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Design and Evaluation of FFT Based FMCW Radar For Range Detection Under Noisy Environment

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Abstract: *There are many short-range monitoring applications, which require detecting the objects, and radars serve this purpose. There are various design parameters responsible for the efficient working of radars for range measurements. This paper proposed to design the 77 GHz FMCW radar and evaluate the performance to identify the impact of varying the design parameters like range, velocity of object, and FFT size and false alarm rate (CFAR). The velocity of object varied from 100 to 200 m/s for evaluation. This paper also presets extended survey of FMCW radar design for range measurement. The FFT based Doppler shift estimation opted for evaluating the performance of radar. This paper evaluated the radar performance under noisy environment. Paper finally concluded various parametric impacts on range detection.*

I. INTRODUCTION

In many navigation and monitoring applications, determining the range of moving targets is a must-do task. Short-range applications are the primary focus of FMCW radars [1]. Due to their inexpensive cost and ease of maintenance, these radars are very popular in the market. Because of its power capacity, this radar's range is limited. As a result, detecting the range of an object using these radars is still a work in progress.

The automobile vehicle mentoring, aircraft navigation and automotive safety [2, 3, and 4] are some of the major uses of FMCW radar for ranging. FMCW radar can function at any frequency, even at very high frequencies, where other types of radar are difficult to create. FMCW radar are extensively used at mm- and sub-mm-wave frequencies. Like in s band 2.4 GHz to 77 GHz and 94 GHz band. Corresponding to the frequency range of operation the sweep beet frequency can be tuned accordingly. Another benefit of using FMCW radar are Because the power supply needs of FMCW radar are generally low, solid-state components that are low-power, low-voltage, light-weight, durable, and stable can be employed..

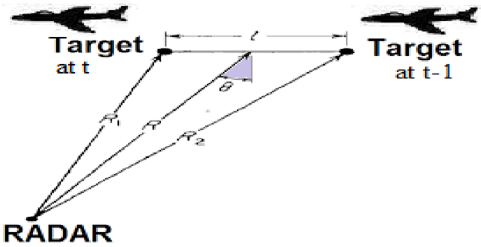
The systematic design technique for FMCW radar and range detection investigated in this work. The goal is to create a efficient radar that meets the requirements. The explanation of the radar specifications to use in this study represented in Table 1. The goal of this work is to construct 77GHz radar that can be utilised for traffic monitoring in automobiles.

Ta**ble1 Radar design specifications used for evaluation in this study**

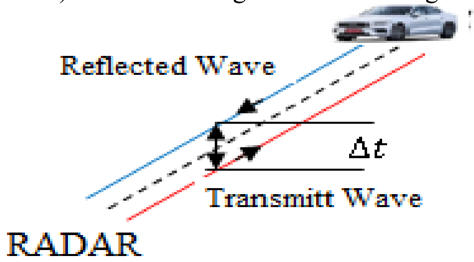
Parameter	Variable	Range
Operating frequency	f_c	77 GHz
Maximum Range	R_{Max}	200 m
Resolution of Range	R	1 m
Extreme object velocity	v_{Max}	120 m/s
Number of Chirps	c	64 – 256
Range cells	Nr	1024

The additional sweep of around 4GHz is considered for designing radars. The less size of design is major motivation behind use of 77 GHz band.

Figure 1 depicts the basic principle of radar-range determination based on the Doppler shift measurement. This graphic is shown for the moving target and two subsequent places at times t and t-1. After striking a moving target, continuous-time radar sends out a frequency-modulated signal R which is reflected back as R The Doppler shift in frequency is used to determine a velocity and range of an object' the Figure 1b) also hows the case of delay calculation.



a) For navigation and tracking



b) For range detection automotive radar

Figure 1 Radar range detection

The temporal range r_t at k[th] time interval t_k of the constant v_{tgt} moving speed object can be calculated for both transmit and directions as;

$$r_t(k) = R_{tgt} + t_k * v_{tgt} \qquad (1)$$

From the range r_t calculation, the two way shift in time or time delay Δt is determined at k[th] time interval by assuming the radio wave speed as speed of light c.

$$\Delta t(k) = r_t(k) * \frac{2}{c} \qquad (2)$$

Fast Fourier Transform (FFT) based estimation is widely being used for range measurement of moving targets [5, 6, 7 and 8]. Usually presence of targets is represented by the random peak FFT spectrums. It is required to identify the impact of the different chirp size on the range detection. The Doppler shift determination depends on the time delay between the transmitted and reflected wave from object as shown in the Figure 1b).

Challenges of Radar Designing

The major challenge of designing the FMCW radar and range measurement are;

- The CW radar's greatest range is constrained by its power. Therefore mostly the CW radar are used for short range applications.
- The parameter selection is a critical step of the radar designing. It is also dependent on the demands of sub systems.
- The amount of isolation and transmitter noise affect the receiver sensitivity, hence maximum power is determined and limited by these factors.
- CW Doppler radar is unable to determine the target range. Also in the presence of multiple targets there is a likelihood of uncertainty of measurements. Therefore the range detection is an open field of research for CW radars.
- The multi target detection is the challenging task in hand for CW radar.

II. Related Works

There are huge related literature is available for radar designing and ranging. The broad classifications of ranging and detection method are shown in the Figure 2.

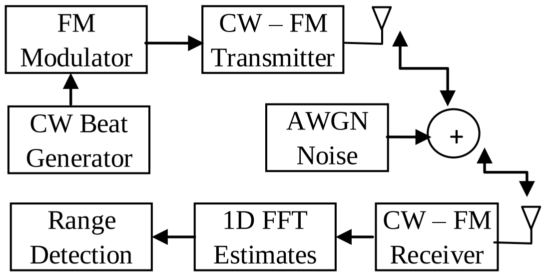


Figure 2 Generalized Classification of the Radar and Range Detection methods

Paper sequentially reviewed the related works in each of field given in Figure 2. Major focus of paper is on designing of FMCW radar and range detection methods.

2.1 Review of Short Range FMCW Radars

M. Song et al [1] proposed a 2D FFT based algorithm for range detection in radar applications in automotive use. They addressed the issue of multi target detection using FFT scheme. Two distant targets consider for algorithm demonstration. M. Tu. et al [2] have design 5.8 GHz radar using the contactless sensor for short range FMCW radar. They achieve 2 Hz Doppler shift along with 10.4 Hz beat.

Reinhard Feger et al [3] have proposed to design single chip based FMCW 77 GHz radar using the SiGe fabrication technique for transceiver design. They have design four channel prototype radar. F. Bien et al [5] have propose to implement the FMCW 77 GHz optimal cost based practical radar system design with goal of noise performance improvement. The FMCW radar transceiver practically implemented using the RT/Duroid 5880 based substrate. Nor Fati et al [6] have designed and evaluated the performance of 2.4 GHz FMCW radar. They have designed a short range FMCW radar and achieved min velocity of 0.77 m/s. But there maximum range is limited to 17 m only. Alexey etal [7] have designed the radar for the urban uses at the frequency of the 77 GHz. W. S. Kouzeiha et al [8] have evaluated the range and velocity for double staircase based FMCW radar. They have demonstrated to improve the intermediate frequency (IF) of the triangular wave. The 60 GHZ radar and C- Band FMCW radars are respectively designed in [9 and 10]. Two independent multi target detection radar methodologies are presented in the [11, and 12]. Shrikant Kumar and Paresh Rawat have reviewed the work based on simulation of the pseudo random based binary sequence (PRBS) Correlation radar in VHDL. Multi target detection methodologies are presented by the authors in [14, and 15] respectively. There are various multi carrier based methodologies for FMCW based radar design are presented in the [16, 17, and 18]. Rohling, H. Et al [19] have designed the good methodology to demonstrate the application of the FMCW based automotive radar design. Overall, there is still a open challenge to design the method for multi target detection approach. And this is the scope of this paper.

III. FMCW Radar Modelling

For the FMCW signal generation, a high frequency-ramp train based technique uses to generate a linear ramp. The broadcast FM signal is periodic and consists of many sweeps, depending on the ramp duration. The proposed block diagram of the FMCW radar based object range identification presented in the Figure 3.

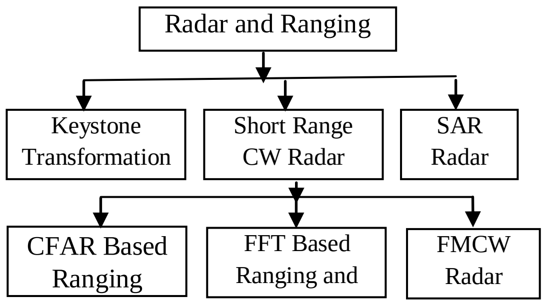


Figure 3 Proposed FMCW radar and Range detection

The Frequency modulated waveform with generalized phase change equation is written as.

$$FM(t) = Cos(2\pi(f + df)t) \quad (3)$$

The frequency is changed for producing the FM signals. Paper focus to design the 77 GHz (carrier frequency f_c) and for the given range resolution R_r the beat sweep frequency B_S defined as

$$B_S = c/2 * R_r \quad (4)$$

The Chirp sampling time is defined corresponding the scaling factor of F=5.5.

$$T_C = F * 2 * R_{max}/c \quad (5)$$

And slope of Chirp is Sl= B_S/T_C. The transmitted FM signal is produced using the equations;

$$Tx_{FM}(t) = cos(2 * pi * (fc * t) + 0.5 * Sl * t^2)) \quad (6)$$

The reflected Continuous wave is calculated using the delayed time as;

$$Rx_{FM}(t) = cos(2 * pi * (fc * (t - \Delta t) + 0.5 * Sl * (t - \Delta t)^2)) \quad (7)$$

An example of transmitted and received FMCW signals, as used for range detection shown in the Figure 4. The time delay can be observed in the Figure for both waves.

The double sided FFT spectrum is cut down to single sided FFT for the range measurement. Since FFT of range can't be negative. The amplitude of the FFT response is normalized for the sake of ease.

$$F(\omega) = \frac{abs|F(\omega)|}{max(F(\omega))} \quad (8)$$

The normalized FFT response is plotted against range with range with resolution of Rr= 1.m

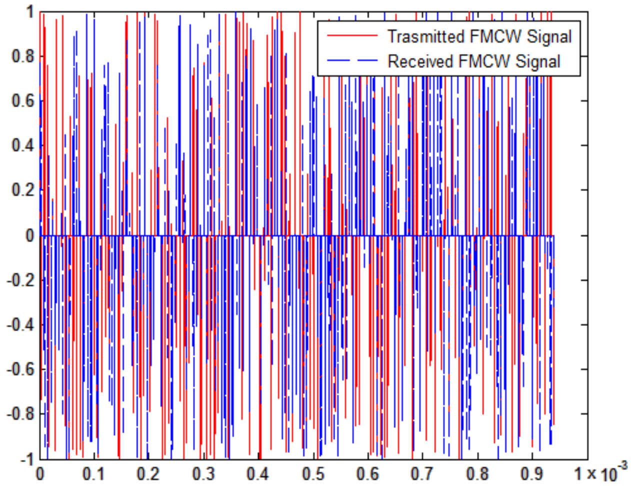


Figure 4 Example of the transmitted and received FMCW signal used for range detection

IV. Range detection

The paper uses the FFT based range detection approach using Doppler estimation. The transmitted signal Tx_{FM} and received signal Rx_{FM} are mix together as $R_{mix} = Tx_{FM} * Rx_{FM}$ and reshape to 1D vector for calculating the FFT

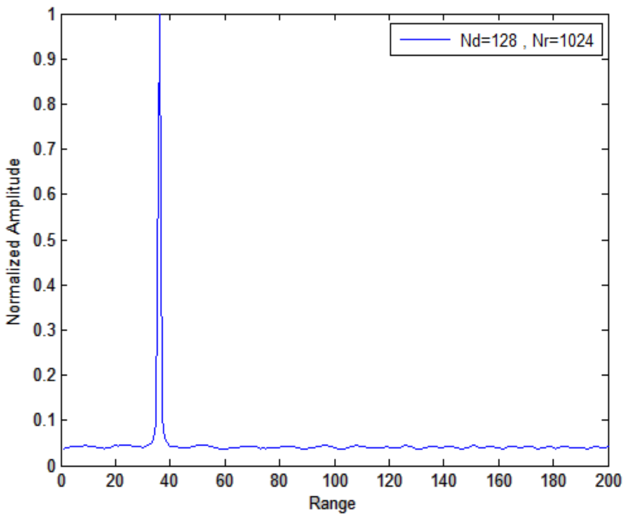


Figure 5 Range detection validation for single object without noise for R=35 m

$$F(\omega) = \frac{1}{T}\int_{-\infty}^{\infty} R_{mix} \qquad (9)$$

4.1 Implementing FFT

Usually for the detection of the range, using the radar the 1D FFT is calculated and just only one directional positive spectrum is utilized to determine the object peak of the spectrum. Range detection without noise for R=35 m target is shown in the Figure 5. The range of the object can be monitor for the FFT peaks as at 35 m range from radar in this case.

V. Proposed Multi Target Detection

In this paper proposed an implementation of a multi target, based range detection method. The multi target detection requires the estimation of the beet frequencies and is a challenging problem in had since targets may move with different speeds. Therefore, paper evaluated the performance of the range detection of different velocity targets in the range. The beat frequency estimation is presented according to the range and velocity.

Paper considered the additive white Gaussian Noise (AWGN) model represented by the A_N, The noise addition module is consider for the double flight of the radio signal between radar and target. The mathematical representation of the received signal under the noisy environment can be represented as;

$$A_N = rand\ (1, length(Tx)) \qquad (10)$$

$$Rx_N(t) = Rx_{FM}(t) + A_N \qquad (11)$$

Where, $Rx_N(t)$, represents the additive noisy received FM signal

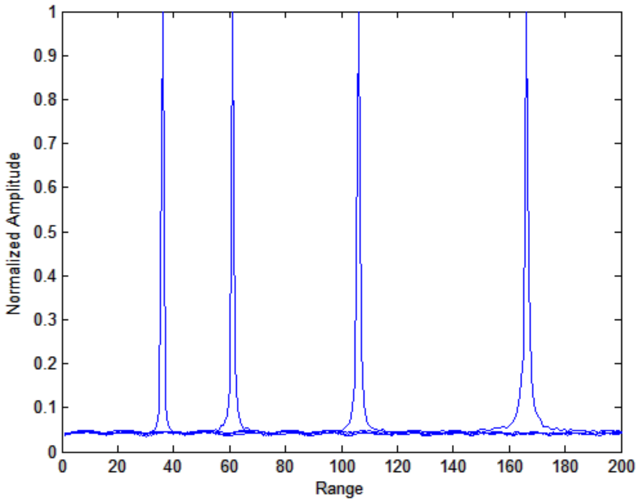


Figure 6 Multi target range detection using FMCW radar under worst AWGN Noise

The paper proposed to design the range adoptive beet frequency sweeping estimation algorithm. The sweep frequency is estimated as

1. Set the B_S as seep frequency;
2. Set the chrip time T_c
3. Very the range of target with range resolution steps and calculate the beet frequency

$$f_b = \frac{R_{target} * 2 * Bs}{c * Ts}; \qquad (12)$$

1. Plot the various beet frequency signals corresponding to range resolutions.

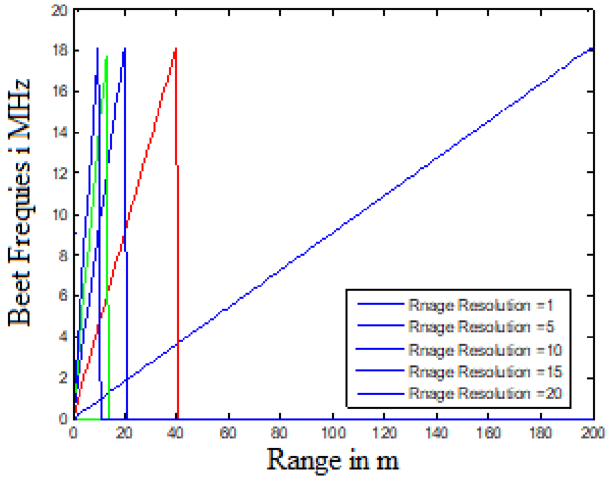


Figure 7 Estimation of the feet frequencies for different range resolutions.

Beet frequency estimation is results are shown in the Figure 7. The five-different range resolutions are considered for the estimation in this paper the resolution is increased by increment of the 5 and maximum resolution of 20 is considered in this paper. It can be observe from the multi carrier proposed system of the sweep beet frequencies that reducing the range resolution may eventually required to reduce the frequency of the beet for CW radars.

VI. CFAR estimation

For solving the false alarm problem, the constant false alarm rate (CFAR), can be used as parameter. Method of CFAR adjusts the identificationit s threshold based on the vehicle's proximity. The CFAR method determines the quantity of interference on one or even both sides of such "Cell under the Test" in the range of radar and Doppler cells, referred to as "Training Cells." The estimation is then used to determine whether the object would be in the Cells under Testing (CUT).

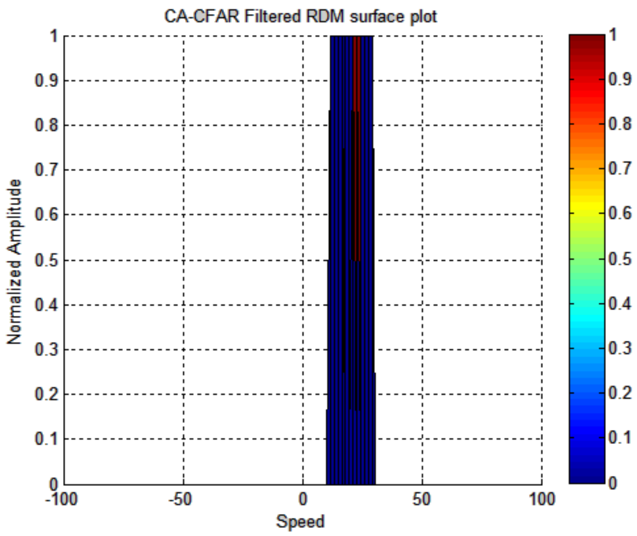


Figure 8 Calculated CFAR for range measurement

The procedure loops through all of the range Doppler cells, determining whether the target is there based on the estimation of noise. The technique is based on the assumption that when noise is present, the cells surrounding the cell of interest will have a decent estimate of the noise, i.e. that the interference or noise is geographically or temporal homogeneous. This should theoretically produce a consistent false alarm rate that is independent of the magnitude of noise or interference.

VII. Conclusions and Future Work

Paper presets the evaluation and the systematic methodology for designing the FMCW radar and range detection. The range resolution and target locations along with velocity of multiple targets are consider for the performance evaluation. Paper initially presets the systematic design steps for the proposed 2D FFT based range estimation. The various related works are review briefly. There is still a open challenge to design the method for multi target detection approach

Beat frequency estimation algorithm is proposed for multiple moving targets. The AWGN noise model is consider for the evaluation in the paper. It is concluded that there is very less effect of the noisy environment on range detection in FFT domain.

A beet frequency estimation based multi-carries are proposed to vary continuously for detecting the multiple moving targets. Proposed method successfully detects the multiple moving targets. CFAR performance calculated for performance evaluation and velocity estimation.

It can be observe from the multi carrier proposed system of the sweep beet frequencies that reducing the range resolution may eventually required to reduce the frequency of the beet for CW radars

In future the multi carrier beet sweep system is used for multiple target CFAR estimation and evaluation for FMCW radar for long ranges. In addition power enhancement methodology can be evaluated ageist the range and the velocity estimate too.

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