Technique of Tracking Multiple Pedestrians Using Monostatic Ultra-wideband Doppler Radar with Adaptive Doppler Spectrum Estimation

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***Abstract*—Techniques of tracking multiple human targets using ultra-wideband radar are important for security applications. Tracking techniques that use the texture information of the received signal have been proposed. However, these methods require off-line processing or are limited in terms of the number of targets that can exist in the same range bin at one time. In this study, we propose a technique that does not have this limitation. First, we estimate the Doppler spectrum employing the Capon method, which is used in adaptive signal processing. We determine the target velocities by detecting peaks in the estimated Doppler spectrogram. We next track targets in the range–velocity plane using density-based spatial clustering because the targets should have different velocities or exist in different range bins. Finally, we track targets using the estimated clusters. In an experiment, the proposed method was used to successfully track three targets intersecting in almost the same range bin at the same time.**

***Index Terms*—Ultra-wideband radar, Doppler radar, pedestrians, walking motion**

1. Introduction

Ultra-wideband (UWB) radar has high range resolution and is a promising technique for security applications; e.g., surveillance systems. Compared with a system using optical cameras, UWB radar is effective in the case of poor vision [1]–[4]. Meanwhile, a surveillance system must be able to track multiple targets.

Recently, a separation and tracking method that calculates target velocities at each pixel using texture information in a range–slow time image of the received echo has been proposed [3], [4]. However, the method might not work when more than two targets exist in the same range bin at the same time. Likewise, another tracking method, proposed by Chang et al., does not assume the situation where more than two targets exist in the same range bin at the same time[1].

The present study thus proposes a technique that is not limited by the number of targets in the same range bin at one time and that employs an adaptive Doppler spectrum estimation [5]. Additionally, an algorithm is proposed for real-time application. The foundations of the adaptive Doppler spectrum estimation are similar to those of the adaptive direction of arrival estimation technique that uses an array antenna. The present study employs the Capon method, which is a commonly used adaptive beamforming technique, for Doppler spectrum estimation. We first apply this technique to the estimation of velocity in each range bin and slow time.

Additionally, we propose a technique of tracking multiple targets using the estimated velocity. After we calculate the Doppler velocity for each range bin and slow time, we apply density-based spatial clustering (DBSCAN) to estimate the number of targets and to track the targets [6].

2. Materials and Methods

(1) Velocity Estimation Using the Capon Method

The Capon method minimizes the output power under the constraint that the echo has the desired velocity. The optimization problem is expressed as

$$\min_{\mathbf{w}}\left(P_{\mathrm{out}}(v,t,r)=\tfrac{1}{2}\mathbf{w}^{\mathrm{H}}\mathbf{R}(v,t,r)\mathbf{w}\right), \quad \text{subject to } \mathbf{a}^{\mathrm{T}}(v)\mathbf{w}^{*}=1 \tag{1}$$

$$\mathbf{R}(v,t,r)=\mathbf{s}(t,r)^{\mathrm{H}}\mathbf{s}(t,r), \tag{2}$$

$$\boldsymbol{s}(t,r)=[s(t-N,r)\ \cdots\ s(t,r)]^{\mathrm{T}}, \tag{3}$$

$$\mathbf{a}(v)=[\exp(-j\theta)\ \cdots\ \exp(-jN\theta)], \tag{4}$$

$$\theta=4\pi vT/\lambda, \tag{5}$$

where $\mathbf{w}$ is the weighting vector, $\mathbf{R}$ is the covariance matrix, $\mathbf{s}(t,r)$ is the signal vector, $\mathbf{a}(v)$ is the steering vector, and N is the number of pulses used for the estimation.

The Doppler spectrum calculated at (t, r), $P_{\mathrm{out}}(v, t, r)$, is given by

$$P_{\mathrm{out}}(v,t,r)=1/(\mathbf{a}(v)^{\mathrm{H}}\mathbf{R}^{-1}(v,t,r)\mathbf{a}(v)). \tag{6}$$

The present study employs sub-array averaging and range-direction averaging for stabilization [7]. To determine the velocity at (t, r), we detect peaks in $P_{\mathrm{out}}(v, t, r)$ that exceed a threshold.

(2) Multiple Echo Tracking Using DBSCAN and Labeling

We next track the echoes from multiple targets using DBSCAN [6]. We assume that different targets have different velocities or exist in different range bins. According to this assumption, we apply DBSCAN in the r–v plane at each moment in time. The echoes reflected from the same targets are classified into the same cluster. We use the center of gravity of each cluster to obtain the representative velocity and position of each target.

Finally, for the tracking of targets, we need to connect the clusters at each moment in time. Because the acceleration of human body should be low, we connect the clusters that has the closest representative velocity and position. Finally, we dismiss the target that has a low number of estimated points.

(3) Experimental Setup

Figure 1 is a schematic illustration of the experimental setup. We make measurements for two scenarios. We use the closely positioned transmitter Tx and receiver Rx as a monostatic radar system. The frequency band is from 3.1 to 5.3 GHz, the pulse repetition time, T, is 5.0 ms, and the sampling frequency is 16.39 GHz. The number of pulse used for estimation, N, is 16. Three people walking at different velocities intersect at almost the same time and range bin.

3. Results

Figures 2 and 3 present the experimental results for scenarios 1 and 2, respectively. Each color map shows the intensity of the received signal. The solid lines are the estimated representative positions of each cluster that means the trails of the targets. The proposed method tracked the three targets correctly and estimated the targets positions.

4. Conclusion

We proposed a tracking technique that employs adaptive Doppler velocity estimation and clustering. The proposed method does not require an iterative process and is not limited by the number of targets existing in the same range bin at one time. In experimental studies conducted for two scenarios, the method accurately tracked three targets intersecting in almost the same range bin at one time. This result suggests the effective application of the proposed method in security applications using UWB radar.

References

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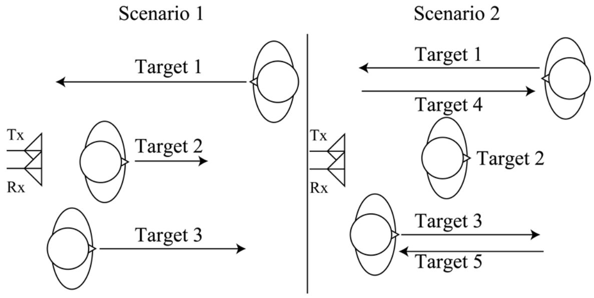

Fig. 1 Schematic illustration of the experimental setup.

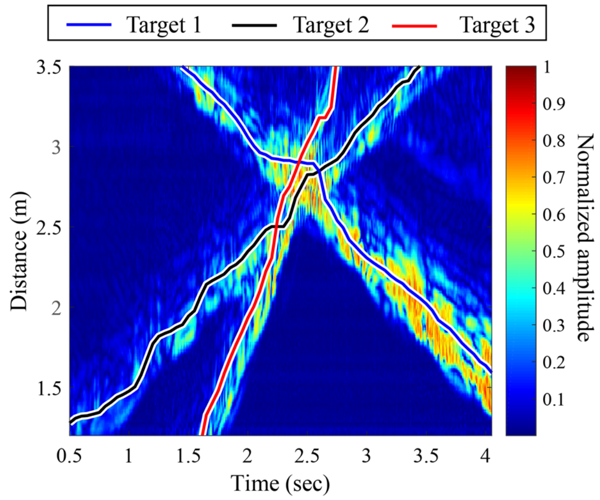

Fig. 2 Target movements estimated using the proposed method. The color map shows the intensity of received echoes.

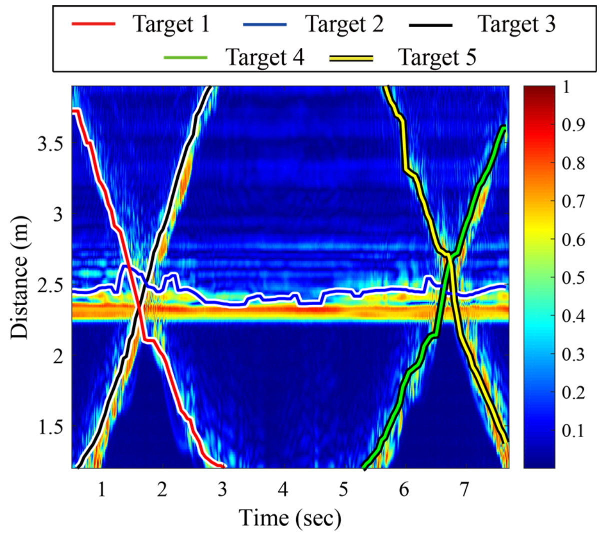

Fig. 3 Target movements estimated using the proposed method. The color map shows the intensity of received echoes.