Recent Progress in Millimeter-Wave Radar Signal Processing

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***Abstract*—This paper summarizes recent topics in signal processing techniques proposed by the author for measurement of human body motion using both microwave and millimeter-wave radar systems. The proposed signal processing algorithms enable accurate and high-resolution measurement of the motion of human body parts. These techniques are applied to measurement of the motion of human participants and their performances are demonstrated experimentally.**

Keywords—radar signal processing, human motion, Doppler

I. Introduction

While the development of radar techniques for measurement of target motion has a long history, the development of these techniques is still a work in progress and remains an important research topic because numerous new applications have started to emerge in recent years. Examples include the radar measurement of human bodies in healthcare and security applications. Unlike cameras, the use of radar for monitoring of people is considered to be acceptable, even in privacy-sensitive places. The Doppler shift caused by body parts is called the micro-Doppler shift and it contains a great deal of information about the person's activity and their health condition. Because many healthcare and security applications require accurate measurements of the target's motion, we have been developing various microwave and millimeter-wave (MMW) radar signal processing algorithms for human monitoring purposes.

II. Radar-Based Human Motion Measurement

A. Sub-Nyquist Radar Measurement of Human Movements

Although radar systems with a high operating frequency such as MMW systems can detect slight body movements, these systems tend to have a low Nyquist velocity, which is the largest velocity that is measurable without ambiguity. We developed an ambiguity-free algorithm for estimation of Doppler velocities that exceed the Nyquist velocity by combining a fine (and ambiguous) estimate determined using a Fourier transform with a coarse estimate determined using the texture-angle technique for the signal envelope [1]. The proposed algorithm was shown to be able to estimate velocity accurately, even from sub-Nyquist radar signals.

B. Spectrum-Free Measurement of Velocity Vectors Using Multiple Radars

Another algorithm was developed to estimate multiple Doppler velocities without using a Fourier transform [2]. This algorithm can separate multiple echoes with different Doppler velocities using a closed-form solution called the extended texture method that does not involve either a Fourier transform or a peak search. The algorithm can thus identify the target velocity within a short time, which is essential for use with real-time applications such as security and healthcare systems.

C. Velocity Vector Measurement Using Multiple Radars

We developed a networked radar system that comprised multiple MMW radar systems and showed that this system could estimate the target velocity vectors rather than the Doppler velocity, which is the radial component of the actual velocity vector [3]. In the developed system, multiple echoes with different velocities are separated within the frequency domain of each radar signal, and these echoes are then combined to estimate the velocity vectors for each of the multiple targets. The system was demonstrated to be able to measure multiple rotating targets that modeled the multiple parts of a human body, and their velocity vectors were shown to be estimated accurately.

III. Conclusions

This paper has summarized three signal processing algorithms that were developed for use with MMW radar systems for applications involving monitoring of the motion of the human body. Combination of the three techniques introduced in this paper and implementation of the resulting technique in a MMW radar system for monitoring of human activities and health conditions in actual applications will be the focus of an important future study.

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