Hand Gesture Recognition Using FMCW Radar in Multi-Person Scenario

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Abstract—Remote hand gesture recognition using radio frequency (RF) waves is an emerging approach for the interaction between users and smart devices. In this paper, the feasibility of using frequency-modulated continuous-wave (FMCW) radar to recognize hand gestures when multiple closely spaced subjects are illuminated by the same sensor is investigated. Four hand gestures are suggested. Existing radar-based hand gesture recognition mainly relied on the Doppler effect caused by one motion in the sensor’s field of view. Besides, they did not consider the random body motion of targets situated at the same range, which is not practical in real-life scenarios. Leveraging the range discrimination capability of FMCW radars and characteristic signal extraction, interference rejection is achieved in this paper. Experimental results confirm the effectiveness of the FMCW radar based remote control approach in the presence of multiple interferers.

Keywords—FMCW radar, hand gesture, micro-Doppler, range profile, remote control.

I. INTRODUCTION

Remote human motion detection and classification has been attracting the attention of researchers in the last decades [1]-[3]. The employment of natural gestures as input in several technologies, such as cell phones, TVs, and home appliances, improves people’s quality of life. Driven by the growing interest in hand gesture recognition, various devices based on accelerometers and camera can be found in the market. However, the use of wearables can cause discomfort over extended period of time; while camera-based technologies, such as Microsoft Kinect, and Leap Motion, are sensitive to ambient light conditions and may infringe user privacy. In such situations, such as Microsoft Kinect, and Leap Motion, are sensitive to ambient light conditions and may infringe user privacy. In extended period of time; while camera-based technologies, such as Microsoft Kinect, and Leap Motion, are sensitive to ambient light conditions and may infringe user privacy. In addition, cameras consume large computational resources and require longer processing time.

Based on the detection of the Doppler shift caused by the moving parts of a human body, portable radars are used for human activity classification and hand gesture sensing [4]-[7]. In [7], a 24-GHz FMCW radar was employed to detect and classify several hand gestures of a person within 0.4 m. In [6], a 5.8-GHz FMCW radar was used to detect hand gestures with two subjects at different ranges. However, in realistic situations, such as remote control of an industrial device, other people and moving targets may be closely around the user, sometimes even at the same range bin. Therefore, purely range-based discrimination may suffer from the interferences of the Doppler frequencies of nearby moving targets.

This work will focus on hand gesture based remote control using FMCW radar in the presence of multiple persons both in the same range bin and moving in different range bins. The

range and Doppler capabilities of FMCW radar systems are key to remove interference from other range bins. The identification of the hand gesture’s signal characteristics enables the discrimination against unwanted micro-Doppler signals of people in the same range. Experiments will show that four hand gestures can be differentiated from random body movements through the analysis of Doppler spectrograms. The results obtained in this paper demonstrate the advantages of FMCW radars to remotely recognize hand gestures in a complex environment.

II. THEORY OF MULTI-PERSON HAND GESTURE RECOGNITION BASED ON FMCW RADARS

Fig. 1 depicts a scenario where a subject does hand gestures while a second person talks and/or uses a cellphone and a third subject walks behind. The radar sensor is placed inside the control device. The three human targets are simultaneously illuminated by the radar sensor. It should be noted that usually the movements done by one when watching TV, talking with someone, or using the cellphone are subtle and random. Thus, their power spectral signatures will not be as characteristic as the ones associated with a specific hand motion.

Since FMCW radars possess range discrimination capability, it is possible to choose where to focus on for the desired micro-Doppler echoes, if the radar’s field of view is not obstructed. On the other hand, if a conventional continuous-wave radar is employed, the micro-Doppler produced by people at different ranges would interfere with each other [6]. Fig. 2 explains the generation of the range profile and the time-Doppler spectrogram, based on the application of the fast Fourier transform (FFT) to the raw-data matrix and the short-time Fourier transform (STFT) at the range of interest, respectively. The sampled beat signals of \( M \) different chirp intervals are sequentially arranged in rows of the raw-data matrix \( \textbf{R}(m,n) \), where \( m = 1,2,3,\ldots,M \), \( n = 1,2,3,\ldots,N \), and \( N \) is the number of sampling points for each chirp. The column-wise axis is referred to as slow-time, whereas the row-wise axis is...
called fast-time. The range profile is obtained after the application of the FFT over each row of the raw-data matrix $R(m,n)$.

In the range profile, the human subject making hand gestures and the person beside are labeled as P1 and P2, respectively. The person moving behind is labeled as P3. Some surrounding clutters may exist too. Initially, the interference from P3’s motion can be filtered out based on the range of P1 and P2. The time-Doppler spectrogram is extracted by performing the STFT to the range of interest with a sliding time window. P1’s hand motion creates characteristic and unambiguous micro-Doppler strip signatures.

It should be noted that the choice of the hand gesture is key to enable the radar-based remote recognition because the radar cross section of the hand is relatively small and the distance between P1 and P2 is less than the range resolution, which increases interferences. Therefore, the hand gestures must be determined to fulfill the goal of maximizing the detected signal strength of the hand/arm motion. Besides, the hand gestures must create unambiguous characteristic micro-Doppler echoes that can be differentiated from the time-frequency signatures of other people’s small-amplitude random body motions. In a scenario where the interferences momentarily dominate, the hand gesture must be repeated until the device clearly recognizes the desired command. Without loss of generality, the situation described in this section is typical case, and it can be applied to the remote control of an appliance, such as a thermostat, in a crowded domestic/industrial environment.

In this paper, the minimum and maximum range of interest are 0.2 m and 3 m, respectively. It should be mentioned that the time-frequency responses are directly extracted from the range history based on power density, which requires less computational load than the motion detection method based on the phase-deramping of the FMCW radar response.

III. EXPERIMENTS AND RESULTS

To validate the feasibility of the proposed application, experiments were carried out in an indoor environment simulating the remote control of a TV with four suggested hand movements. Fig. 3 shows the suggested hand gestures. The analysis of the micro-Doppler signatures of these hand movements can be used to identify the hand gestures of interest even in scenarios with two people moving their body parts beside each other.

The experimental setup of one person (P1) making hand gestures while another (P2) sitting beside doing several random body movements, such as fetching the cell phone to check messages, looking to the other person (P3) coming from behind or randomly moving her head, is displayed in Fig. 4. The 24-GHz FMCW radar shown in the inset had a 600-MHz bandwidth, which yields a range resolution of 25 cm. The beat signal and the reference signal were sampled by the audio card of a computer at a rate of 96 kSa/s. The chirp repetition rate was 745-Hz. The distance between the radar and the chairs was around 2 m. The radar was placed around 1 m above the ground.

Fig. 5(a) illustrates the range profile and Fig. 5(b) corresponds to the extracted micro-Doppler radar signatures, respectively, during the extension followed by the flexion of the arm. On the range profile, the most powerful region enables the recognition of the range of P1 and P2. The stronger, clear, and periodic strips indicate the instants when the extension and the flexion of the arm were performed by the TV user. Initially, the hand of the human subject P1 was above the knee. As the hand started to move up, a small positive frequency is seen. This corresponds to the accelerating phase of the upwards movement. When the radial velocity of P1’s hand reached the maximum value, the maximum positive Doppler frequency of this extension/flexion repetition is achieved on the spectrogram (point A). After that, the hand started to deaccelerate until it reached a velocity equal to zero, which corresponds to zero-Doppler line in the time-Doppler spectrogram (point B). In the second phase of the movement, the hand started to move towards the knee. Because of that, negative values of the Doppler frequency are seen in the time-frequency spectrogram. After reaching the maximum radial velocity (point C), the movement became slower. Eventually, the subject’s hand was again over the knee (point D). Since another person was making random body movements, small micro-Doppler interferences are seen along with the time-Doppler responses of the extension/flexion of the arm in Fig. 5(b). However, it is still possible to identify the latter because its spectral signature has well-defined characteristics.

Fig. 5(c) presents the range profile and Fig. 5(d) illustrates the Doppler spectrogram when the subject of interest (P1) is sweeping the hand towards the radar. The P1’s hand approached the radar, the radial component of its velocity rapidly increased, which is translated in the spectrogram as a strong bump degenerated in a weak vertical strip. Then, the hand started to deaccelerate and to retract towards the user, reaching a maximum velocity (point A) and then finally stopping (point B). It should be observed that the retracting part
of this gesture takes longer than the first part as is revealed in Fig. 5(d).

The range profile and the spectrogram for the continuous rotation of the hand on the horizontal plane are depicted in Fig. 5(e) and Fig. 5(f), respectively. The gesture is divided in two phases. The first phase started when the hand was moving away from the radar with the maximum velocity (point A), and then the hand’s speed decreased until zero (point B), and the hand initiated its motion towards the radar (negative-frequency responses). The second phase started when the hand reached the maximum velocity going towards the radar (point C), and then the hand’s speed reduced until being equal again to zero (point D) and starting its movement away from the radar (positive-frequency responses). A weaker strip close to point D on the spectrogram flags this transition. The final part of the second phase was reached when P1’s hand reached the maximum velocity for the receding trajectory. The spectral power of the first phase dominates over the spectral power of the second one due to the manual pointing of the radar and to the fact that the radar’s angle of view is not the same for both situations. Because of that, only the strip associated with the first phase is completely detailed on the time-Doppler map.

Fig. 5(g)-(h) detail the range profile and the corresponding Doppler spectrogram of the hand-click gesture, respectively. The hand-click gesture causes two signatures on the time-Doppler spectrogram. The first phase started when the hand was moving away from the radar with the maximum velocity (point A), and then the hand’s speed reduced until being equal again to zero (point D) and starting its movement away from the radar (positive-frequency responses). A weaker strip close to point D on the spectrogram flags this transition. The final part of the second phase was reached when P1’s hand reached the maximum velocity for the receding trajectory. The spectral power of the first phase dominates over the spectral power of the second one due to the manual pointing of the radar and to the fact that the radar’s angle of view is not the same for both situations. Because of that, only the strip associated with the first phase is completely detailed on the time-Doppler map.

Fig. 4. Experimental setup for two human subjects seated in front of the TV. The 24-GHz FMCW radar board is shown in the inset.

IV. CONCLUSION

This paper investigated the feasibility of the remote control based on hand gesture recognition using FMCW radars in multi-person scenarios. Benefiting from the range capability, FMCW radars can easily discriminate the range of interest. In addition, through the analysis of the micro-Doppler signatures, it can detect specific hand gestures in the presence of moving people at the same range bin even with potential interference due to the random body movements performed by other people. Future work will focus on the automatic classification of the suggested hand gestures.

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