Activity Recognition and Coordination Analysis of Two-Body Interactions Using Wearable Sensors

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Abstract – This paper describes the application for activity recognition of two-body interactions by using body sensor networks (BSN) and presents a model to give coordination analysis of their cooperation. A monitoring platform based on BSN is established and acceleration data is collected from wearable inertial sensors. Each individual’s signal is divided into several segments, and then recognized corresponding to different stages of movements. The stages’ synchronization between two people could be considered as the principal criteria to evaluate their cooperation quality. Several important performance parameters are also given to provide the necessary feedback for these activities in our system. A gait experiment of two-body interactions was performed on the sensor monitoring platform and the experimental results demonstrate the effectiveness of the proposed method.

Keywords: Body sensor networks; Inertial sensors; Coordination; Two-body interactions

I. INTRODUCTION

Activities of two-body interactions widely exist in industrial production assembly, competitive sports and aerospace exploration, such as synchronized diving, double kayak, and two astronauts carrying out space mission. In such activities, they need cooperate to achieve goals. The coordination of their respective technical movements is important for improving the efficiency and quality in collaborative tasks. Therefore, it is necessary for us to establish an activity monitoring platform to recognize activities of two-body interactions.

Traditional human activity monitoring and recognition is based on visual information, however it might encounter some problems. Firstly, vision data are prone to the influence of environment factors, such as poor lighting conditions and occlusion of obstacles, which would reduce the accuracy of video recognition. Moreover, vision-based recognition just can present body movement gestures without human activity parameter information such as acceleration signal and ECG oxygen parameters. In addition, visual monitoring platform is expensive and inconvenient.

With the availability of low-cost sensors and the advancement in wireless sensor networks, researchers have made a lot of work on human activity monitoring by using body sensor networks (BSN), such as monitoring activities of daily living for the elderly or injured people [1-3]. The main contribution of this paper is to adopt BSN to monitor and recognize a class of activities of two-body interactions, which might give coordination analysis and provide the necessary feedback for these activities.

The organization of the paper is as follows: in section II, the related work is given. In section III, a detailed introduction of our proposed model and method is presented. In section IV, the hardware platform is introduced and an experiment is described. In section V, experimental results and coordination analysis are given to evaluate our system. Finally, concluding remarks are made in section VI.

II. RELATED WORK

Researchers have made significant progress in the area of human activity recognition by using BSN in recent years, including human daily activity recognition [4-6], video games application [7], medical service [8],
sports exercises monitoring and so on [9-11]. Existing work mainly focuses on recognizing single-user activities. Recognizing activities of two-body interactions using wearable sensors is more challenging. The main challenges are user interactions capture and modeling interacting processes, which need to measure and interpret sensor acceleration data from two people [12-13].

Our research mainly focuses on recognizing a class of activities of two-body interactions such as synchronized diving and double rowing, and then giving coordination analysis of these activities. The characteristics of this class of activities are distinctive in movement periodicity and cooperation synchronization. For example in double rowing (Fig. 1), each individual’s technical movement consists of several actions and it is very important for them to perform synchronization in every action stage. There is a delicate balance between their cooperation.

![Double rowing sports](image)

In order to improve the proficiency in cooperative tasks between two subjects which is significant in many fields, the problem how to analyze their technical movements and evaluate their cooperation quality poses scientific challenges for us. In this paper, these problems will be considered and discussed.

In this paper, a monitoring platform based on BSN is established by us and acceleration signals are collected through sensor nodes. After acquiring sensor data, we divided the signals into several segments corresponding to each stage of technical movement. Then, we extract feature vectors from the segmented signals and recognize these movements. The matching of every technical movement between two subjects is the principal criteria for evaluating their cooperation quality. In addition, several important parameters are also given to provide the necessary feedback for our system.

### III. PROPOSED MODEL AND RECOGNITION METHOD

Fig. 2 shows the system architecture for the data analysis and activity recognition of two-body interactions. We establish a monitoring platform in our laboratory which could collect these data and stores them into a database.

![System architecture](image)

#### A. Sensor data segmentation

Sensor data reflects an actor’s behavior which could be collected on the monitoring platform. A key factor in continuous time activity recognition is how to divide the sensor data into different window sequences. Each window sequence corresponds to different ongoing actions. In this study, dynamic sensor data segmentation based on event-driven is used. We define several
parameters to describe how the time window is manipulated. These parameters include start time, end time and window length.

B. Feature Extraction

After acquiring the signals which have been segmented as mentioned above, feature extraction is applied on the sensor data. The extracted features from each window are mean, variance, skewness and the peaks of the discrete Fourier transform (DFT). The usefulness of these features has been demonstrated in many prior studies [14-16]. All features are normalized into the interval [0,1]. These features are calculated as follows:

\[ \mu_s = E\{s\} = \frac{1}{N_s} \sum_{i=1}^{N_s} s_i \]

\[ \sigma^2 = E\{(s - \mu_s)^2\} = \frac{1}{N_s} \sum_{i=1}^{N_s} (s_i - \mu_s)^2 \]

\[ \text{skewness}(s) = \frac{E\{(s - \mu_s)^3\}}{\sigma^3} = \frac{1}{N_s \sigma^3} \sum_{i=1}^{N_s} (s_i - \mu_s)^3 \]

\[ S_{\text{DFT}}(k) = \sum_{i=0}^{N_s-1} s_i e^{-j2\pi i/N_s}, k = 0,1,\ldots,N_s-1 \]

C. Classification Technique

Researchers have made significant progress in the area of human activity recognition by using BSN in recent years, and many classification methods have been used and compared [17]. Typical classifiers include decision tree, k-nearest neighbor (k-NN), support vector machines (SVMs), and artificial neural network (ANN). In addition, some state-space models such as Hidden Markov Model (HMM) and Dynamic Bayesian Network (DBN) have been used in human activity recognition. The classification technique used in this study is Radical Basis Function (RBF) neural network.

D. Action Sequences Matching

The work mentioned above could recognize every action style in a movement period. In the same time, the action sequences matching between two subjects could be considered as the principal criteria to analyze the activity synchronization of two-body interactions, which is an important factor for evaluating the quality of their cooperation performance.

E. Important Parameters

Several necessary parameters are proposed to further evaluate the cooperation quality between two subjects.

Let:

\[ \alpha : \text{the start time for a time window.} \]

\[ \omega : \text{the length of a time window.} \]

\[ \gamma : \text{the ratio of window length in a period time.} \]

We can define a segmented window \( \Omega_k \) with three important properties: \( \alpha \), \( \omega \) and \( \gamma \) as shown in the expression \( \Omega_k : (\alpha, \omega, \gamma) \), where \( \omega \) is the time interval of each action stage, and \( \gamma \) is the ratio of \( \omega \) in a period time. A detailed description will be explained in section V.

IV. EXPERIMENTAL DESIGN

A. Experiment Platform

The experiment platform used in this study consisted of a collection node and a receive node which are shown in Fig.3.

![Fig.3. Configuration of the collection node and the receive node.](image-url)
The collection node consisted of a sensor board, a wireless communication board and a battery board. The receive node consisted of a wireless communication board and a USB port. The sensor board included a tri-axial accelerometer (ADXL330) which could measure acceleration with a full-scale range of ±3g. The wireless communication board ran TinyOS system on a microcontroller (MSP430). Wireless communication between the collection node and the receive node was achieved through wireless transceiver chips (CC2420) with IEEE 802.15.4 protocol. The receiving frequency of acceleration signals was set to be 20Hz in this study with a minimal packet loss rate.

B. Data Collection

To validate the proposed system, we took a gait experiment for example. 8 volunteers (four males and four females, ages from 22 to 28) were invited to take part in the experiment. We performed the experiment in an open corridor which is no wireless interference with a region of 3.5m × 40m. In the experiment, each volunteer wore two sensor nodes on their feet ankle, as shown in Fig. 4. Every two volunteers formed a group and performed gait actions twice, walking about 15m's distance. The main purpose of this experiment is to test the gait coordination between two subjects. Before walking, a demonstration of basic process was given to each volunteer. The first part of experiment was performed to capture gait acceleration signal within the walking distance of 15m. Fig. 5 shows the gait action of two-body interactions in the experiment.

V. EXPERIMENTS RESULTS AND DISCUSSION

Fig. 6(a) and Fig. 6(b) show acceleration signals of two-body interactions collected by the BSN monitoring platform in the gait experiment. From these two signals, we hardly infer the quality of gait coordination between two subjects. Therefore, we divide every a periodical signal into four segments based on dynamic window. A detailed introduction could be demonstrated in the study [18]. After acquiring segmented signals, we recognize these four gait phases which are Foot Flat, Heel Off, Swing and Heel Strike. The phase sequence matching between two subjects is principal for two-body gait synchronization.
Fig. 7(a) and Fig. 7(b) show these four recognized gait phases and their percentages (γ) at the second gait, where two subjects’ gait time interval are 1.46s and 1.42s. From Fig. 7(a) and (b), we can see that each gait phase between two subjects is matched, and has a similar percentage in a gait period, which show that a general synchronization for the second gait of two-body interactions.

Fig. 7. (a) Gait phase percentage (subject A, left foot)

Fig. 7. (b) Gait phase percentage (subject B, left foot)

We can also acquire the start time of each gait phase (α) from the sensor monitoring platform and compute the time interval of each gait phase (ω). These parameters may further help us give good coordination analysis for activities of two-body interaction.

Although we carried out a gait experiment of two-body interactions to illustrate the proposed method and the experimental analysis show that the approach could obtain a satisfactory result, it should be pointed out that this approach just is suitable for a class of activities of two-body interactions, such as synchronized diving, double kayak and double rowing. These interactive activities mentioned above have periodical movements, and every movement period consists of several different actions. Moreover, the coordination of every action between two subjects is necessary.

VI. CONCLUSION

In this paper, the recognition problem of activities of two-body interactions is proposed and discussed. The main contribution of this study is to monitor a class of interactive activities and evaluate their cooperation quality. A monitoring platform based on BSN is established and acceleration data is collected from wearable inertial sensors. We divide every signal into various segments corresponding to different stages of movements. Several important time parameters are also given to further analyze the coordination in their cooperation. A gait experiment of two-body interactions is analyzed on the monitoring platform, and experiment results demonstrate the effectiveness of the proposed method.

There are a number of limitations in this work. Although the datasets we collected in this paper contain some gait actions, more activities of two-body interactions such as double rowing and synchronized diving should be done in a practical scenario to further evaluate our proposed approach. Besides, we also plan to consider the problem of multi-user interactions in a more complex scenario in future work.

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