Accuracy Enhanced RPM Method Using Doppler Based Range Points Clustering for 140GHz Band UWB Radar

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***Abstract* - 140 GHz ultra-wideband millimeter wave radars significantly expand the capacities of three-dimensional (3-D) imaging sensors, making them suitable for short-range surveillance or security purposes. For such applications, we have already developed the range points migration (RPM) method, which achieves highly accurate 3-D boundary extraction. However, to deal with multiple targets with many reflection points, such as a human body, this method suffers from an inaccuracy and an expensive computational cost. As a solution for such difficulty, this paper introduces a Doppler based range points clustering into the RPM method. Results from numerical simulations assuming 140 GHz millimeter radars show that the proposed method achieves more accurate 3-D image associated with Doppler velocity, without sacrificing computational efficiency.**

***Index Terms* — Range points migration(RPM), Multi-static UWB Doppler Radar, Short range sensing**

1. Introduction

The short range millimeter wave radar system has significant advantages; higher spatial resolution or applicability to optically harsh environments, suffering from dark smog, fog or strong back light. This feature promises various sensing applications, such as collision-avoidance sensor for automobile or, watch sensors for elderly or disabled persons living alone with alleviating a privacy issue. Recently, the 140 GHz band radar system has come under a spotlight because this frequency range achieves lower absorption for moisture vapor, which enables detecting a target from an automobile, even in a high-moisture scenery. Moreover, the transmitting and receiving modules can be considerably downsized, making the actual implementation more flexible. There are various studies for 3-D imaging algorithm focusing on short-range sensing, most of which are based on the delay-and-sum (DAS) approach, such as beamforming or Kirchhoff migration [1]. However, they require an expensive computational cost to get a full 3-D voxel image, and also suffer from an accuracy limitation for object with a continuous boundary due to pointwise target assumption. As promising method for solving the above issue, the range points migration (RPM) method has been developed [2], which achieves a batch conversion from range points abbreviated as RP (a set of antenna location and observed range) to scattering center points with one-to-one correspondence. As notable feature of this method, it resolves an inherent paring problem between range and direction of arrival (DOA) using the Gaussian kernel based statistical approach, achieves both lower computational cost and higher accuracy for locating scattering center on continuous boundary, even in richly interfered case.

According to this background, the RPM method has been extended to 140-GHz UWB radar application successfully using multistatic configuration [3]. However, in the case that a sensor receives many reflection echoes, assuming multiple or complicated shaped objects, this method suffers from a large computation time and inaccuracy, because the RPM assesses a focusing degree using all surrounding RPs (called as SubRPs) in conversion from a targeted RP (called as Main RP) to each scattering point, where SubRPs might include unnecessary one. For more time-efficient and accurate imaging, this paper introduces a Doppler velocity based RP clustering algorithm, which would enhance an imaging accuracy by selecting an appropriate set of SubRPs. As an another important feature, this method associates a Doppler velocity with each scattering center, which would greatly help to human body recognition. Results obtained from the GO (geometrical optics) based numerical simulations show that the proposed method considerably enhances both computational cost and accuracy for 3-D imaging, associating Doppler velocity information.

2. System Model

Figure 1 shows the system model. It assumes that each target has an arbitrary 3D shape with a clear boundary, has a different velocity. Antennas are arranged in an array on the $y = 0$ plane to form a multi-static radar configuration. The locations of the transmitting and receiving antennas are defined as $\boldsymbol{L}_T = (X_T, 0, Z_T)$ and $\boldsymbol{L}_R = (X_R, 0, Z_R)$, respectively. For each combination of $\boldsymbol{L}_T$ and $\boldsymbol{L}_R$, the output of the Wiener filter is denoted as $s(\boldsymbol{L}_T, \boldsymbol{L}_R, R', \tau)$. Here $R' = ct/2$ is defined using a fast time t and the radio wave speed c. τ denotes a slow time, sampled by the pulse repetition interval. $S(\boldsymbol{L}_T, \boldsymbol{L}_R, R', V_D')$ denotes the 1-dimensional Fourier transform of $s(\boldsymbol{L}_T, \boldsymbol{L}_R, R', \tau)$ as to τ , so called range-Doppler signals. $\boldsymbol{q} \equiv (\boldsymbol{L}_T, \boldsymbol{L}_R, R, V_D)$ is defined as the range point, which is extracted from the local maxima of $S(\boldsymbol{L}_T, \boldsymbol{L}_R, R', V_D')$ regarding to R' and V_D'.

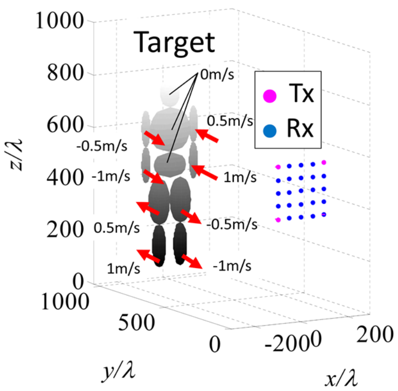

Fig. 1. System model.

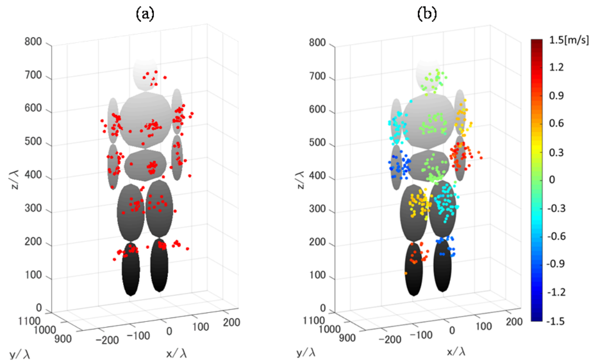

Fig. 2. Scattering center points obtained by the original RPM (a) and the proposed method (b).

3. Proposed Method

It has been already demonstrated that the original RPM suffers from inaccuracy and higher computational costs in the case of multiple objects case, where many reflection echoes are received at each antenna. This is because it calculates an evaluation function for DOA estimation at each range point (Main RP) using all surrounding SubRPs (see detail in [2]), the number of which increases according to that of target portions. Thus, an appropriate clustering of SubRPs for each MainRP becomes one solution for such problem. As one scheme for the RP clustering this paper introduces a Doppler based range points clustering as a preprocessing of the RPM method. In particular, this method introduces the following criteria for $\boldsymbol{q}_i$ (denoted as Main RP) and $\boldsymbol{q}_j$ (denoted as SubRPs);

$$\epsilon(\boldsymbol{q}_i, \boldsymbol{q}_j) \equiv |V_{\mathrm{D},i} - V_{\mathrm{D}.j}|. \quad (1)$$

The group of SubRPs, which satisfies $\epsilon(\boldsymbol{q}_i, \boldsymbol{q}_j) \leq \epsilon_{th}$ is used in conversion from MainRP $\boldsymbol{q}_i$ to its corresponding scattering center through the RPM process detailed in [2].

4. Evaluation in Numerical Simulation

This section investigates the performance evaluation of the original RPM and the proposed method through numerical simulation. The transmitting signal forms a pulse modulated signal, whose center frequency is 140 GHz and 10 dB bandwidth is 10 GHz. Pulse repetition interval is 37.5 μsec, and the number of pulse hits is 56. The center wavelength λ is 2.1 mm, that is, the Doppler velocity resolution is 0.5 m/s and the maximum unambiguous range is 20 m. It assumes that the target is a human body approximated as an aggregation of 11 ellipsoids as shown in Fig. 1. The numbers of transmitting and receiving antennas are 4 and 25, respectively, where the minimum array spacing is 50 λ (see Fig. 1). The received data are generated by geometrical optics (GO) approximation. The left and right hand sides of Fig. 2 show the reconstructed images by the original RPM and the proposed methods, respectively. This figure demonstrates the proposed method considerably increases an accurately located scattering centers associated with Doppler velocity, compared with that obtained by the original RPM. This is because multiple range points within same range resolution can be discriminated by Doppler velocity difference, that is an another advantage of this method. For quantitative analysis, the reconstruction error e is introduced as the minimum distance between an actual target boundary and reconstructed point. It is then confirmed that the numbers of reconstructed points satisfying $e < 10\lambda$ (=21mm) are 116 (41 % from total points) for the original RPM, and 441(70% from total points) for the proposed method, respectively. The calculation time is 550 sec for the original RPM, and 160 sec for the proposed method, using Xeon 3.10 GHz processor.

5. Conclusion

This paper proposed the Doppler velocity based range points clustering algorithm to achieve accurate and high-speed 3-D imaging through the RPM method. The proposed method remarkable enhances the number of accurately reconstructed points associated with Doppler velocity with less computational time. The experimental validation of this method should be investigated in our future work.

Acknowledgment

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