Texture-Based Technique for Separating Echoes from People Walking in UWB Radar Signals

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***Abstract*—The use of ultra wideband radar for security systems is of interest because of the high range resolution. Much research has focused on developing effective methods for detecting, locating, tracking and imaging a human body with multiple radar systems. One important challenge in this field is how to handle data for multiple targets, because many conventional algorithms assume only a single target. In this paper, we propose a technique for separating two people walking using the texture of the time–range image. This method calculates the image flow angle that depends on the motion and velocity of the target. We demonstrate that the proposed method can separate two people walking in opposite directions in the measurement.**

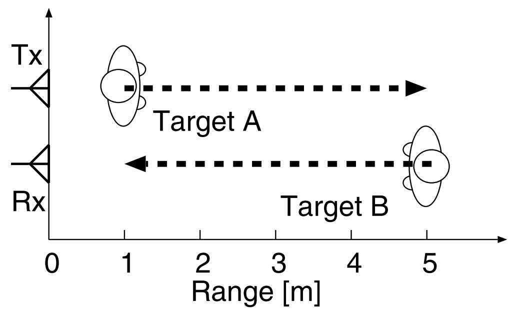

Fig. 1. Schematic of measurement scenario with antennas and two people.

I. INTRODUCTION

Ultra wideband (UWB) radar is a promising technology for security and surveillance systems because of its high range resolution and the additional Doppler information that it provides. There have been numerous studies on micro Doppler analysis for the detection, identification and tracking of a person [1], [2], [3], [4], [5], [6], [7], [8], [9]. However, many of the conventional studies assume that there is only one person in the data; they need an effective algorithm for separating multiple targets in the scene accurately.

One such technology is multiple hypothesis tracking (MHT) [10] that employs a Kalman filter and multiple hypothesis technique tuned for human tracking. Although this technique can estimate multiple trajectories of people, it does not actually separate the received signals into multiple components so that single-target-based algorithms can be applied.

In this paper, we propose a new approach for separating radar data into multiple data sets corresponding to different targets. This method analyzes the texture of the radar image, and uses a texture flow estimation that is used in optical dynamic image processing [11]. The performance of the proposed method has been experimentally evaluated on the measurements of two moving persons. The method is also demonstrated to be effective in separating the spectrogram into multiple components corresponding to different targets.

II. MEASUREMENT SCENARIO

We measured two people walking in opposite directions with a PulsOn 400 radar system manufactured by Timedomain Corporation. The frequency band is from 3.1 to 5.3 GHz, and the signal is modulated by an m-sequence. The received data are compressed with the same sequence. The transmitted power is -14.5 dBm. The transmitting and receiving antennas are dual-polarized horn antennas (model DP240 manufactured by Flann Microwave Ltd.) with 2 to 18 GHz bandwidth. The antennas are separated by 50.0 cm.

Target A walks from a point 1.0 m away from the antennas to a point 5.0 m away. Target B walks in the opposite direction from the point 5.0 m away from the antennas to the point 1.0 m away. The total observation time is 8.32 s, the range measurement repetition frequency is 200 Hz, and the sampling frequency is 16.39 GHz. The received signals are stored and processed afterwards. We define $s(t, r)$ as the received signal at time t and range r. The schematic and photograph of the measurement scenario are shown in Figs. 1 and 2.

Figure 3 shows the measured time–range signals $|s(t, r)|^2$ in the assumed scenario. We see two target trajectories moving upward and downward in the image. They intersect at $t = 4.3$ s. Although it seems obvious that there are two targets in the image, it is not straightforward to separate these components. The objective of this paper is to separate this data set into two components corresponding to different persons.

III. WIGNER–VILLE DISTRIBUTION

The Wigner–Ville distribution (WVD) is used to analyze the time-dependent frequency of dynamic signals. The WVD

Fig. 2. Photograph of measurement scenario.

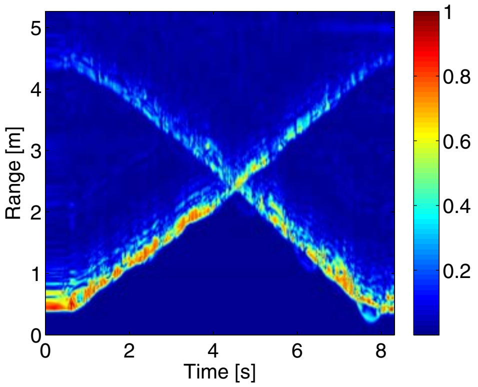

Fig. 3. Time–range signals for two people walking in opposite directions.

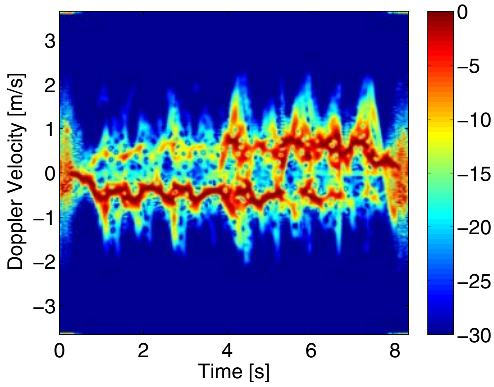

Fig. 4. SPWD of the measured signals (in dB).

is known to have better time and frequency resolution than conventional methods such as the short-time Fourier transform (STFT). The smoothed pseudo Wigner-Ville distribution (SPWD) is a smoothed version of the WVD and has the advantage that it suppresses artifacts caused by multiple frequency components. The WVD of a signal $f(t)$ is expressed as

$$W(t,\omega) = \int f(t+\tau/2) f^*(t-\tau/2) \mathrm{e}^{-j\omega\tau} \mathrm{d}\tau, \qquad (1)$$

and the SPWD is defined using the WVD as

$$W_{\mathrm{s}}(t,\omega) = \int\int \Phi(t-t', \omega-\omega') W(t',\omega') \mathrm{d}t' \mathrm{d}\omega', \qquad (2)$$

where Φ is a smoothing function. In this paper, we use a Gaussian function as the smoothing function

$$\Phi(t,\omega) = \exp\left(-\frac{t^2}{2t_0^2} - \frac{\omega^2}{2\omega_0^2}\right), \qquad (3)$$

where t_0 and ω_0 are the smoothing correlation length in terms of time and angular frequency. We set these values to $t_0 = 0.83$ s and $\omega_0 = 2\pi \times 6.67$ rad/s.

Figure 4 shows the SPWD of the measurement data in Fig. 3. In the image it is seen that there are two trajectory components that have positive and negative Doppler velocities. In this way, the echoes are separated in the spectrogram, but this approach cannot separate the time–range signals, which is the challenge to be addressed.

IV. Proposed Method

The textures of two different targets have different flow directions. We use this feature of the textures to distinguish the two targets. Figures 5 and 6 show the enlarged images of the time–range radar images corresponding to targets A and B, respectively. Note that these images are only part of the data set, and are manually selected. The images show that the texture of the echoes of targets A and B have different flow angles, although small fluctuations are also observed within the same target echo. The image flow is often used in optical dynamic image processing [11] to separate moving objects from the background in video images.

We modify the conventional concept of the texture flow so as to apply it to radar images. We define the texture flow angle of a time–range radar image as

$$\theta(t,r) = \tan^{-1}\left(v_0 \frac{\partial s(t,r)/\partial r}{\partial s(t,r)/\partial t}\right), \qquad (4)$$

where s is the signal amplitude, r is the range, and t is time. Note that v_0 is introduced to make the argument of $\tan^{-1}$ dimensionless, and is set to 1.83 m/s. In future, this value will be automatically determined from the doppler spectrogram. Finally, a 5×5 median filter is applied to the texture flow angle $\theta(t,r)$ to eliminate artifacts, where each pixel corresponds to 0.12 Hz and 5.0 ms.

V. Application of the Proposed Method

We apply the method proposed in the previous section to the measurement data. Figure 7 shows the texture flow angle of the measured signal. It is seen that the texture flow clearly distinguishes the different targets. Targets A and B are indicated in red and blue, respectively. The separation capability is degraded at $t < 0.7$ s and $t > 7.8$ s because neither target is moving at those times. The swinging arms of target B have a positive flow angle $\theta > \pi/2$, and are erroneously labeled in red. For simplicity, we separate the targets with a simple thresholding procedure in this paper. However, further study is needed to improve the separation capability for more complicated scenarios.

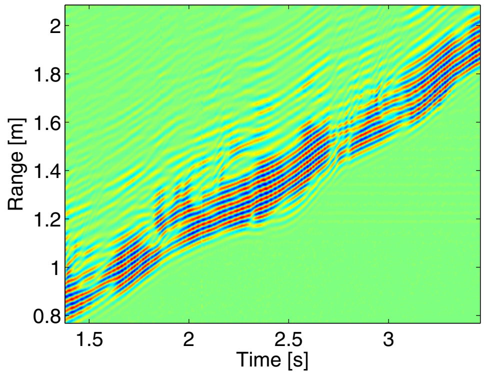

Fig. 5. Enlarged time–range signals for target A walking away from the antennas.

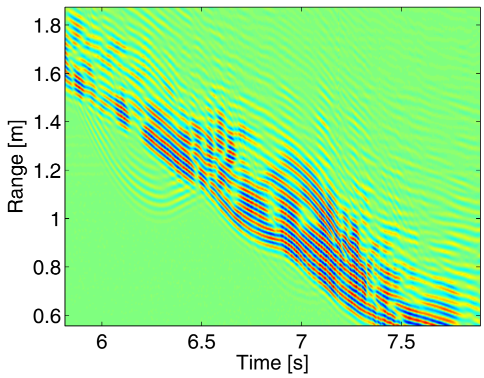

Fig. 6. Enlarged time–range signals for target B walking toward the antennas.

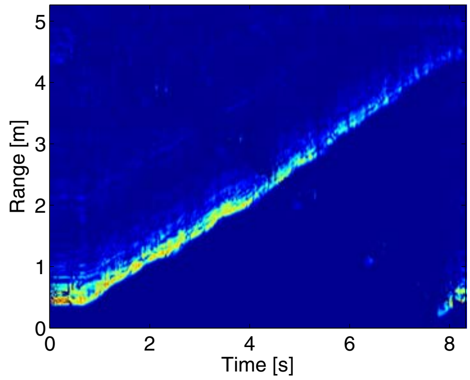

Fig. 8. Separated signals for target A with $\theta > \pi/2$.

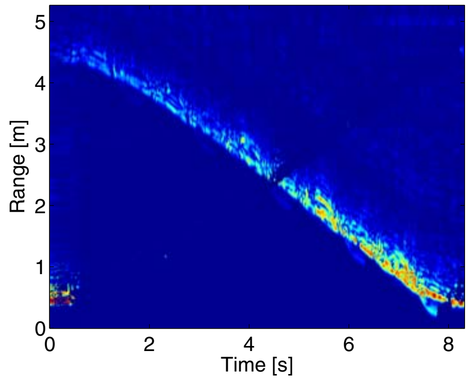

Fig. 9. Separated signals for target B with $\theta < \pi/2$.

Targets A and B chosen with $\theta > \pi/2$ and $\theta < \pi/2$ are shown in Figs. 8 and 9. The signals are almost correctly separated except at the beginning and end of the observation when the targets are not moving. In addition, the echo from target B is masked by the echo from target A at the intersection of the two trajectories $t = 4.3$ s. This is due to the shadowing effect and the configuration of the antennas and targets.

Finally, we apply the SPWD to these separated signals to generate two different spectrograms. Figures 10 and 11 show the SPWDs of signals with $\theta > \pi/2$ and $\theta < \pi/2$, respectively. These signals correspond to targets A and B. The SPWDs are normalized to unity for each t so that detailed Doppler change can be observed regardless of echo intensity. The images clearly show two different spectrograms for the two people walking. After this processing, various conventional micro-Doppler methods can be applied for further analysis. These results demonstrate that the proposed method is effective in separating signals corresponding to people and thus generating separate spectrograms.

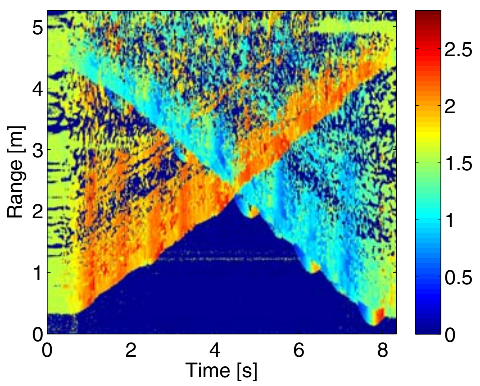

Fig. 7. Texture flow angle of the time–range signals (in rad).

VI. Conclusion

We proposed a new method for separating two persons moving at different velocities using a UWB radar. The proposed method calculates the texture flow angle to estimate an approximate line-of-sight speed of the target at each point of the signals. Targets with different speeds have different texture in the time–range image. The method was applied to the measurement of two persons, and was demonstrated to be effective in separating the targets. In addition, we applied the SPWD to the separate signals to generate two different spectrograms. An important future task is to modify the proposed method so that it is applicable to various scenarios,

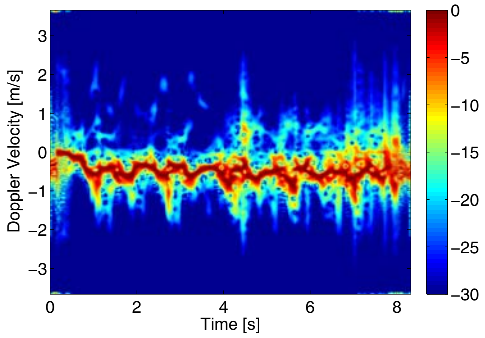

Fig. 10. SPWD of the signals for target A with $\theta > \pi/2$ (in dB).

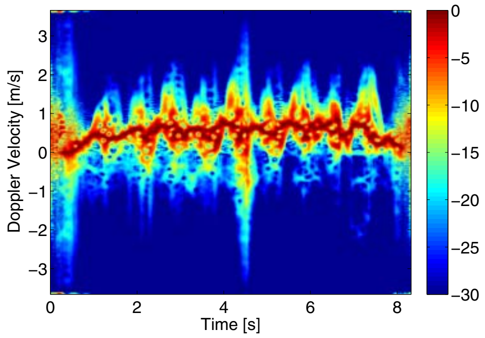

Fig. 11. SPWD of the signals for target B with $\theta < \pi/2$ (in dB).

such as cases of there being more than two people, people having similar motion and a severe shadowing effect.

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