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Movement Classification based on Acceleration Spectrogram with Dynamic Time Warping Method

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***Abstract*— In this paper, we propose a movement classification model using acceleration spectrogram combined with dynamic time warping method. First, the proposed system collects data sets from a mobile device embedded acceleration sensor, and filters only coordinate data, which has an effect on the states of movements. Then the data sets in the form of frequency are converted into spectrograms. The RGB color vectors in these spectrograms are used to classify the states of movements. In order to classify these changes, a DTW algorithm is used. Finally, we validate the feasibility and applicability of the proposed model by implementing and applying it to three typical human navigational movements, namely, plain walking, going upstairs and going downstairs.**

Keywords—movement classification, acceleration data processing, spectrogram processing, dynamic time warping

I. INTRODUCTION

Recently, mobile devices, which are essential part of everyday life for browsing and exchanging information, become smaller and more personalized [1]. These technical developments have caused users to be able to use devices with indiscreet and unlimited accessibility. These infinite usages of devices could lead users not to be aware of or perceiving the surroundings. Therefore, potential carelessness in using mobile devices could trigger accidents such as falling and being tripped. In order to prevent people from such undesired events, it is necessary to identify and monitor a user's navigational movement patterns.

Various researches have been conducted with pertinent techniques such as acceleration signal handling and image processing. The authors in [2] propose a vision-based control system for a mobile robot to detect the movement in terms of the computer vision perspective. With using variable sensors such as wearable sensors, many instances of studies for detecting human movements or motions have been performed to prevent unexpected fall or accident in combination with identified location captured by GPS or indoor localization system. In general, accelerometer is widely used to detect various human movements. For example, the authors in [3] attempted classification of movements by using acceleration sensor and flex sensor. Group of authors at Carnegie Mellon University[4] introduced a performance animation system based on five accelerometers embedded in a shirt which streams data to a computer and accelerometer reading are continuously matched against accelerations identified from existing motion capture data. In addition, the other group of researchers in [5] proposed a system, which could classify a lower lib motion state such as walking, running, going upstairs and downstairs. Obviously, identifying unique pattern for each human action represented by unique accelerometer signal pattern would be the key for successful implementation of such applications.

Unlike precedent studies, we propose an efficient and effective way of classifying typical human navigational actions; walking on a flat surface, going upstairs and downstairs based on multiple sets of spectrograms acquired through accelerometer embedded in a mobile device. In terms of spectrogram handling, a group of researchers in [6] classified the heartbeat sound based on scaled spectrogram and partial least squares regression. Similarly, our proposed system also uses spectrograms that are converted from different sets of frequency data to detect navigational movements. However, proposed system uses spectrograms in the form of images. Those studies in this regards have been conducted in many instances [7, 8, 9]. Representatively, the authors in [7] use the spectrogram images to analyze a set of Doppler information of drone in time and frequency domains by using Convolutional Neural Network (CNN).

The proposed system in this research makes it possible to classify three typical navigational movements of a user using acquired acceleration data sets varying in time dimension. The acceleration data sets from an accelerometer are used to obtain extracted features. These extracted features are then processed to be the input sets of DTW (Dynamic Time Warping). DTW is one of those widely used algorithms in speech recognition and speaker recognition for measuring the similarity between two temporal sequences that may vary in time [10]. Based on the similarity obtained by DTW, distinctive navigational movement states of a user could be classified. In this paper, classification of such movements is focused on three modes, walking on a flat surface, going upstairs and downstairs.

The remainder of this paper is organized as follows. Section II presents our proposed movement classification system using acceleration spectrogram. The experimental results are demonstrated in Section III. Finally, concluding remarks are given in Section IV.

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II. MATRIALS AND METHODS

A. Overall Architecture of the Proposed System

Figure 1 demonstrates an overall concept of the movement classification system using the spectrogram image and dynamic time warping method which is proposed in this paper. As illustrated in Figure 1, the proposed system consists of three modules; 1) data sensing module; 2) preprocessing module; 3) signal classification module. In the data sensing module, data sets are collected with a mobile device embedded accelerometer. Collected sensor data is processed and only a single axis (z-axis) acceleration is filtered out. Then the frequency data is converted into a spectrogram by a preprocessing module. In this research, we take spectrogram in the form of an image and process it with image processing technique. A RGB color vector is extracted from a spectrogram and feature reduction process is conducted with this module. Finally, we apply DTW algorithm to classify a distinctive state of movement to transfer it to a server or service provider.

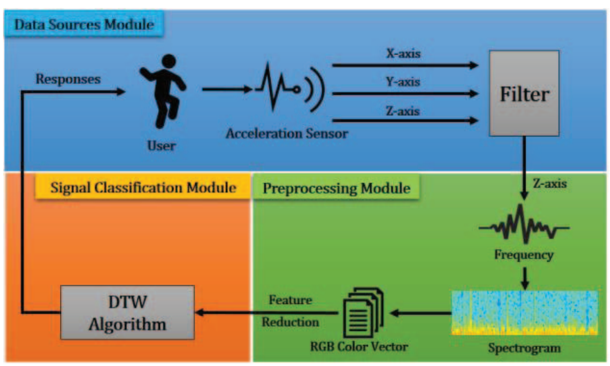
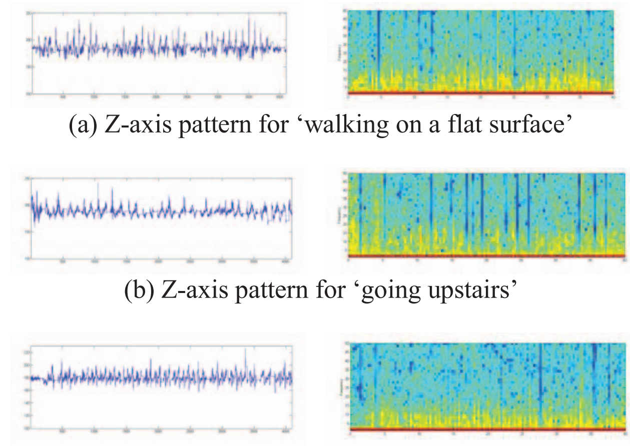


Figure 1. Overall architecture of the proposed model

B. Data Sources

Accelerometer recently becomes a fundamental element of smart devices such as smart phone and tablets. In addition, accelerometer is widely utilized to classify and analyzes walking motion as well as other human physical actions [11,12]. Acceleration normally has three values in accordance with its dimensional diversification. In this research, only z-axis acceleration processed by using a filter is used to classify the state of a user's navigational movement. Among the test cases of going upstairs, down stairs or walking on a flat surface, z-axis acceleration difference identified with those movements is turned out to be larger than that of any other axis.

In many other precedent researches, measured acceleration values in time domain were directly used to assort the state of a certain movement. However, our research uses the spectrogram of acceleration to classify the state of a movement. Since spectrogram normally has richer set of information out of the measured data sets including time, frequency and magnitude when compared to mere values measured in varying time dimension. Accelerations are sampled with 100Hz. Figure 2 shows measured acceleration value series and corresponding spectrogram for 'walking on a flat surface', 'going up stairs 'and 'going down stairs' movements.



(a) Z-axis pattern for 'walking on a flat surface'

(b) Z-axis pattern for 'going upstairs'

(c) Z-axis pattern for 'going downstairs'

Figure 2. Z-axis acceleration and spectrogram

C. RGB Sequence Extractions

In order to classify the target movements, we used RGB color features hidden in spectrogram images which are transposed from frequency plots. These spectrogram images consist of columns and rows, as notated c and r, respectively. Plus, c and r have RGB color values in each pixel. Figure 3 shows a sample of such spectrogram. Pixel P which includes those coordinates such as x and y, has R, G, and B values.

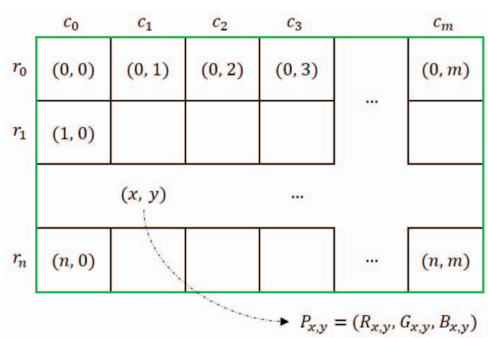


Figure 3. Sample of a spectrogram image

Each spectrogram image has $n * m * 3$ (R, G and B) dimension. However, since these values have a large dimension, it is essential to reduce computational complexity. In order to lower feature dimension, we adopted only most influential features in the spectrogram images. As one of the promising approaches, we conducted summation of each R, G and B for each column, and the largest set is identified as the following equation (1):

$$f_{sel} = Max(\sum_{i=1}^{n}\sum_{j=1}^{m} R_{i,j}, \sum_{i=1}^{n}\sum_{j=1}^{m} G_{i,j}, \sum_{i=1}^{n}\sum_{j=1}^{m} B_{i,j}) \quad (1)$$

In other words, by following the equation (1), one of those color vectors out of R, G and B, represents the total spectrum images. In our cases, $\sum_{i=1}^{n}\sum_{j=1}^{m} B_{i,j}$ shows the largest value in whole cases. As for our experiment, the selected feature, f_{sel}, turns out to be "Blue", thus, the state of movement gets classified by using $\sum_{i=1}^{n} B_{i,m}$, sum of blue color values for each column in the m time domain.

D. Dynamic Time Warping Method

In our proposed model, a DTW algorithm is adopted to classify the state of movement. DTW method is one of those widely used algorithms in signal processing such as speech recognition and sensor data handling. Furthermore, this algorithm can handle phase-shifted shapes and does not require training steps indispensable to all sorts of machine learning approaches [13]. DTW algorithm is capable of comparing two sequences in time dimension as well as to determine how much similar the two types of data sets are as seen in Figure 4.

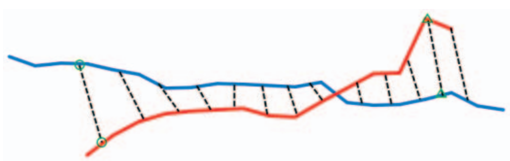


Figure 4. Phases-shifted shape using DTW algorithm

In order to estimate similarity between two sequences, two sequences are denoted as $T(t_1, t_2, t_3, \dots, t_m)$ and $S(s_1, s_2, s_3, \dots, s_m)$, where the length of these sequences is denoted by n and m, respectively. With usage of DTW algorithm, the shortest distance between t_m and s_n could be obtained as an optimal warping path cost. If the result of the DTW algorithm is smaller than threshold, then two sequences, S and T, are regarded as 'similar.' DTW algorithm is expressed as the following equation (2):

$$\mathrm{DTW}(m,n) = \mathrm{D}(m,n) + Min\begin{pmatrix} DTW(m-1, n-1), \\ DTW(m, n-1), \\ DTW(m-1, n) \end{pmatrix} \quad (2)$$
$$where\ D(m,n) = |t_m - s_n|$$

III. Experiments and Results

In this section, we describe our experimental design and the way experiments are conducted to test the feasibility and applicability of the proposed system.

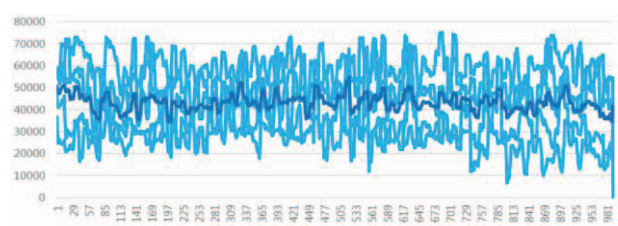
A. Experimental Design

Prior to explaining the details of our experiment, a brief summary of experimental design for validating proposed model needs to be mentioned. In this investigatory work, we tried to classify three major walking related human actions such as 'walking on a flat surface', 'going upstairs' and 'going downstairs' from five subjects. In our experiment, we obtained the fifteen spectrograms images (five walking on flat, five walking on upstairs, five walking on downstairs). With these data, we applied the DTW by comparing the combinations of all two sequences and the average values are calculated. For example, the walking on flat data of subject A is compared with walking on flat, upstairs and downstairs of subjects B, C, D and E.

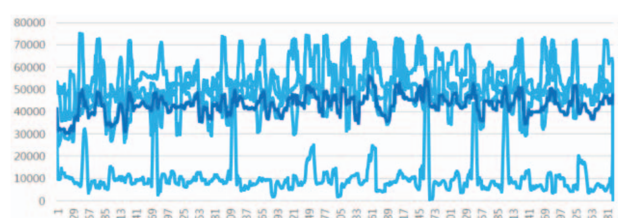
In addition, the distance drawn from it could be regarded as the similarity between the two sequences. The lower the distance value is, the more similar it indicates, and vice versa. Euclidean distance is used to identify the distance between the two sequences.

B. Experiment Outcomes and Discussions

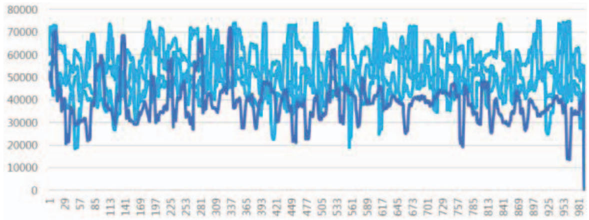
In preprocessing steps, the horizontal domain (n) is separated into 991, and the vertical domain (m) is 313. Therefore, the overall dimension embedded in one spectrogram becomes 930,549 (991 * 313 * 3). By applying the feature reduction step, "Blue" color feature is identified as the feature vector. Figure 5 illustrates the column summation for "Blue" color features as the result of color vector extractions. Figure 5 (a), (b) and (c) represent 'walking on a flat surface', 'going upstairs' and 'going downstairs', respectively. Each graph includes five cases (five test subjects) movements as well as the average of them (bold lines). With the unaided eye, each state of movement cannot be distinguished. Therefore, we used DTW algorithm to classify these sequences.



(a) Color vector for 'walking on a flat surface' case



(b) Color vector for 'Going upstairs' case



(c) Color vector for 'going downstairs' case

Figure 5. Blue color vector sequences for each state of movement

As mentioned above, we conducted a series of experiments and compared the entire test cases with each other by using DTW method. Figure 6 shows that the distances calculated between the movements of 'going upstairs' and 'going downstairs', and between the movements of 'going downstairs' and 'walking on a flat surface' is over approximately 4000. Plus, the movements of 'walking on a flat surface' and 'going upstairs' are 3500. On the other hand, the same states of movements have the lower distance values than those of the different states of movements, which are clearly distinguishable.

Figure 6. Calculated DTW for paired states of movements

IV. CONCLUSIONS

Personalized and customized mobile devices could cause carelessness of use leading to unexpected accidents. To prevent users from the indiscreet usage of devices, there is a need to provide context aware services according to the identified state of movement. In this paper, DTW was used as the method to classify the states of human navigational movements. Designed and executed experiment validated that this method could successfully classify the state of movement using acceleration value with the application of DTW. Three major states of navigational movements could be detected by calculating the distance between existing data and received data. Based on this research, it turns out to be clear that diversified forms of human actions could be successfully classified based on acceleration sending value sets.

We proposed a new movement classification model based on acceleration spectrogram combined with dynamic time warping method. Unlike existing studies, spectrogram images containing various sorts of information rather than mere frequencies, were used. Additionally, RGB color vectors were extracted from those images and the walking movements such as 'walking on a flat surface', 'going upstairs' and 'going downstairs', were classified by applying DTW algorithm. In order to validate the feasibility and applicability of the proposed system, we performed the experiments for entire cases. In the future, further refinement and validation of the proposed system are required to enhance this system up to more sophisticated human navigational movement classifier.

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