Design And Implementation Of The Signal Processor For FM-CW Based Collision Avoidance Sensor For Unmanned Ground Vehicle

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Abstract :
This paper describes the design and implementation of a generic signal processor for an anti-collision system using Linear Frequency Modulation (FM) and operating in continuous wave (CW) mode. The goal of the anti-collision system is to keep the UGV at a safe distance from any obstacle in front of it. In the signal processor, the spectrum of the received signal is analyzed using Fast Fourier Transform (FFT) with windowing and subsequent thresholding , in order to measure the range of the target. Due to very sharp range resolution of the sensor, a large RCS target generally responds to a number of range cells. Conventional CFAR schemes like Cell Averaging CFAR do not work in this case. This paper analyzes such a scenario and proposes an efficient CFAR scheme for detection of such range spread targets. This paper specifically describes the detailed signal processing scheme to design and implement such a generic collision avoidance sensor.

Keywords:- Collision Avoidance, UGV, Up chirp, Down chirp, Dwell Time, HRRP, CFAR

I Introduction

Various research works have been carried out on low cost microwave anti-collision sensors for road vehicles [2]. These systems, especially useful in bad weather conditions, would mould or turn the vehicle, preventing it from collision [3,4]. For anti-collision systems, the modulation technique used is Linear Frequency Modulation. This is because of its specific advantages offered over Non-Linear Frequency modulation[6]. Continuous wave is the choice of radar waveform in this case, because the pulsed waveform presents a limitation of the transmitter to synthesize a very narrow pulse which is required for achieving sharp range resolution [6]. In order to compute the distance between the radar and the obstacle, the received waveform is beaten with the transmitted waveform and the difference frequency (beat frequency) is extracted after mixing and low pass filtering. This is followed by Constant False Alarm Rate to fix the probability of false alarms. The paper is divided into following sections :Section I gives an Introduction to FM-CW Collision Avoidance Sensor. Section II proposes the system model and design equations for such a generic FM-CW sensor. Section III outlines two novel ideas that we propose for implementing this sensor. Section IV presents the simulation results. A detailed analysis of CFAR schemes for detection of range spread targets is presented in Section V. Section VI is the conclusion that highlights the major achievements of the paper.

II. System Model

For the FM-CW radar sensor, the transmitted signal is linearly frequency modulated as shown in fig (i). Let $\Delta\mathbf{f}$ is the radar frequency band and T_{sweep}, the sweep time period. If a reflecting object is put at a distance D, an echo signal will return after a time T = 2D/c, where c is the speed of light. Then the received echo and the transmitted signal are mixed to produce the resulting beat at the intermediate frequency f_b.

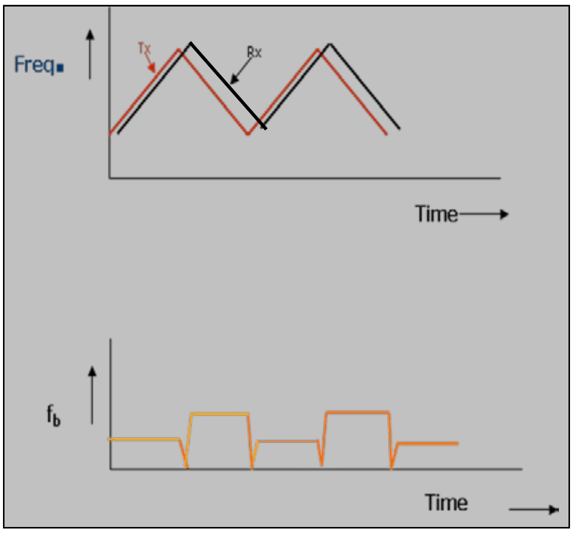

Figure 1 Beating Transmit & Received waveform of targets having a Doppler velocity.

For non-stationary targets, the transmit and receive waveforms will be as shown above. The problem of range-doppler coupling, if any, is resolved by averaging of the filter index for up chirp and down chirp.

$f_b(up) = f_r - f_d$ (1)
$f_b(down) = f_r + f_d$ (2)

The following equations have been used for fixing the system parameters :

$N \geq (f_s) * T_{sweep}$ (3)
where N is the number of samples
f_s is the sampling frequency
T_{sweep} is the sweep time or duration of one pulse

$(f_b)_{max} = f_s/2$ (4)
where $(f_b)_{max}$ is the maximum beat frequency.

$f_b = (\Delta f / T_{sweep}) * \tau$ (5)
where Δf is the sweep bandwidth
τ is the time delay between transmitting and receiving a waveform

$\tau = 2*R/c$ (6)
Corresponding to $(\tau)_{max}$, R_{max} can be determined.

$\Delta R = c/(2* \Delta f)$ (7)
where ΔR is the radar range resolution.
Since this sensor calls for a very sharp range resolution, so a wide sweep bandwidth needs to be employed.

ΔRange Filter resolution $= f_s /N$ (8)

$(\tau)_{min} = 2*R_{min}/c$ (9)

$(f_b)_{min} = (\Delta f / T_{sweep}) * (\tau)_{min}$ (10)

Dwell Time = Beam width / (6*RPM) (11)

Number of hits within 1 coherent processing interval (CPI) = Dwell Time/T_{sweep} (12)

Using these sets of equations and optimizing each parameter, one can develop a model of the signal processor.

III. Innovativeness and implementation of signal processor

Our first innovativeness lies in implementing the phenomenon of "Stretch Processing" which is essentially stretching the wave in time. The high sweep bandwidth required to obtain a very fine range resolution calls for a very high frequency sampling of A/D converter which is not practically feasible. To avoid this problem, the wave is stretched in time to obtain a larger value of T_{sweep} which is increased by an amount equal to the stretch factor. We observe that this reduces the sampling frequency f_s by the same amount [Equation (i)].

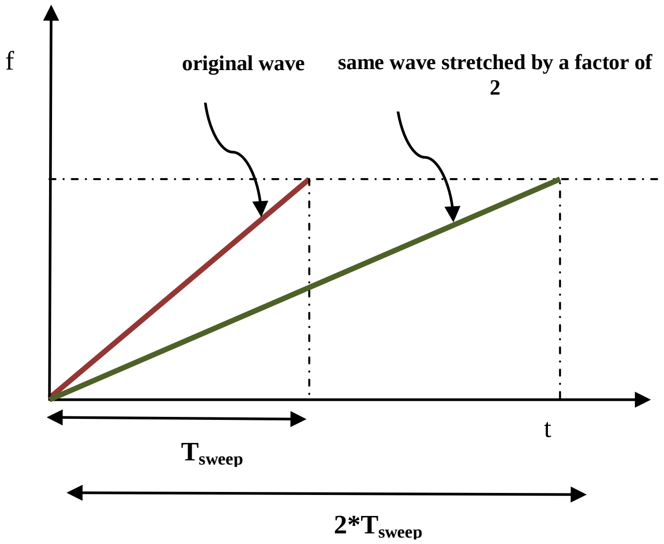

Figure 2 How the effect of Stretch Processing lowers the sampling frequency.

Our second innovativeness lies in the choice of the radar waveform. The linearly modulated FM-CW waveform can be a triangular waveform or a saw-tooth waveform. Out of the two we have chosen the triangular waveform for our design. This is because it is possible to precisely control the sweep timings in the triangular waveform. Also, to avoid Range-Doppler coupling we require to average the filter index of successive Up chirp and Down chirp waveforms. This is only possible if we deploy triangular waveform.
The signal processing flow comprises of :
The incoming analog data (beat frequency) is digitized in a high speed A/D converter. Subsequently Range FFT is performed on the incoming samples to determine the range of the target. Then Ping-Pong memory arranges this PRT wise data to Range Cell wise data. Doppler FFT performed on this Range-Cell wise data will yield the target Doppler. Then this data is passed to a constant false alarm rate receiver to maximize the
P_d keeping P_{fa} a constant. Processed detection reports are read by the NIOS II processor and sent via LAN interface to Display Unit.

IV. Simulation Results

A high frequency signal generated at W-band is chosen as the carrier. It is being linearly frequency modulated by a low frequency sinusoid. Adding a finite delay and finite Doppler to the transmit waveform results in the received waveform. The transmit and received waveforms are beated in the receiver and then band-pass filtered to obtain the beat frequency, which is a single frequency sinusoid corresponding to the range of the target.

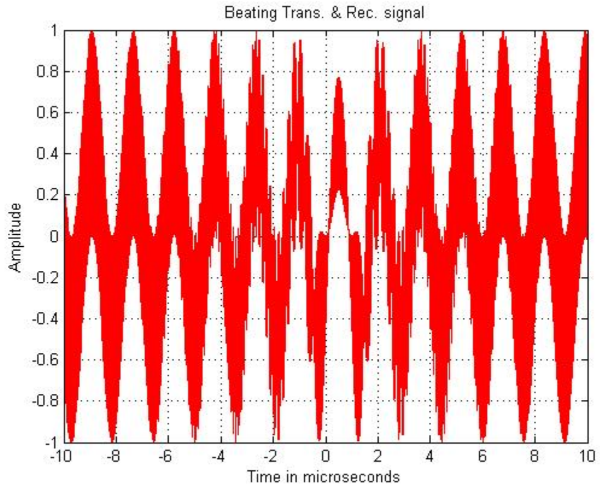

Figure 3 Output of the Mixer after beating Transmitted & Received Signals

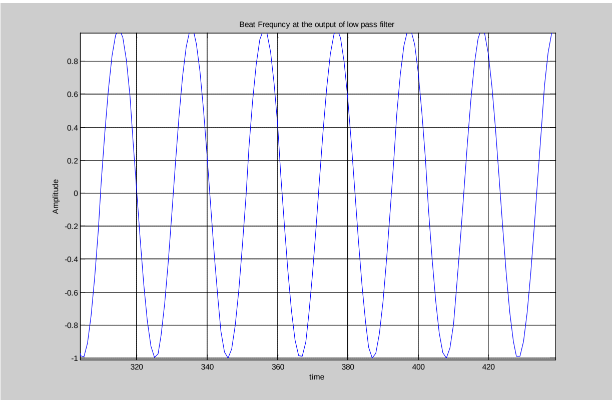

Figure 4 Beat Frequency extracted after Band Pass Filtering. For a single target this is a single frequency sinusoid.

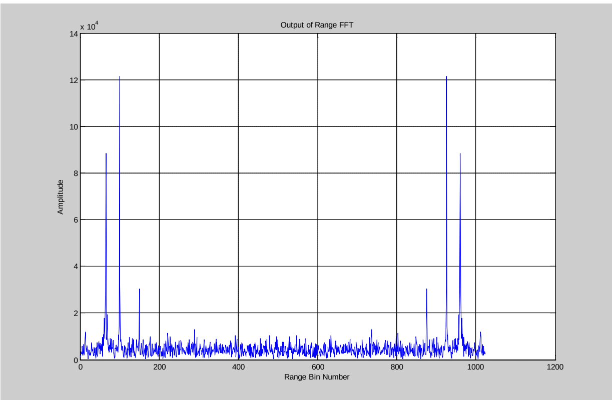

Figure 5 FFT of the extracted Beat Frequencies for 3 targets. As evident from the figure, the filter number which gives the peak response corresponds to the instantaneous range of that particular target. For real signal, the FFT spectrum is two-sided.

V. CFAR Detection of Range Spread Targets

For low RCS targets like small rocks, bush or even human beings, Cell Averaging CFAR works reliably. Since range resolution is very sharp, targets like trucks or big vehicles etc will respond in several successive range cells. In that case the target in test cell for CA-CFAR will be masked by targets in adjoining leading/ lagging windows. Therefore targets with finite range spread calls for special types of CFAR techniques. A comparative study of these techniques is presented here. Final CFAR scheme to be employed is either OS CFAR or Trimmed Mean CFAR.

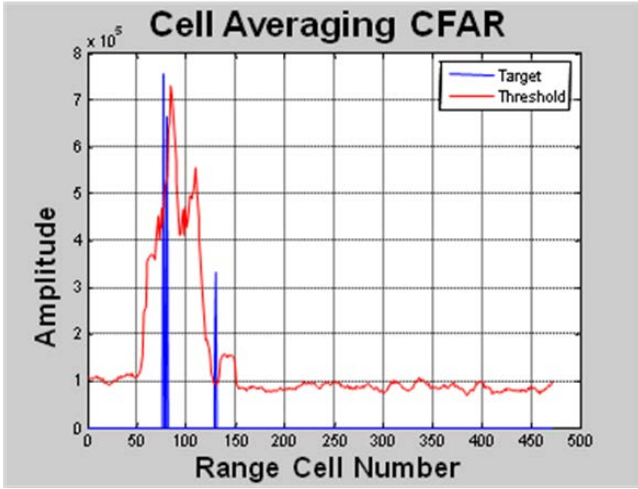

Figure 6 The above figure shows that Cell Averaging CFAR will not work for Range-Spread targets. Here in case of high HRRP's, the threshold is contributing to the target and therefore the target is getting masked.

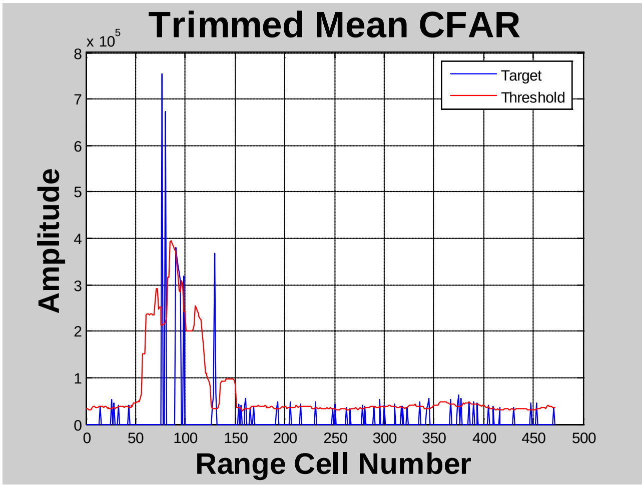

Figure 7 Response of Trimmed Mean CFAR for Range Spread Targets

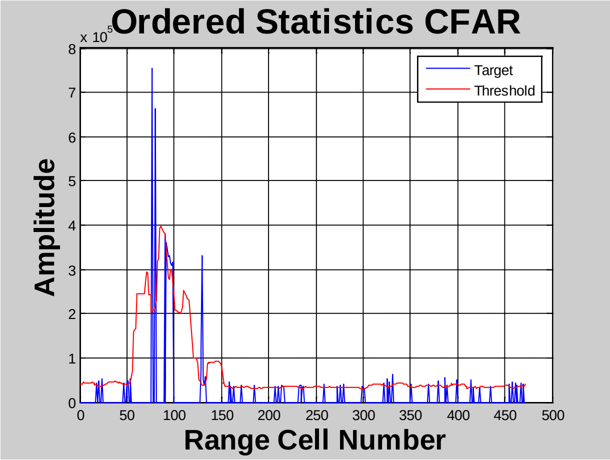

Figure 8 Response of Ordered Statistics CFAR for Range Spread Targets

A comparison of CFAR technique shows that Trimmed Mean CFAR or Ordered Statistic CFAR are the best to employ to resolve HRRP's.

CONCLUSION

In this paper, the system model and design equations to implement the signal processor for a Mill metric wave sensor were established. We further showed that how the implementation of stretch processing lowers down the sampling frequency. Analysis of the choice of sweep technique was done and concluded that linear ramping technique is better over saw-tooth ramping. Further , a comparative study of CFAR techniques to resolve HRRP targets were presented. It was concluded that Trimmed Mean CFAR and Ordered Statistic CFAR gave the best performance in such situations.

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REFERENCES

[1]. M. Labitt "Obtaining Low Side lobes using Non-Linear FM pulse compression" Lincoln Laboratory, Massachusetts Institute of Technology

[2] . Bouraima Boukari,' Emilia Moldovan,' Razvan I. Cojocaru,' "A 77-GHz six-port FMCW Collision Avoidance Radar Sensor with baseband analytical calibration" Centre Cnergie, Materiaux et TBIecommunications, institute national
de la recherché scientifique, 800 de la GauchetlQre, Montreal, QC H4N 1 K6, Canada

[3]. William David " FMCW MMW Radar for Automotive Longitudinal Control" California PATH Research Report UCB-ITS-PRR-97-19

[4]. Young K Kwag and Jung W Kang "Obstacle Awareness and collision avoidance Radar sensor for low-altitude flying smart UAV" Avionics Dept. AERC, Hanhk Aviation University, Seoul, Korea

[5].Matlab7.1 ,Mathworks corporation 2008.

[6] JanakiRaman, *Design of Multi Frequency CW Radars*

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