Single Channel MMWave FMCW Radar for 2D Target Localization
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Abstract—In this paper, we present a 2D target localization method using two low-cost and compact Millimeter Wave Frequency Modulated Continuous Wave (MMW-FMCW) radars. To create a 2D map we exploit the bilateration method followed by a multi-target tracking block to remove the ghost targets. Finally, we present experimental results based on the data gathered from two FMCW radars operating at 79 GHz.

Index Terms—MMW-FMCW Radar, target localization, bilateration

I. INTRODUCTION

Millimeter Wave Frequency Modulated Continuous Wave (MMW-FMCW) radars have become very popular recently. They are low cost and compact sensors with low peak to power ratio. One single channel FMCW radar is capable of measuring the radial distance as well as the velocity of the targets located in the field of view of the radar. In order to measure the Angle Of Arrival (AOA), MMW-FMCW radars have been combined together to create sparse arrays in Multiple Input Multiple Output (MIMO) configurations which will make the AOA estimation possible [1]–[6].

However, MIMO radars have their own shortcomings. To obtain a satisfactory angular resolution limit, the number of elements should be high which in turn makes the system more complex. Issues such as heat sink, power consumption, antenna coupling, synchronization and calibration have to be considered when we increase the number of elements.

In this paper, we use two single channel MMW-FMCW radars that operate independently to localize the energy of the targets in 2D plane. We exploit the bilateration method to find the x-y position of the targets. In order to create two orthogonal signals in space the radars will operate in Time Division Multiplexing (TDM) configuration. Each MMW-FMCW radar is a small and compact single channel sensor with on-chip antennas.

The organization of the paper is as follows. In Section II, we present the system model and the entire signal processing and data processing blocks that are necessary for target localization based on the bilateration method. In Section III, we use experimental data gathered from two single channel MMW-FMCW radars operating at 79 GHz and show the result of the 2D target localization based on the algorithm which we develop in the paper and discuss the results.

II. MODEL DESCRIPTION

To localize the targets based on bilateration method, we use two single channel FMCW radars. Each single channel radar provides the range profile of the targets located in its field of view. In fact, the output of the radar at the Analog to Digital Convertor (ADC) level is the beat signal. After taking Fourier transform from the beat signal we will obtain the range profile of the targets.

We will then apply the Constant False Alarm Rate (CFAR) adaptive threshold [7] to the signal in order to detect the location of the targets. The CFAR block will extract the energy of the existing targets from the additive noise. Since the CFAR block outputs multiple points per each target, therefore, we exploit pruning technique to select the point with highest intensity per each target. Following the CFAR implementation we will then obtain the radial distance of each target with respect to both radars. Based on Fig. [1] for a point target located at $R_1$ and $R_2$ radial distance from radars number 1 and number 2, respectively, the x-y coordinate of the target based on the bilateration technique is calculated as

$$x_t = \frac{R_2^2 - R_1^2 + d^2}{2d},$$

$$y_t = \sqrt{R_1^2 - x_t^2}.$$  

In [1], the radar number 1 has been chosen as the origin of the coordinate system to simplify the equations.

In practice, however, we are dealing with multiple targets. In the case of multi-target scenario, we tune the element spacing $d$ with respect to the range resolution limit of the radar to avoid

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ghost targets. We further implement a multi-target tracking block [8], [9] to help with removing the ghost targets and to provide smooth tracks for the targets.

Since both the measurement and the motion model are linear, therefore, we use Kalman filter for tacking [7]–[9]. Moreover, we choose constant velocity model for the target motion. Also, we use Global Nearest Neighbor (GNN) method [8], [9] for the data association block. In Fig. 2, we have presented the flowchart of the algorithm which includes both the signal processing and the data processing blocks that are necessary for the 2D localization of the targets.

III. EXPERIMENTAL RESULTS

In this section, we present our experimental results. The single channel MMW-FMCW radar is from MediaTek company and has been shown in Fig. 3. We have chosen the same parameters for both radars. The center frequency of the radar is 79 GHz and the bandwidth has been set to 3.49 GHz which results in \( \delta_R = 4.3 \) cm resolution in the range direction. The chirp time is 68.8 \( \mu s \). We have set the maximum range of the radar to 5.5 m. We receive 128 samples per each chirp which means \( N = 128 \).

Fig. 4 shows the test setup based on two MMW-FMCW radars. We have used two 20 dbsm corner reflectors as targets. The space between the two radars has been set to 20 cm. The value that is chosen for the element spacing plays an important role in dealing with ghost targets when bilateration method is used for target localization. We have also tuned the rate of birth and death of the targets in the multi-target tracking block to remove the ghost targets and to create a smooth track for each existing target. Fig. 5 illustrates the result of the experiment performed based on the test setup shown in Fig. 4.

Fig. 5-(a) and Fig. 5-(b) depict the range profile and the output of the CFAR block, including the pruning process, for both the number 1 and the number 2 radars, respectively. The output of the CFAR has been shown as red dots in Fig. 5-(a) and red crosses in Fig. 5-(b). We have implemented the cell averaging CFAR for both radars. The reflections very close to the radar are not from real targets and we have not sent them to the bilateration block. After detecting the targets by both sensors, the output will then be sent to the bilateration block to calculate the x-y coordinates of the targets. The next step is to send the information about the x-y coordinates of the targets to the multi-target tracking unit. The final result has been shown in Fig. 5-(c) which illustrates the x-y coordinates of the two corner reflectors.
For the multi-target tracking block we have used constant velocity model. Moreover, since both the measurement model and the dynamic model for the targets are linear with additive Gaussian noise, thus we have used Kalman filter. For the data association unit, global nearest neighbor method has been chosen. We have removed the ghost targets that appear in bilateration method by tuning the distance between the two radars relative to the range resolution as well as by tuning the rate of birth and death in the multi-target tracking block.

We have conducted another experiment using the same 20 dBsm corner reflectors and have illustrated the result in Fig. 6. The test setup has been depicted in Fig. 6(a) and the output of the system has been presented in polar coordinate system in Fig. 6(b).

IV. CONCLUSION

In this paper, we presented a 2D target localization method based on the bilateration technique using two low cost and compact MMW-FMCW radars operating at 79 GHz.