The Study on FMCW Radar

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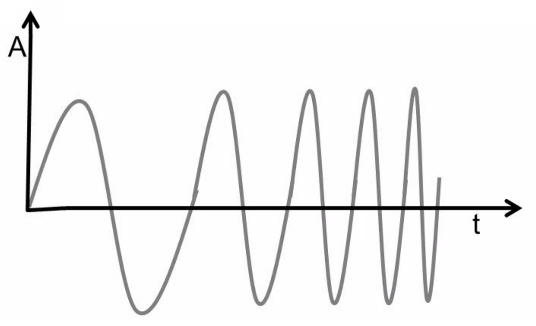
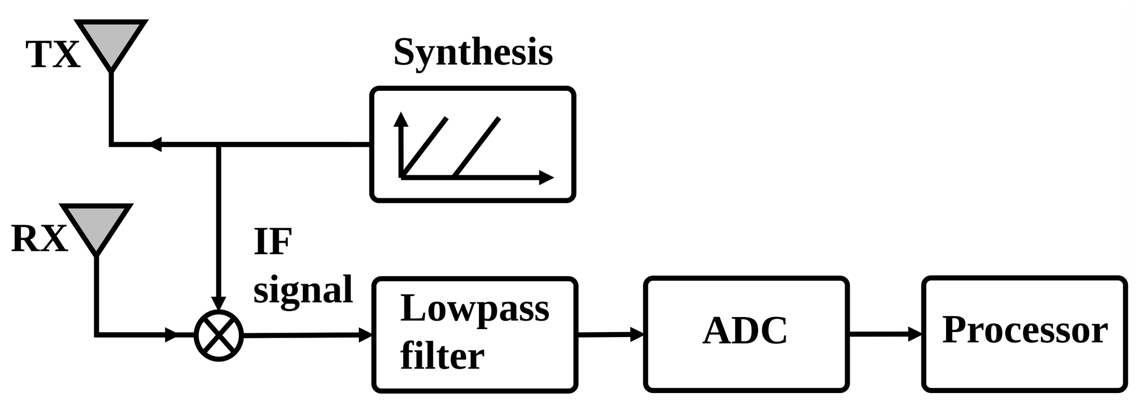
Introduction

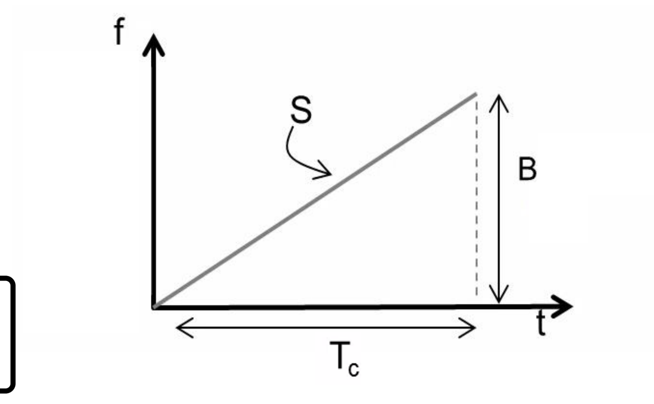
Autonomous vehicles are popular nowadays, and radars for object detection play important roles. Frequency modulation continuous waveform(FMCW) radar is one of the waveforms for radars, which is not only capable of doing object detection but also easy to be implemented on hardware. As the fifth generation communication and Internet of Things(IoT) coming, we got massive data to process. Therefore, it's important to study FMCW. In this topic, we will discuss the ways for FMCW to do parameter estimation. Also, we will use C-FAR and peak grouping algorithms for target detection.

FMCW Structure

FMCW consists of chirps, which are sinusoidal in time domain and its frequency is increasing linearly with time. In time-frequency domain, it is a oblique line with slope S.



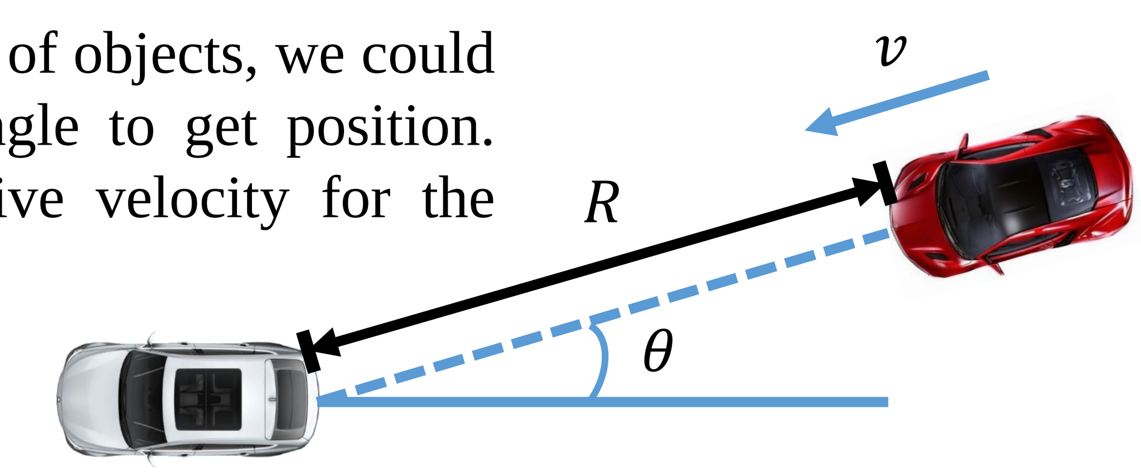




At transmitter, we transmit frames, each composed of N chirps(e.g. N=128). At receiver, mix transmitted signal and received signal to get intermediate frequency (IF) signal. Then, processor would use IF signal to get the information of objects.

Parameter Estimation

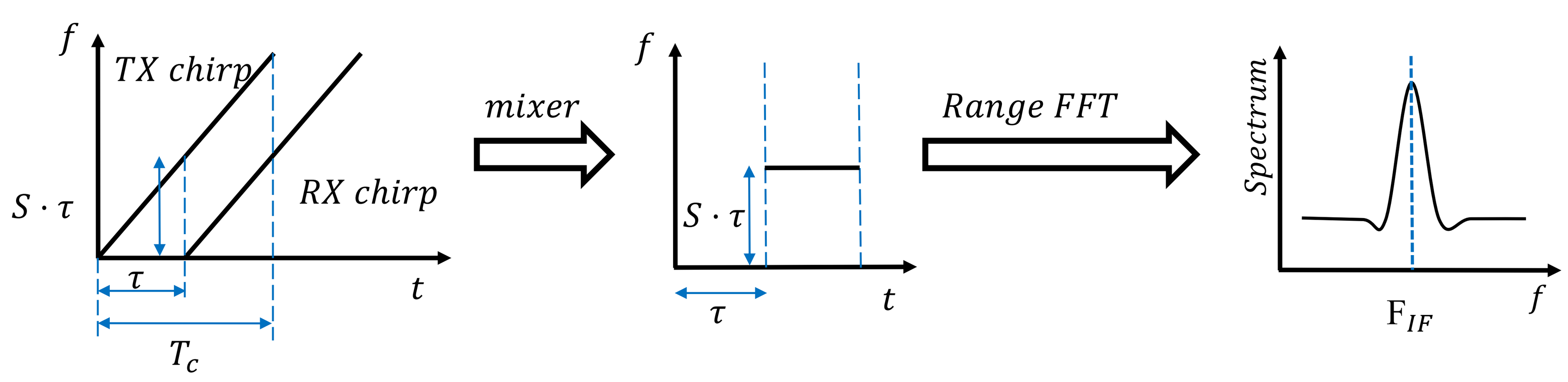
For the information of objects, we could estimate range and angle to get position. Also, estimating relative velocity for the motion of objects.



➢Range Estimation

The distance between radar and object will cause a time delay between Tx and Rx signal. We could get the two chirps' frequency difference, which is contributed by the time delay. In practical, we do range-FFT on the mixer output to extract several frequency differences. Finally, we get the range by the following equation.

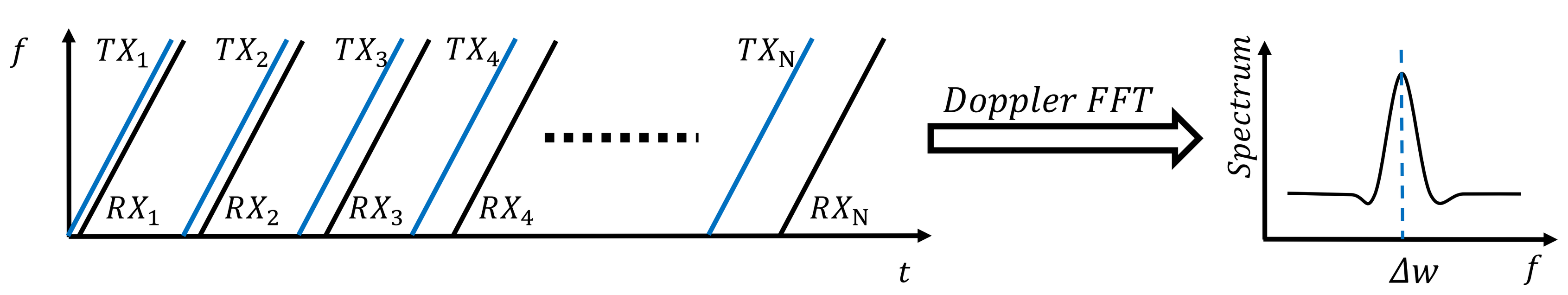
$$F_{IF} = S \cdot \tau = S\frac{2R}{c} \cdots\cdots (1)$$



➢Velocity Estimation

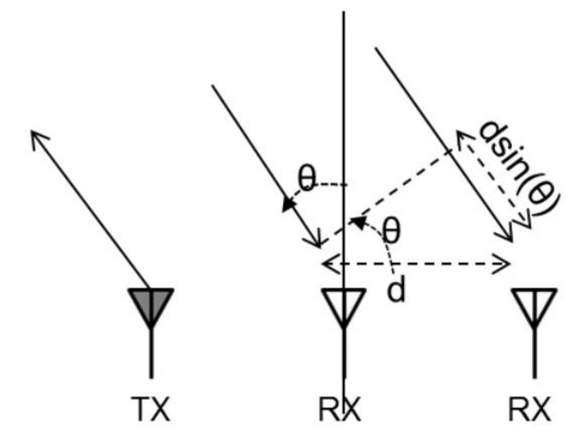
Due to the velocity of objects, The time delay between TX and RX signal is increasing or decreasing among N chirps, which causes phase difference between chirps. In practical, we do Doppler-FFT between chirps to extract phase difference. Finally, we get the velocity by the following equation.

$$v = \frac{\Delta w\, \lambda}{4\pi T_c} \cdots\cdots (2)$$



➢Angle Estimation

Due to the distance between antennas, the travel time from object to each antenna is different. The small time difference causes phase difference between RX signals at different antennas. In practical, we do DFT between RX signals to extract phase difference, which is the concept of Fourier beamforming.

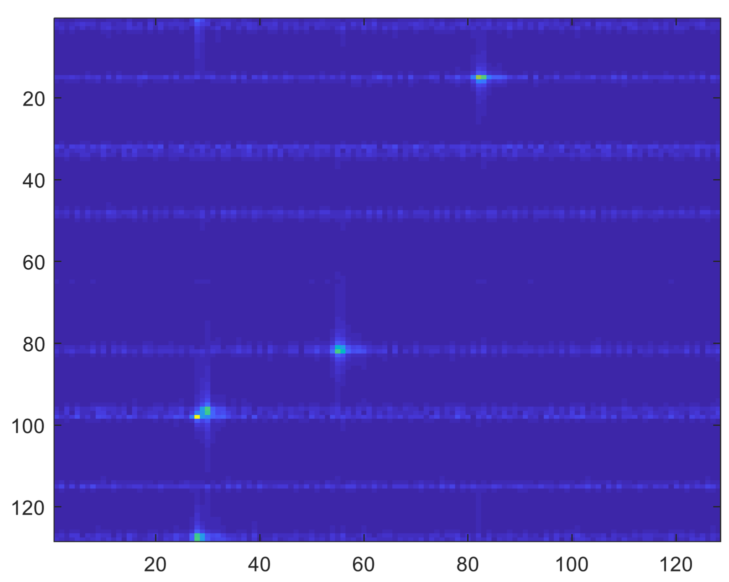


$$\theta = \sin^{-1}\left(\frac{\lambda\omega}{2\pi d}\right) \cdots\cdots (3)$$

Target Detection

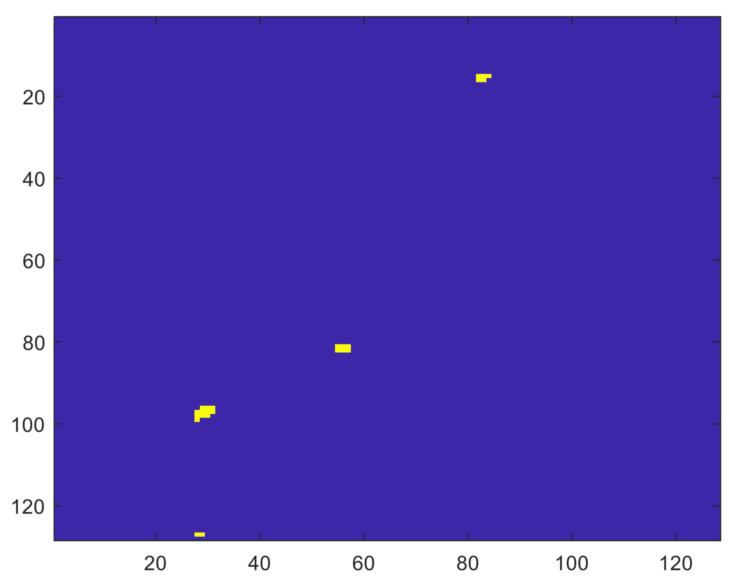
➢R-D map

It is a 2-D FFT map which is combined with range-FFT and Doppler-FFT. Y-axis is related to velocity and X-axis is related to range. Considering both range and velocity leads to better performance for parameter estimation. We can use R-D map to do target detection.



➢C-FAR

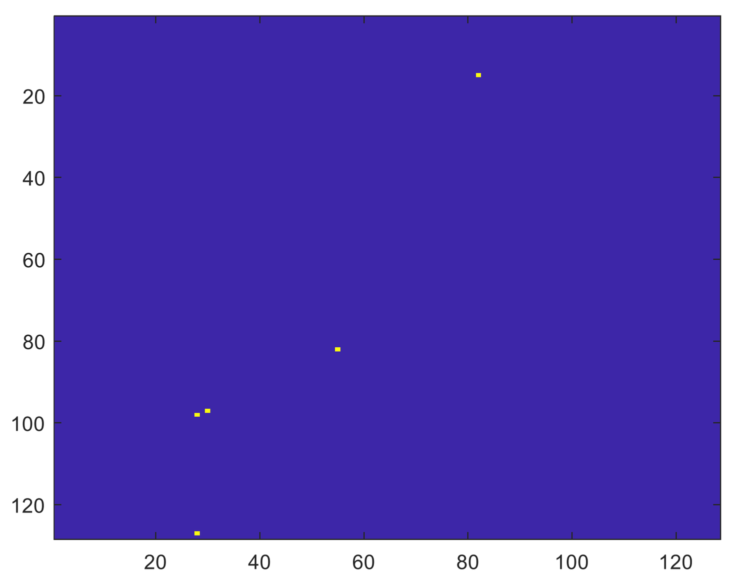
Constant false alarm rate determine the threshold of R-D map by C-FAR. The threshold of a point is related to surrounding noise level and false alarm rate. Once the value is larger than the threshold, it would be chosen as the target.



$$T = K_0 Z,\ K_0 = M\left(P_{fa}^{\frac{-1}{M}} - 1\right) \cdots\cdots (4)$$

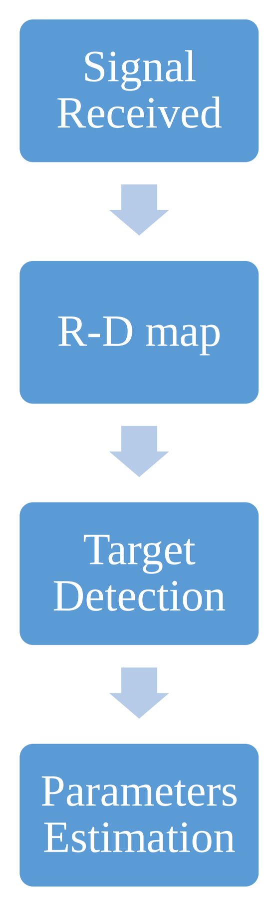
➢Peak grouping

After the process of C-FAR, there might be clusters around objects. We need to find out the peak value among a cluster and let it represent the group.



Simulation Result

We set 5 targets for the simulation. Follow the flow chart to get the estimated R, v and θ. In the result, we are able to separate close objects on R-D map and detect the target within the boundary.



	Target 1	*Target* 2	*Target* 3	*Target* 4	*Target* 5
R	20	10	30	10.5	10
$\hat{R}$	19.8529	9.9265	29.7794	10.6618	9.9265
v	5	10	−15	9.5	18.8498
$\hat{v}$	5.1398	9.9773	−15.1171	9.6749	18.7452
θ	22.5°	45°	60°	−45°	−22.5°
$\hat{\theta}$	22.5°	45°	60.75°	−45°	−22.5°