Concealed Dangerous Object Detection Based on a 77GHz Radar

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***Abstract*—In this paper, we propose a method which can detect dangerous objects such as pistol and knife concealed on pedestrian via a 77GHz radar. The proposed method uses range-FFT and Doppler-FFT to obtain micro-Doppler signature of the concealed object. We extract features from micro-Doppler signature with motion pattern of the pedestrian. A classifier based on Support Vector Machine (SVM) is implemented to distinguish dangerous objects from all detected objects by micro-Doppler features. We set up an experiment platform which uses a PVC dummy to simulate pedestrian to verify our proposed method. Results show that our proposed method can get accuracy of 89.8% and miss alarm rate of 3% among 200 times of detection.**

***Keywords*—dangerous object detection, micro-Doppler, 77GHz radar**

I. INTRODUCTION

As the threat of terrorist increases, public safety becomes more and more important. It is necessary to develop security systems that allow remote detection, avoid personal privacy and are harmless to human health. Our research target is to realize a ubiquitous security surveillance system which consists of multiple low cost radars in small size. The radars in the system can detect dangerous objects such as a knife or a pistol concealed on pedestrian. Alarms will send to service center if such objects are detected, and the service center can do further actions such as calling police. In this paper, we focus on a 77GHz radar to distinguish people with or without dangerous object.

The rest of the paper is organized as follows. In section II, it introduces our proposed method. In section III, our experiment platform and experiment results are described. In section IV, it concludes our work.

II. PROPOSED METHOD

A. Principle of concealed dangerous object detection

When pedestrian carries an object, such as pistol or knife on his torso, his arms swing forward and backward respectively. This motion of arm makes his torso twist so that the object has similar movement. This kind of movement induces frequency modulation on reflected signals and causes micro-Doppler phenomenon [1]. Micro-Doppler provides rich information which can be used for target classification [2-4]. Our proposed method uses micro-Doppler signature to distinguish different objects.

We choose a millimeter wave radar of which frequency band is 77GHz-81GHz. The radar transmits Frequency Modulated Continuous Wave (FMCW) signal which varies up and down in frequency over a period of time. The signal in this period of time is named a chirp. A frame of signal is composed by several chirps.

B. Signal processing method

The purpose of signal processing is to obtain micro-Doppler signature for detected objects.

One chirp i is composed of n I/Q data, which is denoted as:

$$chirp_i = [I_1/Q_1, I_2/Q_2, \ldots , I_n/Q_n] \tag{1}$$

One frame f_j is composed of nc chirps:

$$f_j=[chirp_1, chirp_2, \ldots, chirp_{nc}] \tag{2}$$

Then, we do FFT for each chirp to get frequency spectrum corresponding to distance between detected object and radar. The amplitude of frequency spectrum is denoted as $amp(chirp)$:

$$FFT\{chirp\} \rightarrow amp(chirp) = [amp_1, amp_2, \ldots, amp_n] \tag{3}$$

In the vector amp, the max value is amp_{max}, and index of amp_{max} is id_{max}. According to amp_{max}, the distance between detected object and radar is calculated as:

$$id_{max}\times(c/2B) \tag{4}$$

where c is speed of light and B is frequency shift range of FMCW.

In one frame, it contains nc chirps. Therefore, a vector $[id_{max}(1), id_{max}(2), \ldots, id_{max}(nc)]$of max value for each chirp can be obtained. In this vector, most of id_{max} are same, and the most appeared value is defined as $id_{max}(f_j)$.

After finding id_{max} of each frame, we do 2D-FFT for each frame f_j and calculate magnitude of 2D-FFT result to get a distance-velocity matrix DV(f_j) as:

$$\mathrm{DV}(f_j)=\begin{bmatrix} \mathrm{dv}_{11} & \cdots & \mathrm{dv}_{1n} \\ \vdots & \ddots & \vdots \\ \mathrm{dv}_{i1} & \cdots & \mathrm{dv}_{in} \end{bmatrix} \tag{5}$$

After calculating matrix DV of each frame, the micro-Doppler signature matrix MD can be obtained. Assuming that the number of frame is nf, MD is composed of value in DV of each frame which column index is $id_{max}(f_j)$ as:

$$MD = \begin{bmatrix} md_{(1,1)} & \cdots & md_{(1,nf)} \\ \vdots & \ddots & \vdots \\ md_{(nc,\,1)} & \cdots & md_{(nc,\,nf)} \end{bmatrix} \quad (6)$$

In matrix MD, the j^{th} column is the elements in $DV(f_j)$ of which column index is $id_{max}(f_j)$. For example, the first column is the elements in $DV(f_1)$ of which column index is $id_{max}(f_1)$, and the second column is the elements in $DV(f_2)$ of which column index is $id_{max}(f_2)$.

C. Feature extraction method

In order to find features in micro-Doppler signature, a new method is proposed. It first makes matrix MD to a binary matrix MD_{binary}'. If element *md* is bigger than threshold t_1, then it is set to *p*; if element *md* is smaller than t_1, then it is set to *q*. After that, we calculate sum of elements in each column of MD_{binary}' as:

$$sum(j)=\sum_{i=1}^{nc}(md_{(i,j)}) \quad (7)$$

Then, we find the column index which satisfies conditions of:

$$sum(j)>sum(j\text{-}1), \text{ and}$$
$$sum(j)>sum(j+1), \text{ and}$$
$$sum(j)>t_2$$

Finally, the method extracts feature in the selected column j and its neighbor columns as a vector:

$$feature=\begin{bmatrix} \max(md_{(1,j-1)}, md_{(1,j)}, md_{(1,j+1)}) \\ \vdots \\ \max(md_{(nc,j-1)}, md_{(nc,j)}, md_{(nc,j+1)}) \end{bmatrix} \quad (8)$$

The process of obtaining micro-Doppler signature MD and the process of feature extraction method is shown in Fig.1.

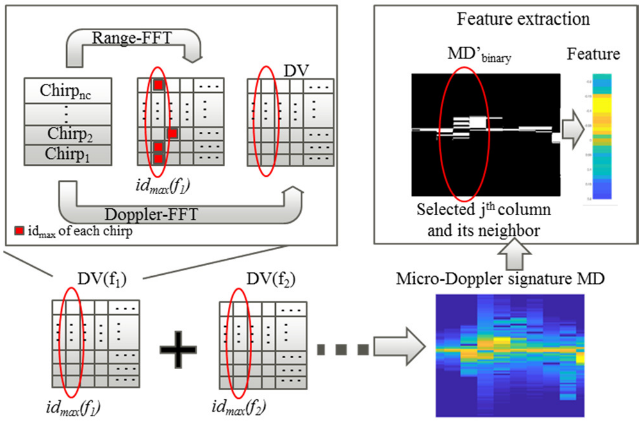

Fig.1. illustration of signal processing method and feature extraction method

We input the extracted feature to Support Vector Machine (SVM) to train a classifier. The kernel function used in SVM is linear kernel.

III. Experiment Result

In order to evaluate our proposed method, we set up a hardware platform and make a series of experiments.

The platform and object of our experiment is shown in Fig.2. Objects are concealed in clothes on the chest of PVC dummy. We use a millimeter wave FMCW radar. The frequency sweeps from 77.0359GHz to 80.1011GHz. The number of A/D samples in one chirp is 1024, and the A/D sampling rate is 2Mb/s. Number of chirps in one frame is 254.

Fig.2. Experiment platform and object

There are 4 scenarios in our experiment: human with concealed pistol, knife, mobile phone and nothing. The SVM-based classifier is trained by 20 samples of each scenario. In the classifier, scenario of pistol and knife concealed on human is labeled as "dangerous", and scenario of mobile phone and nothing on human is labeled as "safe". We do 50 times of tests for each scenario so that in total there are 200 times verification tests. The detection result is shown in table I.

TABLE I. EXPERIMENT RESULT

Experiment scenario / **Detection result**	***Dangerous***	***Safe***
Dangerous	97	11
Safe	3	89

The detection accuracy of dangerous object is calculated as 97/(97+11)=89.8%, and the miss alarm rate is calculated as 3/(3+97)=3%. In the result, there are 3 dangerous objects (knife) detected as safe object. Because there is no element value higher than threshold t_1 in micro-Doppler signature MD, no feature can be extracted. Therefore, they are determined as safe objects. There are 11 safe objects (nothing on human) detected as dangerous. Because there are some elements in micro-Doppler signature MD exceeds threshold t_1, the extracted feature are determined as knife by SVM classifier.

IV. Conclusion

In this paper, we propose a method which can extract features from micro-Doppler signature obtained by 77GHz radar. This method can be used to distinguish concealed objects. The proposed method is evaluated by experiments that the objects are concealed on a PVC dummy. The results show that it has accuracy of 89.8% and miss alarm rate of 3%.

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