Human Posture Capturing with Millimetre Wave Radars

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***Abstract*—Millimetre wave (mmWave) radar, as an emerging technique, is increasing in popularity for human activity recognition. In this paper, we study the potential use of mmWave radars for human posture capturing and analysis. We study the mmWave radars from Texas Instruments, in particular the radars' vertical Angle-of-View when detecting human-size subjects. We show that a single radar has a limited beamwidth and can only detect part of a person. In order to obtain a complete image of the person, we use a vertical radar array to improve the Angle-of-View and we show that the radars are capable of capturing a sufficient amount of data for advanced posture analysis.**

***Index Terms*—human posture capturing, millimetre wave radar, signal processing**

I. INTRODUCTION

Human posture estimation is one of the most popular research topics in computer vision. Camera based methods have shown outstanding performance on various tasks from human detection [1] to posture recognition [2]. However, cameras are intrusive and are not suitable when privacy is a concern. This paper investigates the potential use of millimetre-wave (mmWave) radars for posture recognition.

Typical mmWave radars use frequencies from 60 to 81 GHz and a high bandwidth of a few GHz. The high bandwidth and the short wavelength allow the radars to detect objects at a high resolution while keeping low antenna sizes and cost. Radars are also non-intrusive and can sense in difficult viewing conditions. Therefore, mmWave radars are becoming popular in human activity recognition [3], [4]. However, few researchers have studied their use in posture analysis. In this paper, we have selected the FMCW (Frequency Modulated Continuous Wave) mmWave radars made by Texas Instruments (TI) to carry out our experiments on human posture capturing. We show that, while mmWave radars can have a good resolution for detecting human-size subjects and capturing postures, they have a limited vertical Angle-of-View (AoV) and can only sense a part of a person. For capturing a complete image, at least two radars are required to be joined vertically as a radar array. We show that, with two radars, postures can be captured in detail at short distances between 50 cm and 2 m, and the captured data can have distinguishable patterns, and can potentially be analysed and recognised with advanced machine learning techniques.

The paper is structured as follows. Section II discusses related work and some of the preliminary knowledge of the FMCW mmWave radars we used. Section III gives the antenna characterisation of the mmWave radars with an emphasis on human posture capturing and Section IV gives the antenna characterisation when using a radar array. Section V shows some examples of captured human postures using the radars. Section VI concludes the work.

II. BACKGROUND AND PRELIMINARIES

Human activity recognition has been studied in depth in the computer vision field. With the recent development of neural networks, many systems have been developed and showed good performance on human posture recognition [2], [5]. These systems use visual features from images or videos, identify the human body and limbs, and generate posture models based on them. Cameras provide very detailed and reliable visual features and are capable of complex tasks. However, they are intrusive and rely on good lighting conditions. There are other systems using sensors and wearable devices to recognise human activity. Researchers have also used Doppler radars on specific tasks, such as classification of simple actions [6] and motion detection [4]. Some use radio frequency signals and complex antenna arrays to estimate human posture [7] and generate skeleton models [8]. mmWave radars, as an emerging technique, have been used widely in autonomous applications but not much in human activity recognition. While some researchers use mmWave radars as regular radio frequency radars [4], only a few researchers use mmWave radars as 3D imaging radars for human tracking [9] and identification [3]. The use of mmWave radars in general purpose posture recognition is still a new area.

In this paper, we use the TI IWR1443 FMCW mmWave radars with a frequency of 76-81 GHz. The radar platform has four transmitters and three receivers operating concurrently. Signals will be modulated and sent by the transmitters, reflected by objects and received by the receivers. The radar has an on-chip data processing chain for processing the mmWave signals, estimating the distance, angle and velocity of any object in the scene and transferring the results to a host device [10]. For one object, the frequency difference between the transmitted signal and received signal will be a constant value and can be derived from the time-of-flight. The angular position of the object can be calculated by comparing phase differences between neighbouring receivers. The resolution depends on the number of antennas available. The velocity can be obtained

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by using chirp frames and comparing the phase differences between successive chirps. The CFAR (Constant False Alarm Rate) algorithm is then applied to the processed signal to detect peaks and report them as real objects. The results are then transmitted to a computer through serial ports, in the format of x-y-z coordinates, signal strengths and velocities. Throughout our experiment, the radars are configured for indoor environments with a maximum distance range of 8 m. The chirp is configured to utilise the full 4 GHz bandwidth, and, hence, a 4 cm distance resolution.

III. Single Radar Characterisation

Human posture analysis requires high-resolution detection across the vertical plane around the person, where the quality of the detection is determined by the antenna radiation pattern of the radar. The receivers on the iwr1443 radar module can receive signals from both the horizontal plane and the vertical plane. However, the horizontal AoV is designed to be much larger than the vertical one [11]. Table I shows at which angles the signal strength of the radar will drop to a certain level (at 78 GHz). The radar will receive an attenuation of -6 dB (1/4) on the signal when detecting objects at $\pm 50°$ horizontally or $\pm 20°$ vertically.

TABLE I
Radar AoV (degrees) at given signal attenuation [11]

	Horizontal		Vertical	
	-3dB	-6dB	-3dB	-6dB
IWR1443	28	50	14	20

While the antenna radiation pattern could work well in autonomous applications, the situation in human posture analysis is very different, as the vertical AoV becomes much more important. For indoor environments, when the person is close to the radar, the limited vertical beamwidth will make the radar only be able to sense a part of the person, and might not have enough features for advanced analysis.

In order to investigate this effect in real-world applications, we performed a set of experiments to test the radiation pattern with a focus on the vertical AoV. We placed the radar at 1.2 m high, pointed the radar to a flat wall at various distances between 30 cm and 2 m and recorded the detected frames. At each distance, the amount and the distribution of the detected points are analysed and the effective AoV is calculated to be the 95% confidence interval range. In other words, the radar is considered to have a V_{low} to V_{high} vertical AoV if 95% of the detected points are above V_{low} and below V_{high}, to exclude any outliers. The results are shown in Figure 1. The red dots in the figure are the V_{low} to V_{high} values at each distance and the highlighted area is the estimated AoV region, fitted as a quadratic polynomial function. It can be seen that the AoV increases near-linearly with the distance. The detectable range is around 30 - 45 cm at close distances (30 - 50 cm) and increases to 87 cm at 2 m. The angular AoV is approximately 15° to 20°, conforming to the -3 dB to -6 dB range in Table I.

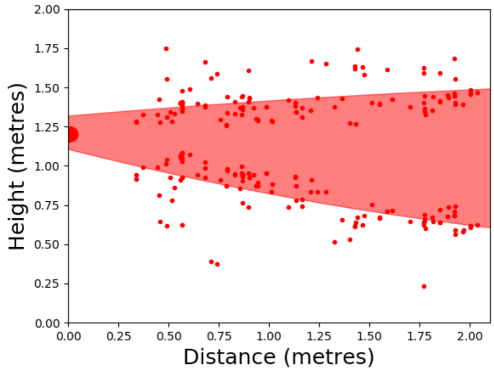

Fig. 1. Radar vertical AoV at various distance when pointing to a flat wall.

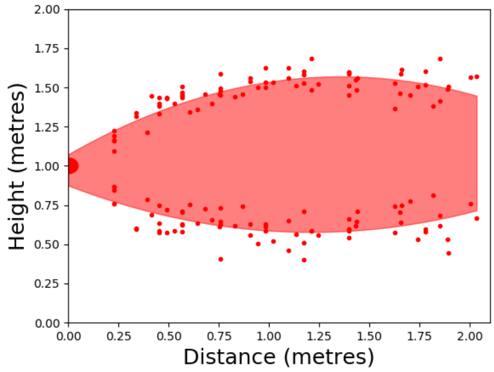

Fig. 2. Radar vertical AoV at various distance when pointing to a human.

The same experiment was also carried out with a person being the subject. The radar is set at 1 m high. The detectable range is calculated using the same method as previously and the results are shown in Figure 2. The AoV region follows a lobe shape, similar to the standard radiation pattern of a general antenna. The radar has a limited AoV of around 50 cm at close distances when the antennas can hardly receive signals beyond 35°. The AoV increases with the distance and reaches a peak of 98 cm at 1.4 m. When the person moves further away, the signal attenuates. Although the radar can still detect the presence of the person, the number of detected points drops dramatically and the result does not carry sufficient information for determining the posture.

Figure 3 shows an illustration of this problem when detecting human postures at an adult-scale. It shows some detection results and a histogram of their distribution at 0.5 m, 1.4 m and 2 m. Based on our experiments, the best AoV can be obtained at around 1.4 m with a 98 cm coverage. Therefore, this distance is considered to be the best distance for posture capturing due to the wide AoV and a sufficient amount of data.

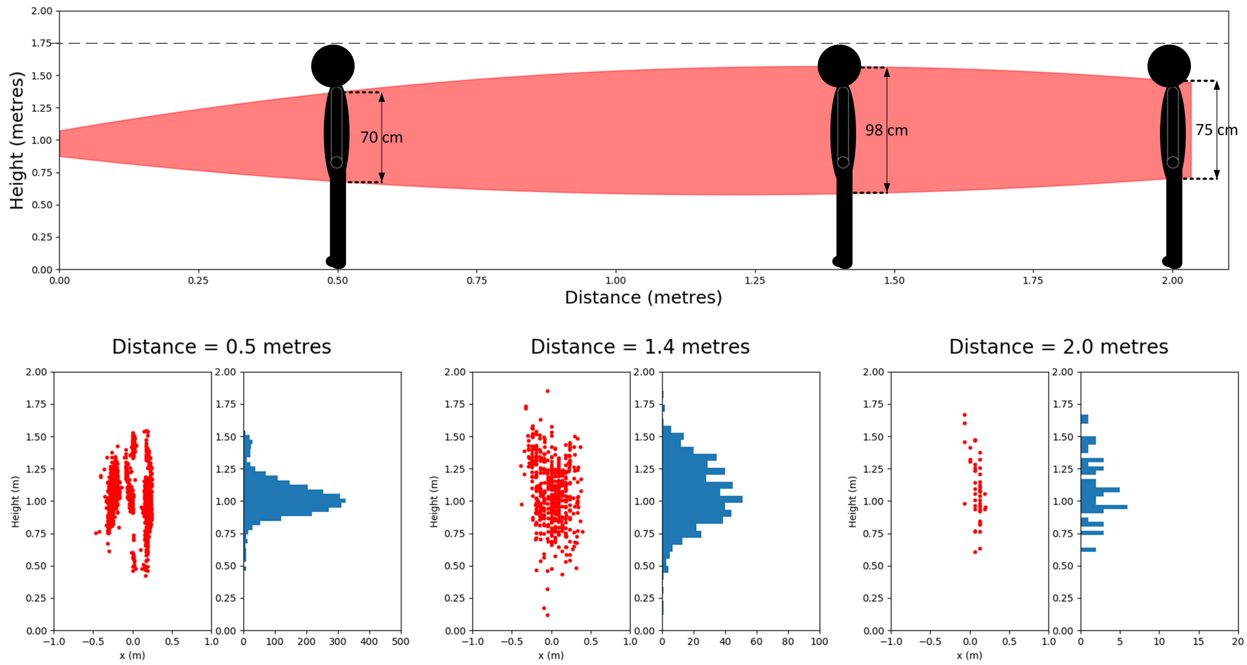

Fig. 3. Radar vertical AoV when detecting human-size subjects. Top: Only a limited area of the person can be detected with one radar. Bottom: The detection results and their distribution at various distances.

IV. Radar Array Characterisation

In order to address the problem, at least two radars are required as a vertical radar array to cover the entire height of an adult. We constructed a radar array by placing two identical radars at the same vertical axis and pointing them forward at the same angle, one at 0.7 m high and the other at 1.3 m high. The setup is found to provide a consistent vertical coverage across different distances. As shown in Figure 4, using two radars can significantly extend the vertical AoV at all distances. In comparison to using only one radar, the average detectable range at close distances (around 50 cm) has increased from 70 cm to 110 cm, and the peak range (at around 1.4 m) has increased from 98 cm to over 140 cm. The average improvement from all distances is around 55%. The variance in the coverage is much smaller than one radar. Figure 5 shows the detection results and their distribution at 0.5 m and 1.4 m. The two peaks from the two radars are still observable at close distances, but the overlapping region is receiving more data and, hence, could contain more useful data. The distribution is much smoother at larger distances and the two detection results are no longer separable. In both cases, the radar array can detect over 100 points at each height bin and can capture useful shape information from the scene and the human body-parts.

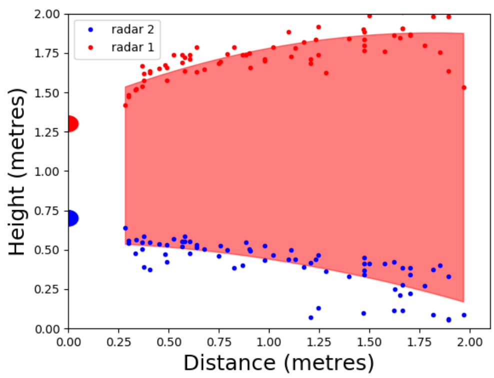

Fig. 4. Two radars vertical AoV at various distances when pointing to a person.

V. Radar Array Posture Capturing

We have shown that using an array of two radars can capture a large amount of data when a person is present. Figure 6 shows some example data captured when the person was holding different postures. The distance between the radars and the person was between 1.2 and 1.5 m. It can be seen that the radar array had successfully captured a complete view of the subject and the data contained distinguishable features corresponding to the postures. This allows advanced machine learning algorithms to be developed and applied to the data for a more precise posture analysis.

It is worth noting that the captured image did not have any data close to the floor, i.e. between 0 and 25 cm. Our hypothesis is that, lower body parts of a person have a close distance to the floor and have a small area, which make them hard to be identified by the CFAR peak detection algorithm. Therefore,

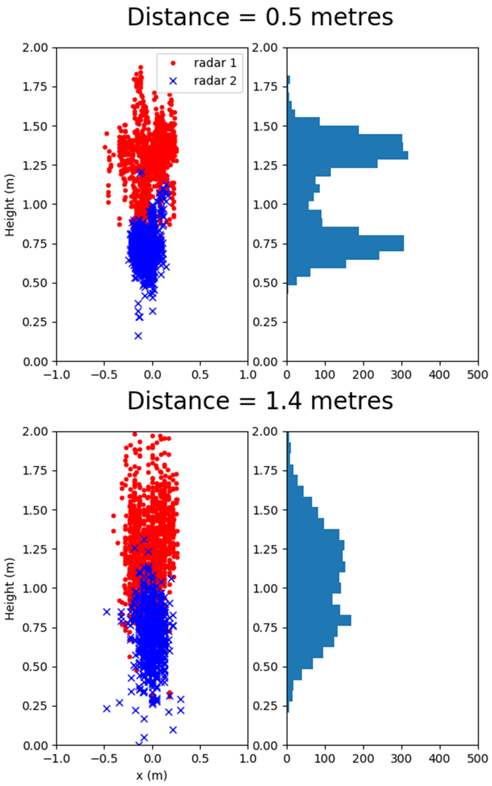

Fig. 5. Detection results and their distribution using two radars.

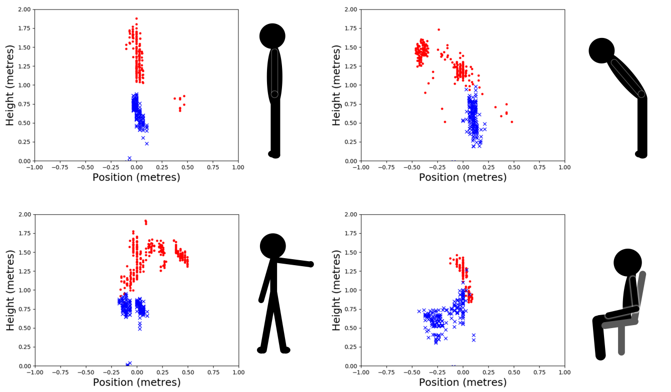

Fig. 6. Radar array vertical AoV at various distance when pointing to a human. Top-left: Standing still. Top-right: Bowing. Bottom-left: Standing and holding one arm. Bottom-right: Sitting.

they are not reported by the radar as real objects. This issue should not make a big effect in posture analysis, as the lower body parts, like feet, are often less important than the other body-parts like limbs, and we left it as a future research topic.

VI. Conclusion

In this paper, we have studied the use of mmWave radars for human posture capturing. We studied the vertical AoV of commercial mmWave radars from Texas Instruments and discussed the issue of the limited beamwidth when detecting a human-size subject. We suggested a vertical radar array to address the problem and showed that the coverage can be increased significantly, with a 55% average improvement. The radar array is found to be able to cover up to 1.4 m height at 1.4 m distance. We showed that mmWave radars are able to capture detailed data with a rich set of features for human posture analysis. This work opens future research opportunities for developing advanced posture analysis algorithms on mmWave radars for a non-intrusive and contactless human posture recognition system.

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