Movement-Type Classification Using Acceleration Sensor

Chu-Hui Lee and Jyun-Han Liou

***Abstract*—The most common moving processes include walking, running, going up stairs, and going down stairs. People distinguish the first two types of movement based on their perception of speed. However, people's values are different, making it difficult to distinguish walking from running objectively. On the other hand, speeds of walking are usually not far from speeds of going upstairs/downstairs. Thus, it is difficult to train a computer to objectively distinguish these four types of movement only based on "speed". This study tried to find a way to quantify movements during the experiments. Also a sensor was used in the experiments to help obtain the data during the movements. The sensor could continuously record the detailed information of each movement using packets. The pattern of each movement was represented using the corresponding acceleration data along the three axes of this study, the x axis (horizontally moving back and forth), the y axis (vertically moving up and down), and the z axis (horizontally moving in and out). Through the Fast Fourier Transform, the differences among various types of movement were observed. The extracted information was further used as the basis for computers to distinguish the four types of movement, walking, running, going upstairs, and going downstairs.**

***Index Terms*—Fast fourier transform, walking-pattern, running-pattern, motion profile.**

I. Introduction

Walking and running, are usually distinguished by people based on their value (of speed) judgments and inductions regarding these two types of movement. However, people's subjective definitions of speed are different. Thus it is very difficult to objectively classify walking and running based on speed. To try another perspective, some scholar had proposed the different phenomenon between these two types of movement [1], [2], for example, the airborne phase can be found during running [2], but it is still a challenge to expressly indicate this phenomenon in quantification independently through one single device or computer. Hence, this study has attempted to find the key factors from the movement for the purpose of training a computer to distinguish walking, running, go upstairs and go down stairs further.

This study used a sensor during the process of collecting motion data from the experiments to help record various information of movement. According to the recording rules of the sensor, these data of the detailed information of the movement processes were stored in the form of packets. During each movement, the packets were stored through binary input-stream into a .bin file. Then with the corresponding recovering function of the sensor, each .bin file was decompressed into 8 .csv files, which contained the packets of the related characteristics (for example, all the packets in CalBattAndTherm.csv were used to record the battery voltage and the information from the thermometer). Through the data in the files DateTime.csv and CalInertialAndMag.csv, the information regarding the characteristics recorded by the sensor, sampling methods, and sample sizes could be retrieved.

Each of the motion data was composed of many packets. The sensor created 390 packets per second for recording. In order to observe the differences between different types of movement and the associations between movements of the same type, it was necessary to collect continuous motion data for observation. Thus, this study invited 7 people to participate in the experiments for data collection. During the process, they had to put on the sensor. And they did not start moving until making sure the sensor had started recording. Considering the required stability of the experiment results and the physical strength of the research subjects, in this study, the subjects were asked to perform the walking movement before running and take a break after running before the movements of going upstairs and downstairs.

A distinguishing feature of this study was that the research subjects were allowed to perform movements within a larger range for motion data collection. Thus, their movement habits were not limited by any rules. Then, the sensor was tied to their foot right above their right ankle. In this way, they wouldn't feel being influenced when moving and the sensor wouldn't get loose or come off while the subjects moved. Under this circumstance, the subjects' movements would be closer to their movements in their daily life so the data would be more conform to nature. And this study applied the Fast Fourier Transform to these data in order to describe the differences and relationships between different types of movement.

The following part is an introduction to the previous work and to briefly discuss the studies related to this research in Session II. Next, Session III is going to describe how the data were collected in this study. The content includes the processes of movement, the information regarding the sensor and the subjects, and how the collected data presented. About the features which this research adopted and how to extract the features of the movements from these data to perform classification are in Session IV. The final session is the conclusion of the research.

II. Previous Work

Although we can see these four types of movement in our surrounding very often, it is still very difficult to help a computer to distinguish any two or all of the four types of movement. Many studies have used various methods to explore the differences between different types of

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movements, from considering the physical side such as muscle changes to observing movement processes. All these scholars have had their unique opinions based on their experiments. About the three movements, walking, going upstairs, and going downstairs, Jeen-Shing Wang *et al*. [3] attached a sensor to their subjects' right foot just above their ankle to collect the data of their walking. The collected data were compared with the observed rhythms of the gaits. Each cycle was called a gait cycle, containing four phases. That study combined the collected data and the previous study results to determine the types of walking and estimate the distances of moving. Laura Guidetti, another scholar, used electromyography (EMG) to analyze the motion changes in the seven muscle groups focused by the experiments while the subjects ran, and then proposed the connections among the seven muscle groups during movements [4]. EMG was also applied to observe muscle group motions during movements in the studies by Marnix G. J. Gazendam and At L. Hof [2]. They first defined a specific range of movement speed. Then, their research subjects were asked to run at various speeds on the treadmills. Then a special function was used to collect the information of the gait rhythms. In other words, while collecting the EMG data, the treadmills were also collecting gait rhythm information of the current movement. These two scholars combined the information from two devices to categorize the types of movement with previously defined speeds (walking, jogging, and running). There have also been studies using different devices to classify movements. For example, Thyagaraju Damarla [5] combined four different sensors (Acoustic, Seismic, Ultrasonic, and E-Field). This study indicated the experiment results showed that within a fixed range the types of movement of objects could be determined, as well as the number and types of the objects. Similar to the three previously mentioned studies, this study also limited the space for the subjects' movements or the observation space. What is special is that this study mainly aimed to find out whether there was an object moving into that space, the number of objects in that space, and these objects' movements.

There have been various studies regarding the differences between walking and jogging which are all very interesting. This kind of experiment often collects motion data through equipment or a device (e.g. EMG, treadmill, acceleration sensor, etc.) and then performs observations and analyses. Thus, this study defined the research issue as classifying the motion data of the research subjects collected from their various movements. In the data collection phase of this study, a sensor was attached to each subject's right foot right above the ankle (the end of the lower leg). In the fixing position, the device would retrieve the motion data from the walking, running, go upstairs, and go down stairs movements of the subjects. Furthermore, the sensor used in this study would not influence the subjects to perform movements. And it could collect data within a large range. This way, the experiment data would be closer to motion data from real life.

III. Motion Data Collection

A. The Process of Movement

This study assumed that people perform four types of movements, running, walking, going upstairs, and going downstairs, using their both feet continuously at a steady speed (in other words, during each movement, they don't actively increase or decrease their speed.). During the experiments, the subjects were asked to wear a sensor above their right ankle for the research. Before each movement began, it was required to check if the recording function was working before starting to collect data.

B. The Sensor

The sensor used in this study was sold from the x-io Technologies Corporation in UK (Fig. 1). It helped to collect the motion data during the movements. When the sensor started to record, the information was stored in a .bin file in the form of packets of binary input-srationtream. As the recording rule changed, the packets would continuously store the information of the corresponding motions. The sensor stopped recording when receiving the sleep or stop command packet. Each .bin file contained a type of motion data. This study invited several people to be the research subjects to perform the four types of movement in order to provide the motion data for observation. Each of them had a sensor titled to their right foot right above their ankle. A piece of Velcro was attached to the back side of the sensor during the experiments to make sure the sensor could be tightly fixed during large movements. The Velcro could be adjusted based on the size of each subject's lower leg.

C. Subjects

This study invited seven people as the research subjects to help collecting motion data. The average age of these subjects was 23 (S.D. = 0.5774). Each of the subjects had to perform the four types of movement in the order of walking for 400 meters, running for 400 meters, going upstairs, and going downstairs. Each subject performed the movements separately. The order of the four types of movement performed for data collection was: walking, running, going upstairs, and going downstairs. There was a 10-minute break between two movements, so that the subjects wouldn't be too tired and the motion data would be more accurate. Each subject had to wait on the movement path before every movement. When the sensor was activated and started to record, he would start to perform the movement. When the movement was completed, the sensor stopped recording to avoid collecting too many noises which might influence the experiment data. In addition, in case an animal or other resident showed up on the path while a subject was performing a movement, this study allowed the subject to go around the animal or the resident without stopping or suddenly increasing his moving speed and with his both hands swinging. Or the experiment could be stopped and started over.

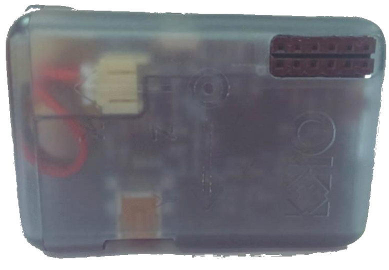

Fig. 1. Font of sensor.

D. Data Presentation

All the collected motion data were stored in the memory card of the sensor in the form of a .bin file. After using the “recover” function provided by the x-IMU, eight .csv files were extracted. This study tried touse the CalInertialAndMag.csv (CAM) file to detect possibly features based on the data of acceleration along the three axes in the .csv file, the differences between different types of movement were found and used to help the computer for classification. The three axes were presented using the Cartesian coordinate system. The horizontal axis represented the order of the packets from the CAM file, which values began with 1 and ended with the packet number of the last entry in the CAM file. The vertical axis represented the acceleration values along the three axes from the CAM file. The fluctuation profile color blue, red, and green represent the values along the x axis, y axis, and z axis, respectively.If the three axes observed separately, three profiles along the three axes could be obtained. Thus, this study could apply the Fast Fourier Transform at each fluctuation profile to explore the correlation and the difference of the profiles of movement.

The motion data (acceleration values along the three axes) of the four types of movement performed by one of subjects were presented in the coordinate system, as Fig. 2. No. 65, 66, 67, and 68 represent walking, jogging, going upstairs, and going downstairs, respectively. These four pictures are also the one of 100 times of randomly sampled. That could be observed which are construct of similarly periodic fluctuation in each same motion data, so it is one of reason why this study could apply Fast Fourier Transform on the motion data. In contrast, different motion was constructed by different fluctuation. However, the fluctuations are still similarity and periodic in a same motion data of a subject.

Fig. 3 is the fluctuation of motion data from another subject, no. 79, 80, 81, and 82 represent walking, jogging, going upstairs, and going downstairs, respectively. It could prove that even if in the same motion, the fluctuation of different subject would be similarity.

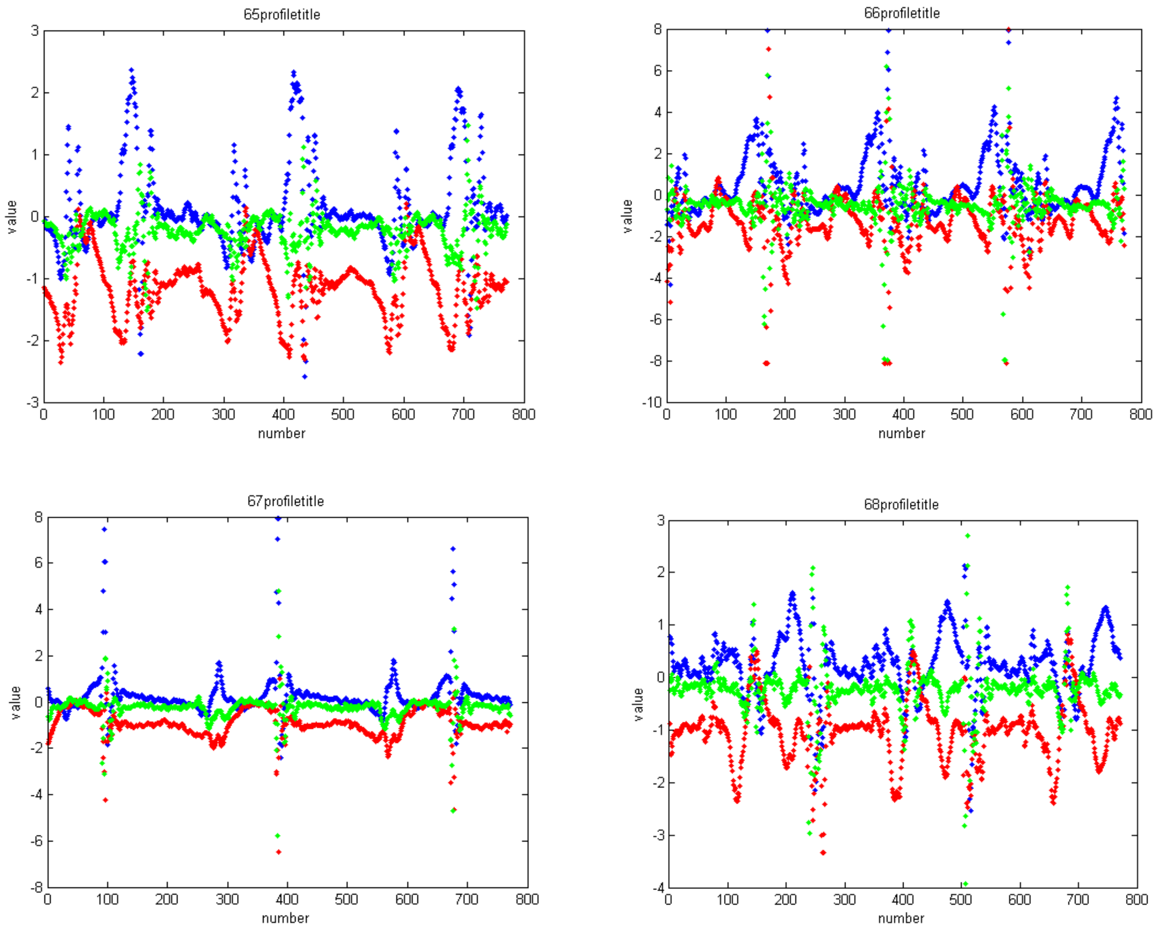

Fig. 2. The motion data (acceleration values along the three axes) of the four types of movement performed by subject A were presented in the coordinate system.

IV. Experiment Method

The axes were based on the direction of the sensor. The correlations of the data along the z axis were rather weak, for the values on the z axis represent the subjects’ lower leg angel toward the inside or the outside while moving. These values were usually related to their personal habits no matter they were walking, running, or going upstairs/downstairs. The influences of these data were rather small. Thus, before the analyses were performed, the acceleration data along the z axis were discarded, for the purpose of reducing the extra time spent on analyses. Then, the Fast Fourier Transform was applied to the acceleration data along the x axis and y axis (see Eq. 1) to find out if there was any significant difference among these four types of movement.

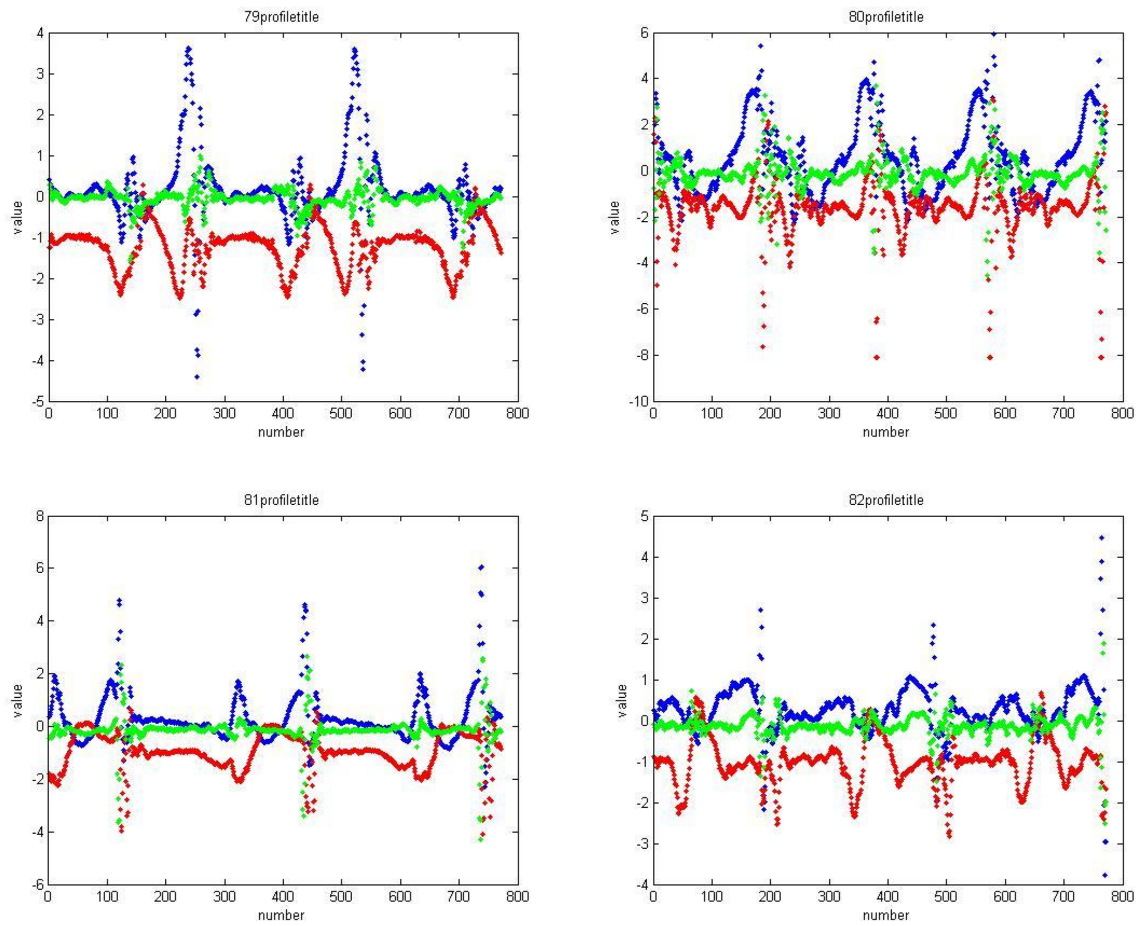

Fig. 3. The motion data (acceleration values along the three axes) of the four types of movement performed by subject B.

$$y_j = \sum_{k=0}^{n-1} e^{\frac{-2\pi i}{n}jk} \cdot x_k \quad j = 0,1,\ldots,n-1 \tag{1}$$

where y_j is the predict function of the Discrete Fourier Transform. During the calculation in this study, the order of time $O(n^2)$, and it was reduced to $O(n\ logn)$ through the Fast Fourier Transform for operations. The profiles were transformed into values in the frequency field through the Fast Fourier Transform. This study found that the distributions of the acceleration motion data along the x axis and y axis after the Fast Fourier Transform were rather concentrated in the Cartesian coordinate system than before the transform, as shown in Fig. 4, shows the data of the 100 randomly sampled and different 5-second continuous time periods from each set of motion data. The green dots represent the motion data of different subjects while they walked, while the black, red, and blue ones represent those of different subjects while they ran, went upstairs, and went downstairs, respectively. The acceleration values along the x axis and y axis of each set of motion data were transformed using the Fast Fourier Transform and marked in the Fig. 4. The vertical axis of the Fig. 4 represents the y-axis acceleration after the Fast Fourier Transform, while the horizontal one represents the x-axis acceleration after the Fast Fourier Transform.

In the graph, different colors represent different types of movement. It is obvious that the motion data of similar movements after Fast Fourier Transform were usually gathered within the same area. However, to help a computer to automatically determine the types of movement, extra judgments were required. This study used the C-SVM classifier to divide the four types of movements and set up the interval between the motion data of two different movements as shown in (2):

$$\frac{1}{2}\, w^T w + C\sum_{i=1}^{N} \xi_i \tag{2}$$

$$k(x,y) = exp\ (-gamma \times |x-y|^2) \tag{3}$$

The value of w indicates weight was set to 1, parameter C represented the risk was set to 1000. The index i labels the N training cases and theξ represents parameters for handling inputs. The kernel function of the classifier C-SVC was the radial basis function (3). The parameter gamma was set to 0.00125. There were five sets of motion data in this study. We randomly sampled a continuous five-second time period from 4 different motion data(running, walking, go upstairs, and go down stairs) individually, of each set, to retrieve the acceleration values along the x axis and y axis and repeated this sampling for 100 times for each set (with no the starting packets number of any two sets are duplicate). Hence, there are non-duplicate fluctuations were exist in these 100 sample. This way, it helped to examine whether the acceleration features along the x axis and y axis after the Fast Fourier Transform met the requirements for classification.

V. Conclusion

There have been few studies classifying the four types of movement, walking, running, going upstairs, and going downstairs using a few features and one single device. However, there are a lot of software packages (APP, smart watch, etc.) available which can help users to find out the duration and distance of movements from beginning to end. Yet, the paths drawn on graphs can hardly further present the interactions between movement processes. Especially, those who just started to jog or walk may easily change their speed, meaning they may sometimes run, sometimes walk, and even sometimes stop walking. However, some of these people may want to monitor their calorie consumption while doing exercise. The method we developed can be a precise foundation to develop some useful product for this group of people, so that they can record their amount of exercise from walking and running separately and specifically during their exercise. This way, they can have a better control of their calorific capacity.

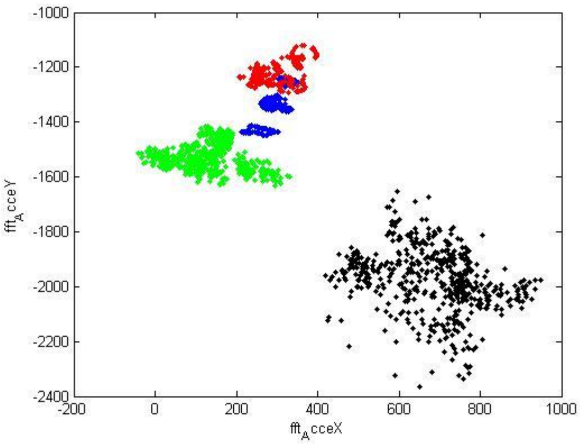

Fig. 4. This graph shows the data of the 100 randomly sampled and different 5-second continuous time periods from each set of motion data after fast fourier transform.

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