IR-UWB Radar Sensor for Human Gesture Recognition by Using Machine Learning

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IR-UWB Radar Sensor for Human Gesture Recognition by Using Machine Learning

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Abstract— **In this paper, we propose a human gesture recognition algorithm using impulse radio ultra-wideband (IR-UWB) radar. The radar signal is transmitted into a three dimensional space, however, the received signal is only expressed in one dimensional. Therefore, it is difficult to classify 3-D gestures by analyzing specific features, such as power, peak value, index of peak value, and other values of received signal. To resolve this problem, a new human gesture recognition algorithm using machine learning is proposed. Two machine learning technics are used in this paper. One is unsupervised learning technic which is used for extracting features from received radar signal is principal component analysis, and the other one is supervised learning which is used for classifying gestures. The features are extracted by using the principal component analysis (PCA) method, then neural network method is used for training and classifying gestures using the extracted features. In training and classifying step, other method can be used, such as supporting vector machine (SVM), however, this method is hard to recognize noise gesture which means untrained gesture. To resolve this problem, we use neural network method in this paper, then in order to classy noise gestures and trained gestures, a noise determining algorithm is used.**

Keywords—hand gesture recognition; motion recognition; machine learning; impulse radio ultra-wideband (IR-UWB); radar sensor

I. INTRODUCTION

Nowadays, human motion recognition has attracted serious concern in a lot of fields especially in industry. Generally, the video technology is used for motion recognition [1], but the video has some drawbacks such as invasion of privacy, weakness of environmental factors like light, fog, and smoke. Contrastively, radar does not have these limits, therefore many researchers try to recognize human motion by using radar [2-4]. Hand gesture recognition using radar can control without direct contact so it can replace remote controller or switch. For example, when we need to control some equipment by dirty hand in the kitchen, we do not need to wash hands or pollute the equipment. Smart city need many smart sensors, and human gesture recognition radar sensor is very useful in many areas.

Impulse radio ultra-wideband (IR-UWB) radar is a type of UWB signaling technology which makes use of the streams of baseband pulses with extremely short duration, typical nanosecond order, hence spreading the radio signal's power spectral density form almost zero to a few gigahertzes. Ultra-wideband refers to radio technology with a bandwidth exceeding the lesser of 500 MHz or 20% of the arithmetic center frequency, according to the U.S. Federal Communications Commission [5]. The UWB radar, compared with the narrow-band radar, can obtain a higher time resolution by the relationship between frequency and wavelength. The higher the frequency is, the shorter the wavelength is. The signal transmits by UWB radar is very weak whose transmit power is lower than -41.3 dBm/MHz. Because of this reason the transmitter of UWB radar module does not need high power signal generator, therefore the system can be designed for low power consumption. In this paper, the IR-UWB radar consists of one transmit antenna and one receive antenna, and the detection range is 10 meters.

The machine learning is mainly used in solving the problems which are difficult to clearly express using algorithm. The result of machine learning may not an optimum answer, but it can be the best answer. So many researchers try to solve complex problems using machine learning. Recently the most famous case of machine learning is Google's AlphaGo. A machine learning also can be a good method for human motion recognition [6-9].

To recognize human motion using radar, we need to extract some useful features from received signal. But it is difficult for human to find useful features from the large data set which consists of many types of human motion. Therefore, machine learning is used in order to extract features from received signal. PCA which is unsupervised machine learning method is used for extracting features from received signal, and neural network which is supervised machine learning method is use for classifying human motion. SVM also can be used in classifying human motion [10], but it cannot distinguish noise gesture which means untrained gesture from trained gesture. It is because the output of SVM is always 1 or 0, so it cannot derive the different answer from untrained input. Contrastively, the output of neural network does not have these limit, so the neural network can make up for the deficiency of untrained input.

This paper is organized as follows. In section 2, experimental set up, measurement method, and signal processing method for

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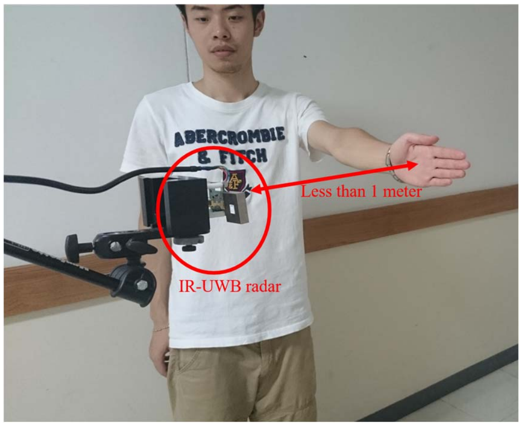
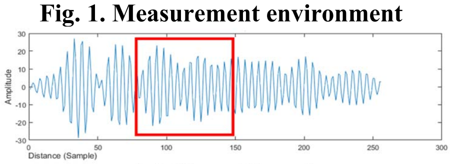
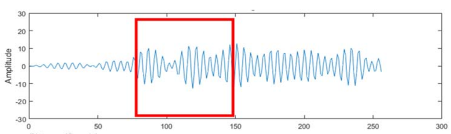


Fig. 1. Measurement environment



(a) Raw Signal



(b) Filtered Signal

Fig. 2. Comparison of radar signals.

feature extraction are described. In section 3, feature extraction using PCA and feature selection for training are described. In section 4, gesture recognition method, experimental result, and noise decision method are described.

II. Gesture Measurement

The gesture measurement environment is described in Fig. 1. The detection range of IR-UWB radar is set from 0-meters to 1-meters and hand gestures are measured in this area. The hand gesture mentioned in this paper is continuous motion and the observation frequency of IR-UWB radar is 40 times per second.

The received radar signal is described in Fig. 2. (a). We call a received radar signal as raw signal. In this figure, the red squared area is hand existing area. The raw signal contains background information like human body, and unwanted signal from obstacle. Therefore, in order to measure the gesture accurately, background signal removal step is required. Fig. 2. (b) shows the background subtracted signal. We call a background subtracted signal as filtered signal, and this signal contains only moving component from raw signal. in order to improve the accuracy of gesture recognition, both the raw signal and the filtered signal are used. and we are just interested in the signal of the hand. The received radar signal consists of 256 samples per meter, however, we are just interested in hand motion so there is no need to observe all samples. From experiments, we observe that the signal of hand movement contains 81 samples, therefore only these samples are used in this paper.

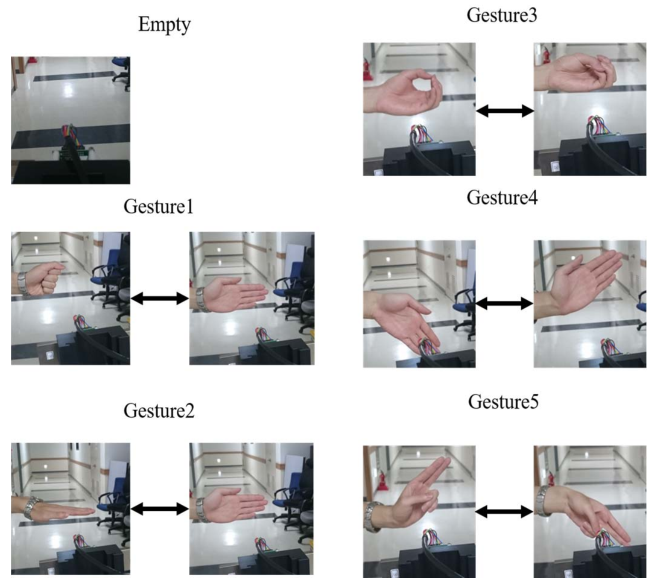


Fig. 3. The definition of gestures

We define six gestures in this paper, and the gestures are described in Fig. 3. From the figure, we can observe that it includes five continuous gestures and background only situation. We call a background only situation as an empty gesture.

In our experiment, the radar measure 2700 times for one gesture. As mentioned at the beginning of this section, the observation frequency of radar is 40 times per second, so 2700 times means 67.5 seconds. In this duration we repeat same gesture motion in similar speed. Training set is made up of 2200 signals which are randomly selected from measured data, and the test set is made up of the remaining 500 signals from measured data which are used for verification.

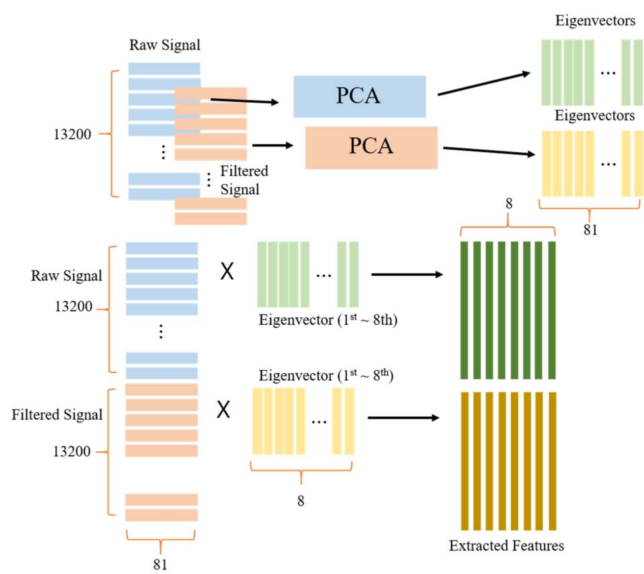
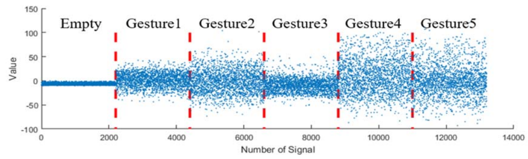
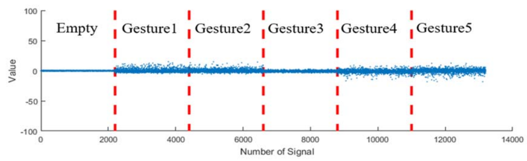


Fig. 4. The block diagram of feature extraction



(a) 1st Feature



(a) 9th Feature

Fig. 5. The feature of raw signal.

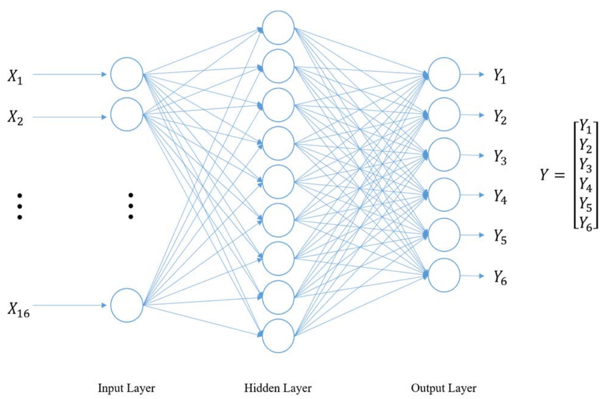


Fig. 6. The neural network for gesture recognition

III. Feature Extraction

In this section, feature extraction is introduced. For gesture recognition, although we can put the training set into the neural network directly for training, it exists some problems. In this case, the number of features is equal to the length of hand movement signal, it means that the computation load is very high. It also has hazard of overfitting problem. For machine learning, numerous features do not always return good result, selection of right features are more important. So we need to select significant features from training set, PCA works on this mission. The PCA is a kind of unsupervised learning, it helps to categorize cluster of data set and reduce the size of data. The block diagram of feature extraction method is described in Fig. 4.

We can get 81 Eigenvectors from the raw signal and 81 Eigenvectors from the filtered signal by PCA. We choose 8 Eigenvectors in descending order of Eigenvalue for each signal. Each feature is presented by one value which is made of vector multiplication of hand movement signal and Eigenvector. The length of the input signal is 162 samples, and it has been compressed into 16 features by using PCA. The feature made of multiplication of training set and one of the Eigenvectors is described in Fig. 5. (a). We can choose more than eight Eigenvectors, the feature which is made of the 9th Eigenvector

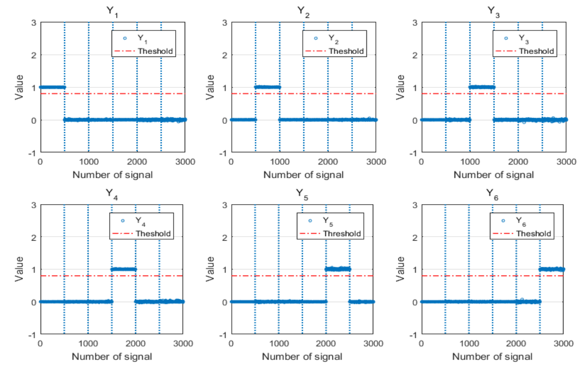


Fig. 7. The result of validation check

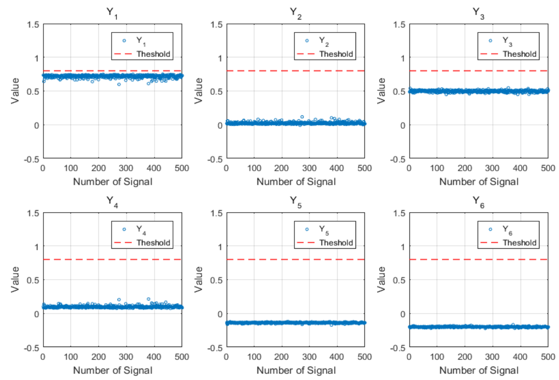


Fig. 8. The result of untrained gesture

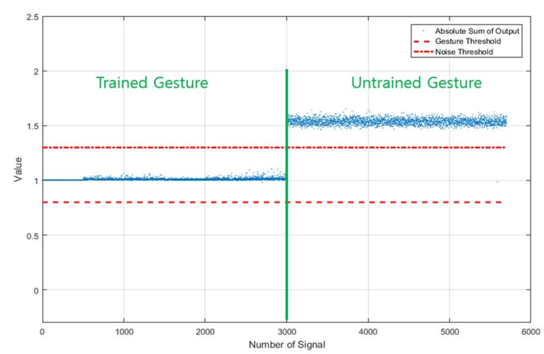


Fig. 9. The Difference between trained gesture and untrained gesture.

is described in Fig. 5. (b). From the figure we can observe that the 9th feature does not have any special characteristic among different kinds of six gestures, so it is worthless feature. Therefore, 16 features, 8 from raw signal and 8 from filtered signal, are used for training input data.

IV. Neural Network Training

We use neural network for classify gestures. The neural network is described in Fig. 6. The neural network has one hidden layer, and the output is a matrix form. The hidden layer has nine units and output layer has six units. This neural network trained by scaled conjugate gradient method and back-propagation algorithm. After the training, the test set put into trained neural network to validate training. The result of validation by test set is described in Fig. 7. So we can classify gestures by using threshold value.

If untrained gesture put into the trained neural network, it has to classify noise. The output of untrained gesture is described in Fig. 8. The output of untrained gesture has various component, and it can distinguish trained gesture and untrained gesture. The absolute sum of output is described in Fig. 9. The absolute sum of trained gesture converges on 1, but the absolute sum of untrained gesture exceeds 1. So we can make threshold value for noise decision, and it described red line in Fig. 9. The accuracy of gesture recognition is listed in the Table1, and Table2.

TABLE I. THE ACCURACY OF GESTURE RECOGNITION

Gesture	**Result of Recognition**		
	Number of Trial	***Number of Correct***	***Accuracy***
Empty	500	500	100%
Gesture1	500	500	100%
Gesture2	500	500	100%
Gesture3	500	500	100%
Gesture4	500	500	100%
Gesture5	500	500	100%

TABLE II. THE ACCURACY OF NOISE DECISION

Gesture	**Result of Recognition**		
	Number of Trial	***Number of Correct***	***Accuracy***
Trained Gesture	3000	3000	100%
Untraine d Gesture	2700	2699	99.69%

The total gesture recognition accuracy is 100%, and the accuracy of noise decision is 99.69%. The accuracy is very high, and we can say the new algorithm shows the possibility of gesture recognition. In addition, the gesture4 and the gesture5 are very similar but it distinguishable. It means that smaller gestures can be classified.

V. CONCLUSION AND FUTURE WORK

A new algorithm for hand gesture recognition are proposed using IR-UWB radar. We can recognize hand gesture by analysis characteristic of received radar signal. But it is very difficult to human, it need to new strategy. The new strategy is machine learning, and we use PCA and a neural network. Using principal component analysis, we can extract useful features and reduce number of features. The neural network has advantage of distinguish trained gesture and untrained gesture. The trained neural network can classify gestures and noise. The proposed algorithm is reliable, and it need to more study.

In this paper, we use 6 gestures for gesture recognition. And similar gestures are distinguishable, it is worth to try smaller gesture. In the future, we add more gestures and try to classify gestures that made only fingers movement.

VI. ACKNOWLEDGEMENT

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