A study of FPGA-based real-time action estimation with multiple accelerometers

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Abstract: This study proposes an approach to estimate human action in real-time by analyzing sensing data from multiple accelerometers with FPGA. The body action distinguished by sensing data is estimated by a neural network called a self-organizing map (SOM). It produces a low-dimensional representation of data sensed by multiple accelerometers using unsupervised learning. It can visualize them in the learning space automatically and classify humans' actions with high accuracy. However, the iterated computation on SOM requires many computational efforts, which requires choosing efficient computational chips. In this study, FPGA was chosen to develop a computational technique because the spatial parallelism on FPGAs is useful to implement SOM parallelism. In our experiments, the trial system comprises one Xilinx Spartan-6 FPGA, a small FPGA, and five multiple 9-axis sensors. Although it was small and straightforward, it could distinguish five actions: walk, run, stand, stair-up, and stair-down.

Keywords: FPGA, Self-Organizing Map (SOM), human action detection, monitoring

1. Introduction

Human action recognition is a fundamental technology with immediate applicability to system control, sports monitoring, driving behavior analysis. It can be extended to improve system control and analyze human behavior for rehabilitation aid. However, it requires distinguishing person-to-person variability and adapting to a person by using new data captured by sensors. Thus, the computational effort tends to be large and has been off-loaded to particular hardware accelerators after capturing data. If it can implement a small-sized, wearable, and low-cost system with low-power consumption, the use of human action recognition will be spread to many fields.

This article proposes an approach to realize the system on an FPGA, and the computation is done in real-time because of accelerating by massively parallel circuit design. To achieve high-speed computation, this approach chooses a neural network called a self-organizing map. SOM is an appropriate learning approach with FPGAs' affinity because its spatial parallelism can be represented as a parallel circuit efficiently. Besides, its pipelined circuits can propose a low-latency circuit for high-speed and low-latency computation. In this study, we proposed and implemented the SOM-based sensing analysis on FPGA, and it could distinguish five motions with high accuracy.

2. Proposed System

In this study, five accelerometers are used to capture the X-, Y-, and Z-axis acceleration in real-time. In the future, the number of sensors will be increased. The larger the number of sensors, the larger the SOM size, which makes the recognition and prediction results more accurate. However, it increases the complexity of the neural network.

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In the current stage, as shown in Figure 1, five sensors are placed on a person's feet, arms, and waist. That is because the limbs' speed and direction are different when the person is doing different exercises. The waist is about the center of the person, which can sense the direction and speed of the person's movement as a whole.

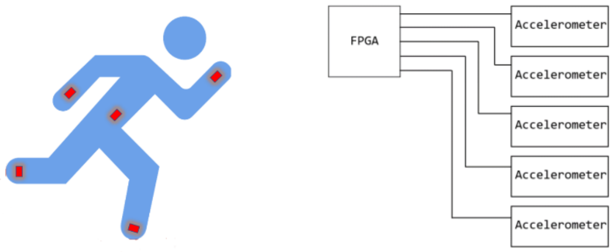

Figure 1 Position of accelerometers and the system overview

The entire system is built based on FPGA. FPGA is the host responsible for controlling sensor data reading and writing, and decoding and analyzing it. Because FPGA has the characteristics of high parallelism and low latency, it can control multiple sensors simultaneously and perform synchronous real-time processing on the data transmitted by them.

3. Experiment

To obtain training data, you can use the sensor measurement application provided by Sports Sensing. A total of five sensors are placed on a person's arms, feet, and waist, and communicate with a computer wirelessly. In the preliminary training, people will perform walking, running, standing, and stairs up and down movements. The duration of each movement is one minute—the sensor samples at 200 Hz. After the measurement is completed, the data is collated. Since five three-dimensional accelerometers are used, each sample will be a 15-dimensional vector. Each action will be sampled 12,000 times.

In this training experiment, 5000 samples were selected from each action data set to form a training set with 20000 15-dimensional vectors and 5000 vectors for testing set. The side length of the SOM neural network's output layer is 27, and the corresponding number of neural in the output layer will be 729. After that, the data will be input into Matlab's neural network and perform 200 iterations to train the SOM neural network.

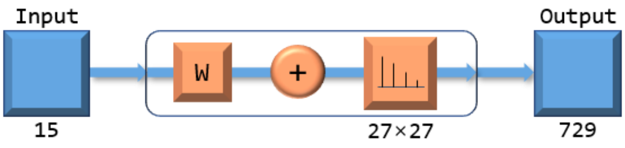

Figure 2 SOM Process

4. Results

After 200 iterations, the clustering results can be analyzed by observing the SOM nearest neighbor weight distance. In the image below, dark blue hexagons represent neurons. Red connects adjacent neurons, and the color in the area containing the red line indicates the distance between neurons. The darker the color, the distance between neurons is longer. It can be seen from the diagram below that the darker color band also divides the graph into several parts, which means that the data input into the network is clustered into several different groups.

However, the change of motion is a continuous process, when discrete sampling is performed on this continuous process, some data in the comparative boundary state cannot accurately represent the characteristics of this behavior, which is also a noise for motion analysis using accelerometers.

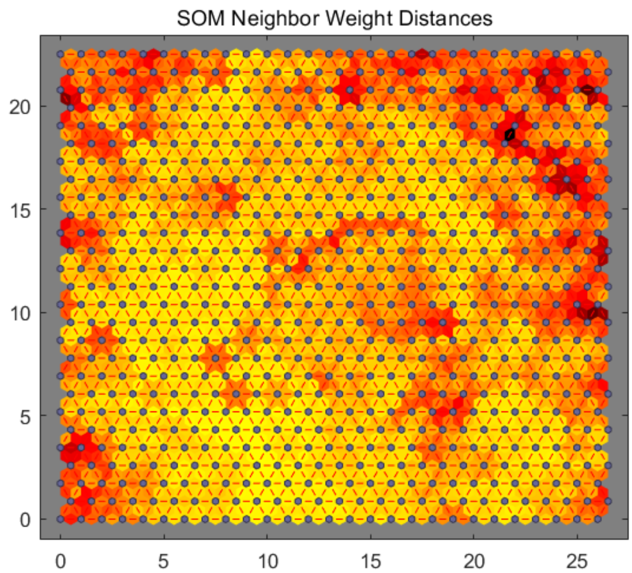

Figure 3 Result of SOM Neighbor Weight Distances

It is possible to get a detailed clustering information of each neuron by using python script, and the testing set can be used to evaluate the classification accuracy. By now, the classification accuracy could reach more than 81% considering the influence of noise.

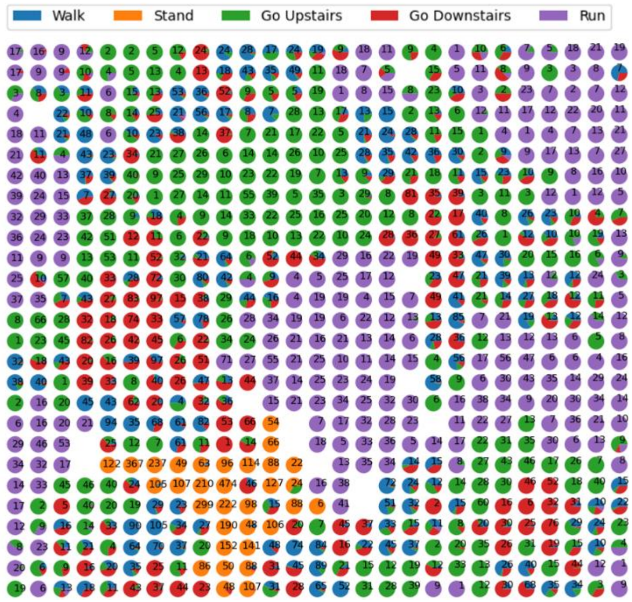

Figure 4 Label information of each SOM neuron

5. Conclusion

This study proposes a method based on FPGA for clustering the acceleration data input into the SOM neural network to achieve the estimation of human movement. Sensors placed on the person's feet, legs, and waist have collected acceleration data during different movements and used these data for training. The SOM neural network trained in Matlab can roughly divide the data into 5 categories with an accuracy more than 81%, but it can also be seen from the obvious noise impact.

Reference

[1] T. Ito, "Walking Motion Analysis Using 3D Acceleration Sensors," 2008 Second UKSIM European Symposium on Computer Modeling and Simulation, Liverpool, 2008, pp. 123-128, doi: 10.1109/EMS.2008.95.

[2] A. Jalal et al, "Depth map-based human activity tracking and recognition using body joints features and Self-Organized Map," Fifth International Conference on Computing, Communications and Networking Technologies, 2014, pp. 1-6.

[3] M. A. de Abreu de Sousa and et al, "An FPGA distributed implementation model for embedded SOM with on-line learning," 2017 Int’l Joint Conf. on Neural Networks, 2017, pp. 3930-3937.

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