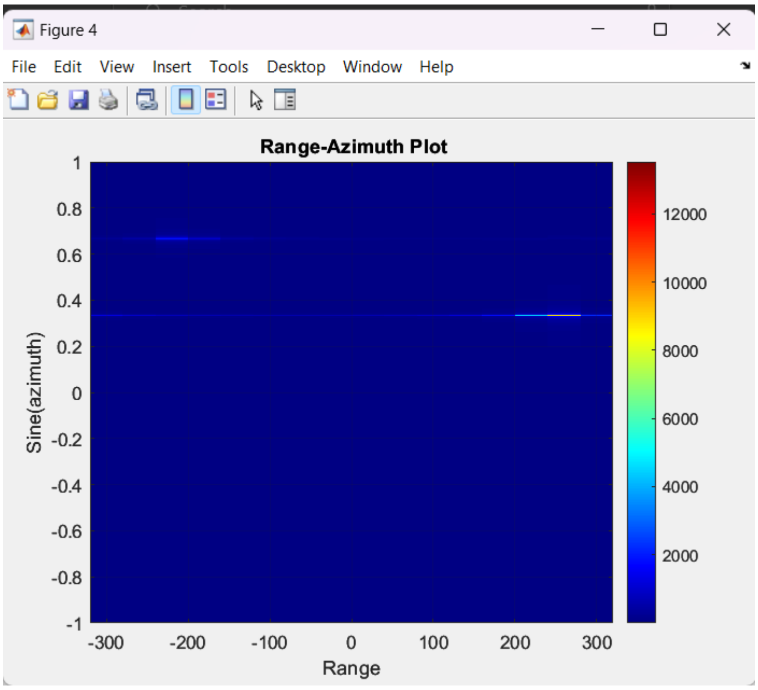


Fig. 6 Range Azimuth plot

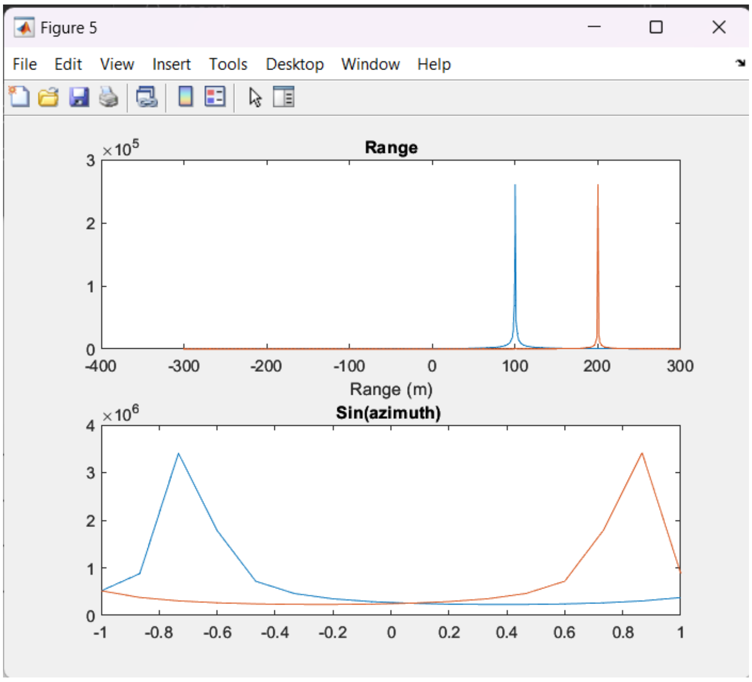


Fig. 7 Azimuth and Range Slices

5. Conclusion and Challenges Faced

The LMCW radar was implemented and simulated in MATLAB and the required plots were displayed. The radar was able to detect the range, speed and the angle of two targets by using 3D FFT and mixed beat signals. Although the range and speed of both the targets were accurately depicted on the plots, the azimuth was not up to the mark. All the necessary plots have been displayed except for the birds-eye-view.

REFERENCES

[1] M. Stephan, T. Stadelmayer, A. Santra, G. Fischer, R. Weigel, and F. Lurz, “Radar Image Reconstruction from Raw ADC Data using Parametric Variational Autoencoder with Domain Adaptation,” in *2020 25th International Conference on Pattern Recognition (ICPR)*, Jan. 2021, pp. 9529–9536. doi: 10.1109/ICPR48806.2021.9412858.

[2] P. J. Honnaiah, E. Lagunas, S. Chatzinotas, and J. Krause, “Interference-Aware Demand-Based User Scheduling in Precoded High Throughput Satellite Systems,” *IEEE Open Journal of Vehicular Technology*, vol. 3, pp. 120–137, 2022, doi: 10.1109/OJVT.2022.3161621.

[3] B.-S. Kim, Y. Jin, J. Lee, and S. Kim, “FMCW Radar Estimation Algorithm with High Resolution and Low Complexity Based on Reduced Search Area,” *Sensors*, vol. 22, no. 3, Art. no. 3, Jan. 2022, doi: 10.3390/s22031202.