The Design and Evaluation of a Kinect-Based Postural Symmetry Assessment and Training System

by

Henghao Zhou

A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Approved April 2016 by the
Graduate Supervisory Committee:

Pavan Turaga, Chair
Todd Ingalls
Antonia Papandreou-Suppappola

ARIZONA STATE UNIVERSITY

May 2016

ABSTRACT

The increased risk of falling and the worse ability to perform other daily physical activities in the elderly cause concern about monitoring and correcting basic everyday movement. In this thesis, a Kinect-based system was designed to assess one of the most important factors in balance control of human body when doing Sit-to-Stand (STS) movement: the postural symmetry in mediolateral direction. A symmetry score, calculated by the data obtained from a Kinect RGB-D camera, was proposed to reflect the mediolateral postural symmetry degree and was used to drive a real-time audio feedback designed in MAX/MSP to help users adjust themselves to perform their movement in a more symmetrical way during STS. The symmetry score was verified by calculating the Spearman correlation coefficient with the data obtained from Inertial Measurement Unit (IMU) sensor and got an average value at 0.732. Five healthy adults, four males and one female, with normal balance abilities and with no musculoskeletal disorders, were selected to participate in the experiment and the results showed that the low-cost Kinect-based system has the potential to train users to perform a more symmetrical movement in mediolateral direction during STS movement.

ACKNOWLEDGMENTS

I would like to thank those who have contributed to my study and my life in Arizona State University during the past two years.

First and foremost, I would like to thank my advisor, Pavan Turaga, for the support and guide in the whole past year. Pavan helped me to open my mind in my research interests and gave me so much freedom to explore and discover by myself. Also his approach to problem formulation and presentation has greatly shaped my way of thinking.

I would like to thank professor Todd Ingalls. Thank you for helping me a lot with the audio feedback part in my study and your suggestions also inspired me a lot and also thank you for kindly agreeing to serve on my thesis committee.

I would like to thank all the senior Phd students in our lab, especially Qiao Wang, for helping me improve my algorithm design in this study and give me so much guidance to set up the experimental user study in the lab. Also Qiao's sharp insight in solving research problems inspired me a lot.

Many thanks to my friends who shared my life in ASU. Without them my graduate study experience would not be as pleasant and colorful- Rushil Anirudh, Vinay Venkataraman, Suhas Lohit, Kuldeep Kulkarni, Aaron Faith, Anirudh Som, Prashanth, Varsha, Yi Weng Huang, Xiaoxiao Wang, Jian Zhong.

TABLE OF CONTENTS

Page

CHAPTER Page

LIST OF TABLES

Table Page

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Motivation and Research Problem

Symmetry is a ubiquitous and prominent feature not only in human body itself but also in movements. Poor and asymmetrical posture in every day movements may result in health conditions like chronic back pain [1][2], and balance problems which contributes to fall risks. Thus, a lot of physical education professionals and physiotherapists place balance exercise as a part of the daily training routine. Also the ability of efficiently maintaining balance depends on physical fitness factors such as muscle strength and anaerobic capacity.

Among elderly people, due to the deterioration of the regulatory mechanisms of the neuromuscular system associated with aging [3], falling down while doing everyday tasks becomes the leading cause for injuries, disabilities and can even result in death. Furthermore, even when no injury has occurred, the fear of falling can also lead to the loss of confidence and independence [4]. Research shows that every year one in three over 65 years of age suffer a fall and secondary injuries, such as fractures, joint dislocations, concussion and severe lacerations which may result from a fall, and can worsen or diminish the ability to perform physical activities [5][6]. Approximately 30 percent of aged 65 to 80 years and about 40 percent of those over 80 years of age experience falling accidents [7]. In USA, the annual medical costs associated with falling accidents for those aged over 65 years is totally more than 20 billion dollars and, taking into consideration the forecasts of changes in demographics and income levels, these medical costs are expected to increase considerably in the near future [8]. Excluding environmental factors, the ability of balance control when doing basic movements and activities, such as sit-to-stand, walking and stepping up or down in daily life, is one of the most important factors that falls are associated with.

The sit-to-stand (STS) movement, described as the change in body posture from a sitting to standing position, is one of the functional activities that people most commonly perform in everyday life and the capability to move from a sitting position to a standing position is essential as it is related to functioning and mobility of independent living, and is a prerequisite for walking [9]. The execution of the STS movement varies within and between persons as a lot of factors influence the way how people perform an STS movement, such as the seat height, feet positions, age, muscle strength and so on [10-16]. Different movement strategies are used to achieve STS task, depending on balance control ability of individuals [17].

According to the previous research on balance control training tests, conventional methods, such as using marker-based motion analysis system like Vicon Nexus motion analysis system [18] and the WATSMART motion analysis system [19] to track human movements, together with two force plates under user's feet to test the varying distribution of body weight or the sway path of the center of pressure(COP) in response to combined stimuli delivered through a moving platform and a visual display [20], showed good results that these systems can successfully discriminate between subjects with or without balance disorders [21], evaluate the rate of fall risk of stroke patients [22] and also achieve improvements in STS performance through symmetrical body-weight distribution training [23]. Alternatively, wearable sensor systems consisting of accelerometers and/or gyroscopes have gained popularity in recent years as a means of collecting physical activity and gait data in real-world environment, thus can help researchers study the characteristics of changes in the center of body mass (COM: the point equivalent of the total body mass in the global reference system) and the center of body pressure (COP: the point location of the vertical ground reaction force vector and represents a weighted average of all the pressure over the surface of the area in contact with the ground) [24] during STS. However, although these previous methods can provide promising results due to their high degree of accuracy, the reasons why we are not using these methods in our study are two-fold:

1. The inconvenience to set up an in-home motion capture system and they are usually unaffordable and unavailable outside a laboratory environment.
2. Some older adults are reluctant to use wearable sensors because they consider them to be invasive or inconvenient.

Therefore, the problem now is that a user-affordable system, which should be unobtrusive and not inconvenient, needs to be designed for users. Questions are what kind of sensors should we use to detect and track STS movement and is it reliable enough to reflect the balance control ability of users and train them in a proper way?

1.2 Challenges

Now there are two main challenges yet to be addressed for designing such an in-home system. First, users are required to run the system themselves without any assistance. The system should be easy to set up, taking into account that those who have balance disorders or those who suffer from such diseases like stroke, it is unrealistic to introduce a marker-based motion analysis system and expensive wearable sensors. As well, inaccurate placement of markers can have negative effect on the activity analysis modules. Second, the sensor we use should have low tracking errors or delays. The advantages of traditional methods are obvious as they are able to track human movements accurately in real-time, and many calculations of kinematic features in balance ability tests require a high accuracy and low tracking errors.

Taking all these factors into consideration to meet as many as the requirements of an ideal system, a vision-based sensing system in the home offer a unique set of characteristics to meet these criteria. The release of Kinect camera in November 2010 opens up interesting perspectives not only for games but also for functional analysis of user movement assessment [25]. This cost-effective and portable device combines a regular color camera with a depth camera which consists of an infrared laser projector and an infrared camera. Through the ready-to-use skeleton tracking algorithm in the Kinect Software Development Kit (SDK), the device is able to detect 20 skeleton points and get the 3D coordinates in real-time [26]. Figure 1.1 shows the 20 skeleton joints that a Kinect camera can detect and track. Besides the application in gaming, studies show that the Kinect system has been used in many other fields, such as movement detection [27], face detection [28], clinic assessment [25], rehabilitation training [23].etc. Furthermore, due to previous studies which have already evaluated the accuracy and precision of the Kinect camera sensor for measuring various movements (timed up to go test, timed 10-meter walking test and joint range of motion measurement) [29], it leads us to focus on whether and how it could be applied as an effective solution for our in-home system.

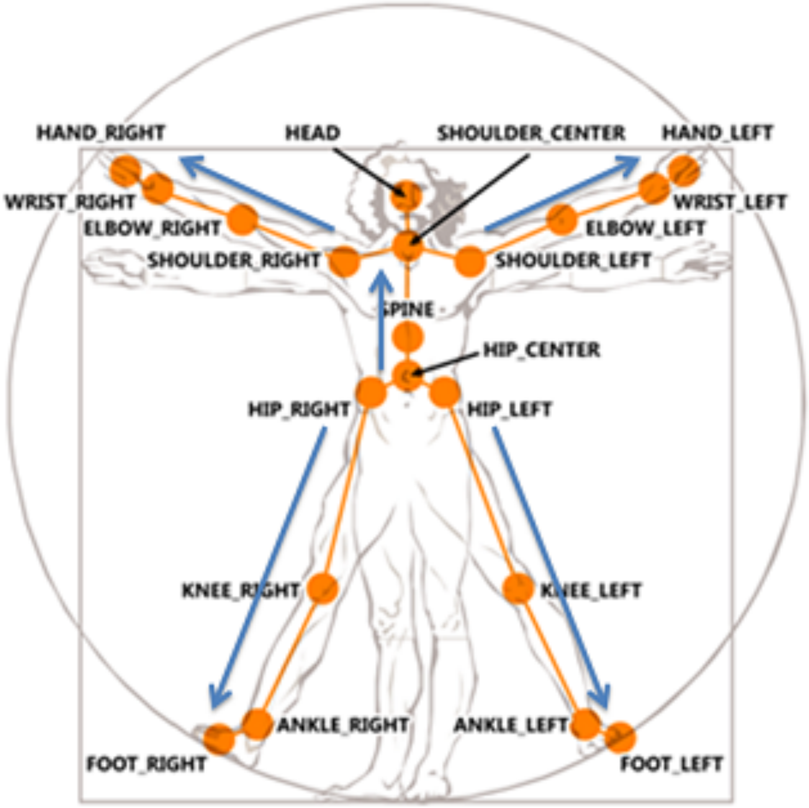


Figure 1.1 The 20 Skeleton Points Detected and Tracked by a Kinect Camera.

1.3 Contributions

There are two main contributions in this thesis:

1. Because of the benefit of the off-the-shelf skeleton tracking algorithm in SDK, we developed a symmetry score which can reflect the asymmetrical or unbalanced degree of human body in mediolateral direction during STS movement based on the raw 3D Kinect skeleton data and compared the result with our reference value (the angular velocity varying of upper body center recorded by a wearable IMU sensor) to prove the feasibility of the symmetry score when users are doing STS movement.

2. We carried out an experimental user study to test with our system to show the potential of our Kinect-based system to train users to perform more symmetrical postures during STS movement and also discussed how this system can be applied to test and measure other movements such as walking and standing still in various conditions.

1.4 Organization

The rest of the thesis is organized as follows: In Chapter 2, we introduce the design of our system and the related method to calculate our symmetry score. In Chapter 3, an experimental user study is described. In Chapter 4, we present the experiment results and made some discussions. In Chapter 5, we propose future work and conclude the thesis.

CHAPTER 2

SYSTEM DESIGN

In this chapter, the design of the multimedia Kinect-based system to assess human upper body postural symmetry in mediolateral direction, which consists of context, associated data collection, data computation and feedback, is introduced. First, for context, there are a lot of people suffer from various health problems and the increasing fall risks when they are getting old due to their bad postures and balance disorders when doing basic movements and activities in everyday life. Our system aims to help to assess their postural symmetry when doing STS movements. Also we are trying to encourage our users to self-assess their movements and make them to be able to stand up in a more symmetrical way in the mediolateral direction by providing them with a real-time audio feedback. Second, a Kinect camera is used to track users' skeleton points and collect real-time (30 frames per second) 3D skeleton coordinates. Third, we implemented gradient descent method to calculate a symmetry score which is used to evaluate the postural symmetry degree of movements for each frame in real-time from the data acquired by Kinect and finally give users a feedback to adjust their STS movement.

Figure 2.1 depicts the diagram and procedure of our low-cost and easy-setup system which consists of a PC, a single Kinect camera and an audio feedback designed in MAX/MSP in a Macbook. Figure 2.2 showes the real system we set up in a laboratory setting.

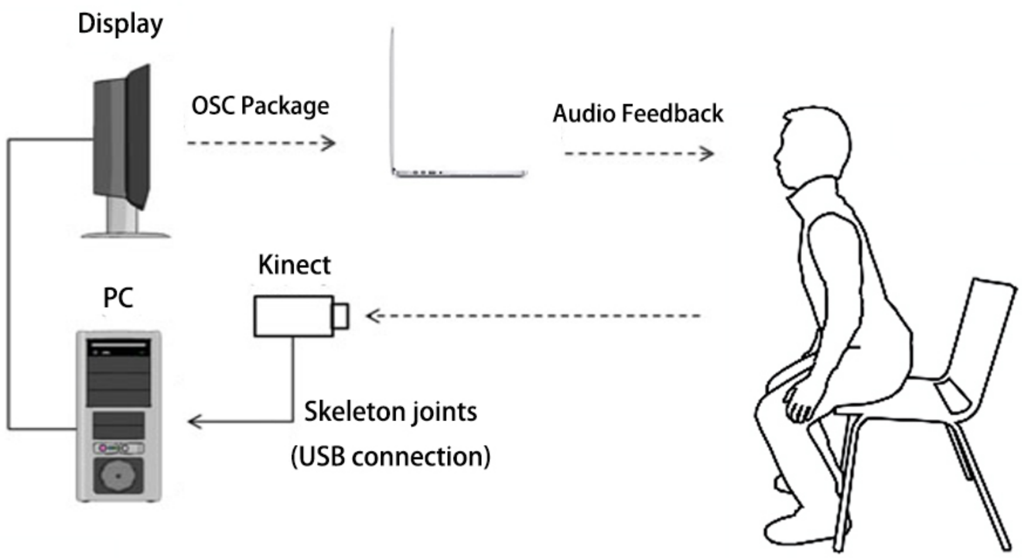


Figure 2.1 An Illustration of Various Components of the Proposed Interactive System.

Figure 2.2 The System Consists of a Kinect, a Laptop and a PC.

2.1 Kinect Sensing Technology

Kinect was initially developed for the XBOX games console and it has been leading a revolutionary change in the gaming industry by creating an engaging and interactive environment. During the past few years, due to the low-cost and easy-setup, Kinect has been attracting researchers to uncover the potential of using its features into a wide variety of applications, mainly being applied to movement-related fields. Also, to meet the requirement of different application areas, a reliable motion sensing ability of Kinect is indispensable and it has already been shown that the depth sensor itself is accurate for assessing 3D position in a workplace environment [30], and that joint centers derived from Kinect camera can be used to classify human gestures [31].

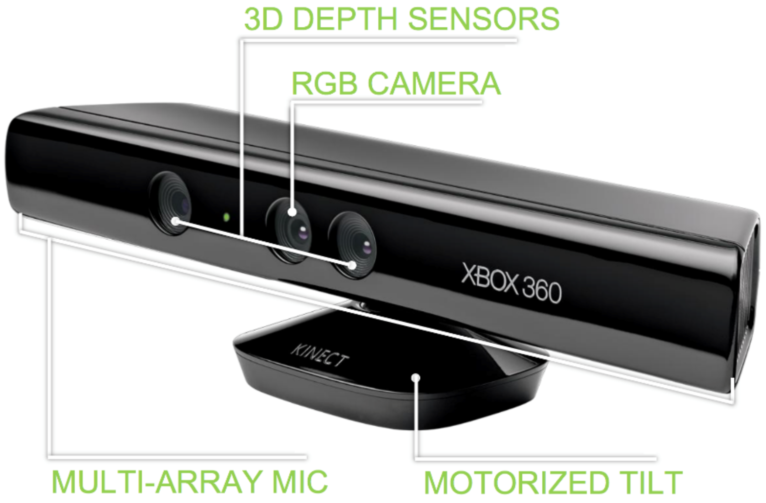


Figure 2.3 Main Kinect Camera Components.

2.1.1 Device Specification

It can be seen from Figure 2.3 that a Kinect sensor contains a USB hub with three different devices: A camera device with an IR projector, a depth camera and a RGB camera; an audio device equipped with a multi-array microphone; a motor/LED device. It covers 3D space about 4 meters in depth and an angular field of view of 30 degrees to right and left. Furthermore, inferring body position is a two-stage process: first a depth map is computed (using structured light), then body position is inferred (using machine learning). Depth maps are constructed by analyzing a speckle pattern of infrared laser light, without using the RGB camera for depth computation [32]. Then body parts are inferred from depth maps using random decision forest classifiers, which are trained from one million training samples [33]. Table 2.1 shows the specification for the Kinect device.

In our system, by using an off-the-shelf skeleton detection and tracking algorithm in Kinect SDK, the camera tracks up to 20 3D joints points in human body running at 30Hz and exports accurate and robust motion data during the repetitive STS movement and other functional tasks, without wearing any markers. As human upper body consists of several segments: head, torso, arms and hands. The movement of these segments are captured by tracking the joint positions in upper body, such as shoulders, hips and wrists. The data stream is finally regarded as the input to calculate symmetry score and trigger the audio feedback.

Table 2.1 Kinect for Windows Specification

Kinect	Specifications
Sensor	Color and Depth Cameras IR projector Voice microphone array Tilt motor for sensor adjustment
Field of View	
Angle Ranges	(Horizontal) 57 degrees (Vertical) 43 degrees (Physical tilt range) +/- 27 degrees
Distance Ranges	(Default Mode) 0.8 to 4 m (Near Mode) 0.4 to 3m
Resolution	320*240 or 640*480 Depth 320*240 or 640*480 or 1280*960 Color
Frame Rate	30 fps Depth 30 fps @ 320_240 , 640_480 Color 15fps @ 1280_960
Skeleton Tracking System	Tracks up to 6 players (2 active players) (Default Mode) 20 joints per active player (Seat Mode) 10 joints per active player

2.1.2 Related Work

Human body part detection and tracking has a wide range of applications. In the past, camera-based motion capture system that required cumbersome markers or suits were used. Kinect, as an inexpensive motion capture device, has impacted many computer vision applications, such as face detection and gesture recognition [34][35]. Moreover, in rehabilitation and other healthcare applications, Kinect was found to be reliable in many human movement tests and then was used in many studies instead of expensive, large and complex motion capture systems in order to make the system more user-friendly and unobtrusive.

Besides, in order to estimate the participant's body postures based on image sequences, skeleton calibration is indispensable in traditional motional capture systems which is a pre- stage of skeleton tracking. Kinect SDK includes the calibration process automatically, which means it does not require participants to do a 'T' pose for skeleton calibration.

2.2 Gradient Descent

Gradient descent, also called steepest descent, is a first-order optimization algorithm which uses the first derivative of the function with respect to its variables and is one of the most popular algorithms to perform optimization. Gradient descent method is a way to find a local minimum of a function. The way it works is we start with an initial guess of the solution and then take the gradient of the function at that point. Then move the solution in the negative direction of the gradient and iterate till consequence.

2.2.1 Background

Gradient descent is usually applied to solve unconstrained minimization problems:

$$\min_{x \in R^n} f(x)$$

where $f(x)$ is the function to be minimized and x is a vector quantity.

Gradient descent method updates the value of variable x through iteration to find out the local minimum value of $f(x)$. The iteration process starts with a guess x_0 for the local minimum of $f(x)$, and considers the sequence $x_0, x_1, x_2, \dots$ such that

$$x_{k+1} = x_k + \alpha \cdot (-\nabla f), k \geq 0.$$

in which x_k is the value after the kth iteration, α is the step size of each iteration and ∇f is the gradient of $f(x)$. Thus we have $f(x_0) \geq f(x_1) \geq f(x_2) \geq \cdots$.

This process is illustrated in Figure 2.4. Here $f(x)$ is assumed to be defined on the plane, and that its graph has a bowl shape. The blue curves are the contour lines, that is, the regions on which the value of $f(x)$ is constant. A red arrow originating at a point shows the direction of the negative gradient at that point. Note that the negative gradient at a point is orthogonal to the contour line going through that point. We see that gradient descent leads us to the bottom of the bowl, that is, to the point where the value of the function $f(x)$ is minimal.

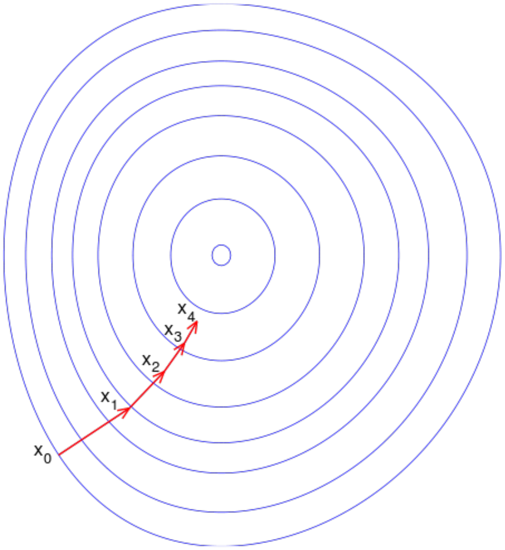


Figure 2.4 The Process of Gradient Descent.

2.3 A Postural Symmetry Score of Human Body

In our system, in order to give users more flexibility, a human body symmetry plane (a sagittal plane) is calculated as the prerequisite to get the symmetry score. With the raw

3D skeleton point coordinates, we assume a plane that is perpendicular to the ground, which is parallel to Y axis of Kinect camera coordinate system (the Y axis is the vertical axis when Kinect is put horizontally). Then we use gradient descent method to find an optimal sagittal symmetry plane that makes the Euclidean distance between the joints and the flipped versions across the plane to be minimum. Thus the distance is our symmetry score which can sensitively reveal the symmetry of movement. From the 10 continuous frames in Figure 2.5(b) we can see that the symmetry score can reflect very subtle changes in the same posture. Also according to the 5 frames in Figure 2.5(a), by judging the direction of movement through the positions of joint points in upper body, we set the symmetry score to be positive when the body movement is toward left side while tilting right will get a negative score.

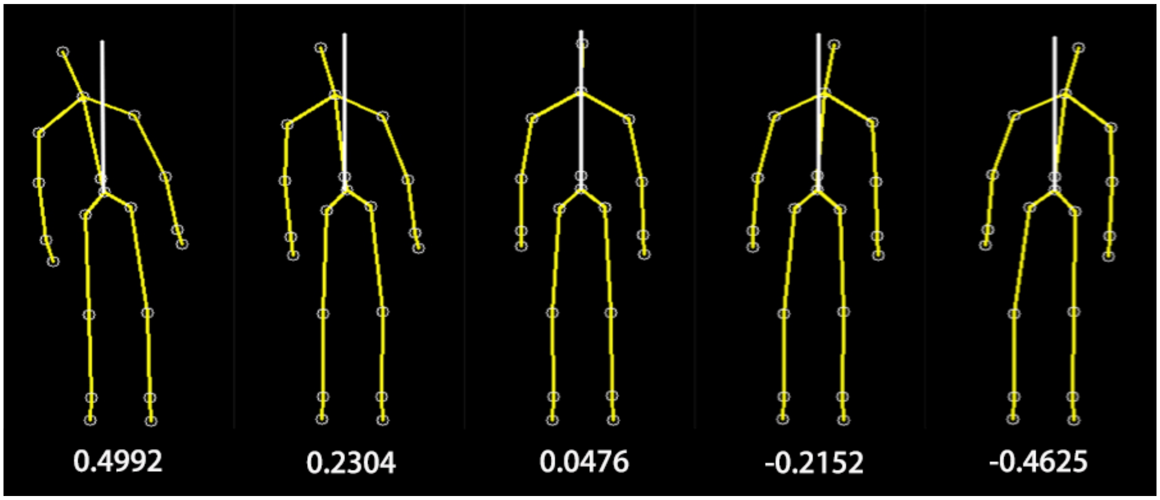


Figure 2.5(a) The Sign of the Symmetry Score.

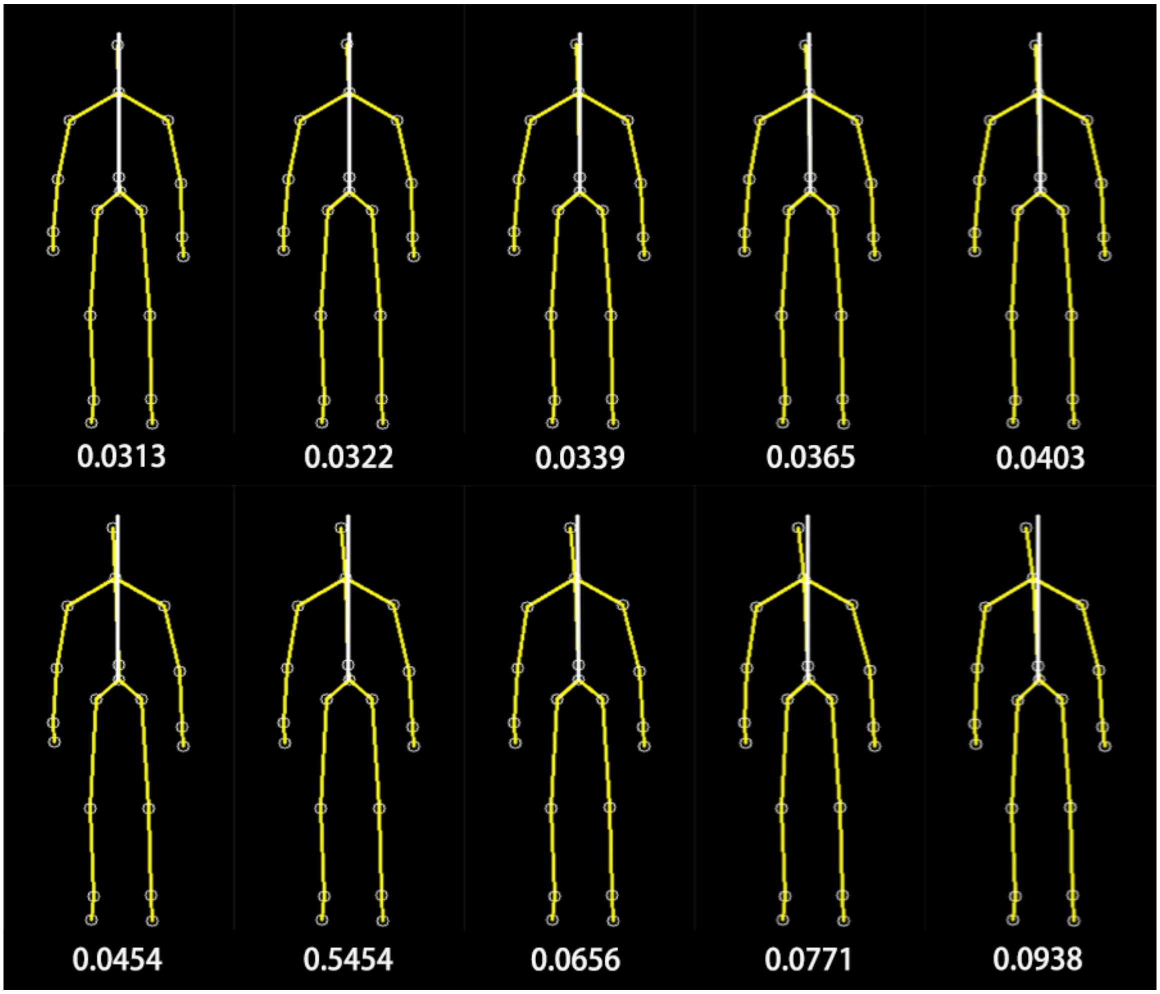


Figure 2.5(b) The Sensitivity of the Symmetry Score.

Furthermore, the complete upper body sagittal plane computation method is presented as followed.

1. Acquired six 3D joint positions in human upper body from Kinect camera: left and right shoulders, left and right hips, left and right hands.
2. Define a initial vertical plane which is parallel to Y axis in Kinect coordinate system as:

$$ax + cz + d = 0$$

3. Use another two joint coordinates (Ankle and Knee) to initialize the symmetry plane parameter a_0, c_0, d_0, where we set a_0 to be a scalar equals to 1.
4. Flip the three left side joints to the right side according to the initial symmetry plane and calculate the Euclidean distance which is defined as $D = f(a, c, d)$ between the flipped joints and their related right side joints.
5. Calculate the gradient of the distance function, which is $\nabla f(a, c, d)$, the first-order partial derivatives of the function $f(a, c, d)$ with respect to variable a, c and d which can be represented as:

$$\nabla f(a,c,d) = \begin{pmatrix} (f(a+\Delta, c, d) - f(a,c,d))/\Delta \\ (f(a, c+\Delta, d) - f(a,c,d))/\Delta \\ (f(a, c, d+\Delta) - f(a,c,d))/\Delta \end{pmatrix}$$

6. Then we use gradient descent method to start iteration process and keep updating the output plane parameters. The initial value is $(a_0, c_0, d_0)^{\mathrm{T}}$ and the iteration process is presented repeatedly as

$$(a_{n+1}, c_{n+1}, d_{n+1})^{\mathrm{T}} = (a_n, c_n, d_n)^{\mathrm{T}} - \alpha \cdot \nabla f(a, c, d)$$

7. In order to decrease the iteration, we use varying step-sizes, ranging from 0.00001 to 3 (each value is 3 times bigger than the previous one). In each iteration, we choose a step size which can get the minimum $f(a, c, d)$ in the current iteration step.
8. We set a tolerance value $\varepsilon = 0.01$, which implies 1 cm difference between $f(a_{n+1}, c_{n+1}, d_{n+1})$ and $f(a_n, c_n, d_n$. When $|f(x_{k+1}) - f(x_k)| < \varepsilon$, the iteration stops and thus the final minimum $f(a_{n+1}, c_{n+1}, d_{n+1})$ is regarded as our symmetry score.

2.4 Open Sound Control

As all of the programming part is running in C++ in Visual Studio platform, we need to send real-time data to MAX/MSP with which we build our audio feedback. Open Sound Control (OSC), which is a protocol for communication among computers, sound synthesizers and other multimedia devices, is a good option in our system to transmit data streams. OSC are interoperable, accurate, flexible and make enhancement in organization and documentation by bringing the benefits of modern networking technology to the world of electronic musical instruments.

This simple yet powerful protocol provides everything needed for real-time control of sound and other media processing while remaining flexible and easy to implement.

The unit of transmission of OSC is an OSC Packet, which is simply a set of C++ classes for easily constructing, sending, receiving and parsing OSC packets. PC acts as an OSC client in our system to send OSC packets and the MacBook that used to perform audio feedback is an OSC server.

2.5 Real-Time Audio Feedback

MaxMSP (Cycling ’74 Inc) is a visual programming language that helps build audio, MIDI, video, and graphics applications where user interaction is needed. In order to generate real-time feedback in our study, the symmetry score of each frame was used to drive the feedback. In STS movement sessions, the feedback consists of two types of sound which is rhythmic intermittent from different instruments. If the user performs his movement tests totally symmetrical (under the threshold we set), he will hear both of the sounds all the time, but during which the user loses his balance and tilts some degree to left or right side (the symmetry score exceeds the threshold), he will hear only one of the sounds (The negative score triggers one sound and the positive one triggers the other). Besides, the greater the angle of tilt of the body, the higher the pitch of the sound will be. Also the sensitivity of the judgment of movement symmetry can be adjusted by experiment designers and there are many different types of sounds and music in the library for users to choose as their feedback. However, in Walking session, as the good and balanced walking postures is judged by the comparison of the trajectory of left-side body movement and the right-side body movement, including both hand swing and the tilt angle in left and right direction of each step, the intermittent music feedbacks are not able to reflect clearly whether the walking posture is in a balanced performance or not. Thus we changed the audio feedback to two steady and sustained signals and the more balanced the walking movement is, the length of each sound related to each step will be more similar.

CHAPTER 3

EXPERIMENTL USER STUDY

After the system was fully developed, a preliminary user study was implemented to evaluate the system.

3.1 Subjects

A total of 5 young healthy participants (4 males and 1 female, 22±1 years, 170±2.5cm, 60±6kg), were recruited for our study. The participants were eligible if they had no diagnoses of lower limb injury or lower limb surgery within the last 6 months and did not suffer from a neurological disease or recent concussion, also they did not have a balance disorder and no musculoskeletal disorders. In addition, the experimental procedures used in this study and the selection of the participants were approved by Arizona State University Institutional Review Board.

3.2 Procedure

We carried out our user study in a laboratory setting. The subjects performed each STS test on a fixed chair (seat height 44cm) which is about 2.5 m away from the Kinect camera. The audio feedback was placed 1 m right behind the chair.

The STS postural symmetry study consists of two sessions with four sub-sessions in each. In the first session, participants did STS movement with both of their feet touching the ground and the four sub-sessions were performed as Normal, Control, Feedback and Control in sequence. Each sub-session required subjects to do STS eight times on the fixed chair, with both of their hands on thighs. In the second session, we put a soft foam board under one foot of the subject and a hard wood board which has the same height as the foam under the other foot. The sub-sessions are the same as the first one. The purpose of the second session was to induce asymmetrical conditions when they are performing STS to see more clearly whether the system is reliable. During each session, unlike the many limitations set in other STS task, all the participants in our study were told to do the STS movements in their normal and comfortable way because this system was used to evaluate the postural symmetry of movements in different conditions. Figure 3.2 (a) showed the participant perform STS movement with his feet on the ground and Figure 3.2 (b) showed the second big session that a foam and a same-height wood board were put under each foot.

Besides, there were a five-minute break between two sessions and a three-minute rest during each sub-session in order to decrease the degree of fatigue of participants' body conditions.

The following is a description of each sub-session.

1. Normal: This was the first sub-session and participant was asked to do STS in the way they preferred, just like the usual way they stand up from a chair. This sub-session was used to be compared with the last three ones to see if the audio feedback have the positive influence to perform a more symmetrical STS movement.
2. Control: In the second sub-session, the only difference was that the participant were told to perform the STS movement in their most symmetrical way, that is, they need to pay attention to their STS movement and adjust by themselves. This sub-session was used to be compared with the third sub-session to see if the feedback is necessary for them to perform a more symmetrical STS movement.

3. Feedback: Participant will be given an audio feedback, as discussed in section 3.4, placed 1 meter behind their chair. They need to perform the STS movement in a symmetrical way to hear the rhythmic intermittent music from both instruments. If they cannot hear both sounds, they have to try their best to lower the level of pitch to get a more symmetrical performance.
4. Control: The last one is carried out as the same way with the second sub-session, participants were told to stand up without any feedback but were required to keep balance themselves. The purpose of this sub-session was to see if the fatigue of their body will badly influence the results and also see if the audio feedback can have a lasting effect on the users to perform a more symmetrical STS movement.

To verify that the score can be used in multiple functional tasks and conditions, we add one walking session consisting of four sub-sessions: normal, control, feedback and control. The four sub-sessions are carried out as the same sequence with the four in STS. As there is a limitation of the distance from the user to the Kinect camera, approximately 0.8 to 4 meters, the subjects were asked to walk 5 steps in front of the camera. Also subjects are given audio feedback in the third sub-session.

Figure 3.1 Participant Wear the Opal Sensor in the Center of Chest for Evaluation.

[redacted]

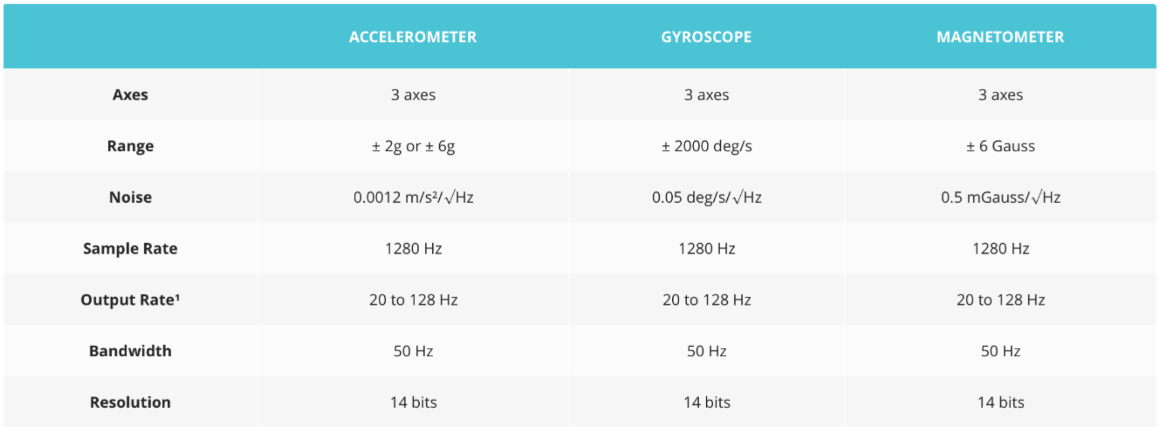
[redacted]

(a) (b)

Figure 3.2 Participant Preparing to Perform STS with and without Foam Board.

3.3 Data Collection

In our study, data was obtained from Microsoft Kinect using the official SDK (https://www.microsoft.com/en-us/download/details.aspx?id=44561), the skeleton tracking algorithm was programmed with C++ and running in Visual Studio 2010 platform. All the 3D skeleton joint position data (x = horizontal, y = vertical, z = depth), which were collected approximated 0.33s each time, were used to calculate our symmetry score in real-time. Other than Kinect camera, in order to verify the reliability of our symmetry score, the calibrated angular velocity data in roll axis which was used as our reference value, were concurrently recorded by a small, wireless and inertial-based sensor (Opal sensor, APDM Inc, Portland, OR) wore at the center of chest of human body, just like that shows in Figure 3.1. The angular velocity data were processed in Motion Studio platform (APDM Inc). Moreover, in each 8-trial-STS-performance sub-session, the first three trials were regarded as the familiarization trials and the last five were used to evaluate the feasibility of our symmetry score. In walking session, all the five steps movements was used to evaluate the validity of our symmetry score.



	ACCELEROMETER	GYROSCOPE	MAGNETOMETER
Axes	3 axes	3 axes	3 axes
Range	± 2g or ± 6g	± 2000 deg/s	± 6 Gauss
Noise	$0.0012\ \mathrm{m/s^2/\sqrt{Hz}}$	$0.05\ \mathrm{deg/s/\sqrt{Hz}}$	$0.5\ \mathrm{mGauss/\sqrt{Hz}}$
Sample Rate	1280 Hz	1280 Hz	1280 Hz
Output Rate[1]	20 to 128 Hz	20 to 128 Hz	20 to 128 Hz
Bandwidth	50 Hz	50 Hz	50 Hz
Resolution	14 bits	14 bits	14 bits

Figure 3.3 Opal Sensor Parameters.

3.3.1 Device Specification and Applications

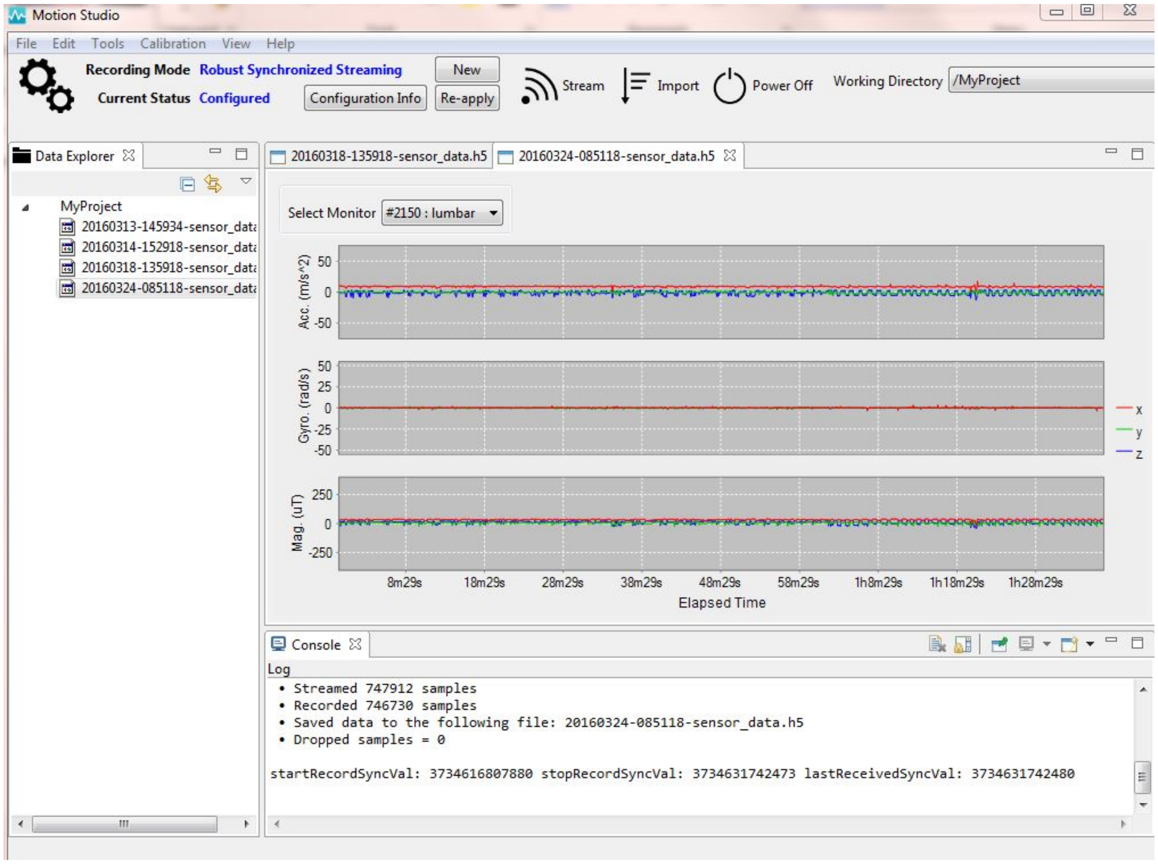
Opal sensor, an inertial measurement unit (IMU) device, contains a tri-axial accelerometer, a tri-axial gyroscope and a tri-axial magnetometer. Accelerometers measure the translational acceleration and acceleration due to gravity. This is useful to measure changes in velocity and changes in positions. A gyroscope measures either changes in orientation or variation in rotational angular velocity and a magnetometer in IMU measures magnetic fields. Figure 3.3 lists the parameters of an Opal sensor.

With the three sensors in an IMU device, the opal sensor is able to measure both lower and upper limb activities and movements, such as the swing of human body or arms, the gait speed, the stride features and so on. Figure 3.4 is an opal sensor which can fit on different joint points on user's arms.

Figure 3.4. The APDM Wearable Opal Sensor.

3.3.2 Motion Studio Software

Motion studio is the software that provides advanced configuration, recording, real-time visualization, calibration and data management features. From Figure 3.5, we can see the main interface and Motion studio consists of a working space to show the recorded data files and a console to draw the real time data samples sensed by the three sensors. In this study, we used Motion Studio to import the raw acceleration data recorded by the opal sensor.



Recording Mode Robust Synchronized Streaming
Current Status Configured
Working Directory /MyProject
Select Monitor #2150 : lumbar

```
• Streamed 747912 samples
• Recorded 746730 samples
• Saved data to the following file: 20160324-085118-sensor_data.h5
• Dropped samples = 0

startRecordSyncVal: 3734616807880 stopRecordSyncVal: 3734631742473 lastReceivedSyncVal: 3734631742480
```

Figure 3.5 The Interface of Motion Studio.

3.4 Data Analysis

For STS postural symmetry tests, we first calculate the spearman correlation coefficient (bad: 0-0.39, moderate: 0.4-0.75, good: 0.76-1) between our symmetry score and the reference value which is the rotational angular velocity around the roll axis concurrently recorded by the opal sensor of each STS movement in every sub-sessions. Then we calculated the arithmetic mean value and the standard deviation of the absolute symmetry score in each sub-session (the last 5-times-STS in a total of 8-times-STS movement) and compared the value among the four sub-sessions intra-personally to see if the feedback can have a positive influence to improve the postural symmetry of participants in doing STS movement. Furthermore, for walking session, we collected the symmetry score of all the five trials and also compared them intra-personally to see whether the score is valid and the feedback can make participants more balanced when walking.

CHAPTER 4

RESULTS AND DISCUSSION

The five participants completed all the sessions without incident. From Table 4.1 we can see that the spearman correlation coefficients between our symmetry score from the Kinect for Windows camera and the angular velocity data acquired from gyroscope in Opal sensor range from 0.476- 0.976 (from moderate to good) with an average of 0.732. Figure 4.1 (a)-(e) shows the intra-personal comparison of two sessions consists of four sub-sessions.

Subject 1 and subject 3 performed the similar results with each other. From Figure 4.1 we can see that their normal sub-sessions are the most asymmetrical performance and the feedback sub-sessions performed the best among the four sub-sessions. With the foam under one foot and the wood board under the other, they performed all the four sub-sessions more asymmetrical but the feedback sub-session was still the most symmetrical one. Furthermore, from Table 4.1 we can see that the standard deviation of the average symmetry score of the third feedback sub-session the smallest in most of the sub-sessions, which means the two participants did the 5-trial STS movement more stable with the audio feedback than either their normal performance (Normal sub-session) or their self-adjustment performance (the second control sub-session).

Subject 2 performed the first session the same as others that his feedback sub-session is the most symmetrical performance and the normal sub-session is the most asymmetrical one. In the second session, with the foam and the hard wood board under his feet, his performance is getting more and more symmetrical from the normal sub-session to the last control sub-session. There are two possibilities that may cause this result. First, the audio feedback has a longer influence on the subject so that he can still learn to do his movement more symmetrical even without a feedback. Second, the subject has a slow self-adaptability that after he was told to perform his most symmetrical movement in the second control sub-session, he needs more practice than the other four subjects to make himself more balanced to do STS movement. In this possibility, the audio feedback may or may not have enhancement to his final performance. Besides, we can see form Table 4.1 that in either the first or the second session, subject 2 also performed his feedback sub-session the most stable among the four sub-sessions.

Form the results subject 4 we can see that in his first session, although the subject did not perform his most symmetrical movement with an audio feedback, we can see the standard deviation of the feedback sub-session is the smallest, which means the subject performed his most stable movement with and audio feedback. And in the second session, his normal sub-session is the most symmetrical but unstable and he did not performed a more symmetrical movement by given an audio feedback.

Subject 5 also got the similar results in his first session with the other subjects, but from the result of the second session we can see this subject did his most asymmetrical performance in the second sub-session and his feedback sub-session is the most symmetrical and stable one.

In the five scatter plots in Figure 4.2 (a)-(e), we combined all the data of the eight sub-sessions in one subject together and calculated the Spearman correlation coefficient and most of them showed a moderate correlation coefficient value.

Besides, from Figure 4.2 (a-e), we can see the results of Walking session, the feedback session did not have any obvious improvement of the walking movement but from the score we can see clearly the participants body swing in the left and right direction. However, though haven’t designed any other functional tasks for the five subjects, we can see from Figure 2.3(b) that the symmetry score can sensitively reveal the subtle changes in standing posture, which makes us think about the potential of the system in evaluating the postural symmetry during standing still and help users to perform a symmetrical posture with the audio feedback.

Table 4.1 STS User Study Results

subjects	session		Spearman Correlation Coefficient/P-value	Average symmetry score	Standard deviation
Subject1	Ground	Normal	0.786/0.028	0.1363	0.0395
		Control	0.833/0.015	0.1251	0.0265
		Feedback	0.500/0.216	0.0568	0.0135
		Control	0.476/0.243	0.0775	0.0216
	Foam	Normal	0.976/0.0003	0.1681	0.0657
		Control	0.571/0.151	0.1518	0.0481
		Feedback	0.905/0.005	0.0990	0.0227
		Control	0.619/0.115	0.0991	0.0237
Subject2	Ground	Normal	0.619/0.115	0.2051	0.0526
		Control	0.500/0.216	0.1227	0.0513
		Feedback	0.929/0.002	0.0848	0.0215
		Control	0.786/0.028	0.1175	0.0448
	Foam	Normal	0.810/0.022	0.2382	0.0637
		Control	0.786/0.028	0.2170	0.1547
		Feedback	0.976/0.0003	0.1692	0.0432
		Control	0.643/0.096	0.1400	0.0497
Subject3	Ground	Normal	0.952/0.001	0.1175	0.0294
		Control	0.595/0.132	0.0744	0.0196

		Feedback	0.929/0.002	0.06	0.0087
		Control	0.905/0.005	0.0907	0.0183
Subject3	Foam	Normal	0.714/0.058	0.1542	0.0698
		Control	0.691/0.069	0.0912	0.0092
		Feedback	0.619/0.115	0.0804	0.0199
		Control	0.905/0.005	0.0915	0.0294
Subject4	Ground	Normal	0.548/0.171	0.1140	0.0419
		Control	0.714/0.058	0.0976	0.0298
		Feedback	0.786/0.028	0.0981	0.0088
		Control	0.571/0.151	0.0892	0.0204
	Foam	Normal	0.667/0.083	0.1501	0.0859
		Control	0.810/0.022	0.1745	0.0341
		Feedback	0.691/0.069	0.1698	0.0419
		Control	0.881/0.007	0.1516	0.0697
Subject5	Ground	Normal	0.905/0.005	0.0651	0.0184
		Control	0.619/0.115	0.0648	0.0206
		Feedback	0.786/0.028	0.05	0.0086
		Control	0.524/0.197	0.0571	0.0178
	Foam	Normal	0.691/0.069	0.1327	0.0602
		Control	0.571/0.151	0.1572	0.0458
		Feedback	0.571/0.151	0.1081	0.0309
		Control	0.905/0.005	0.1449	0.0507

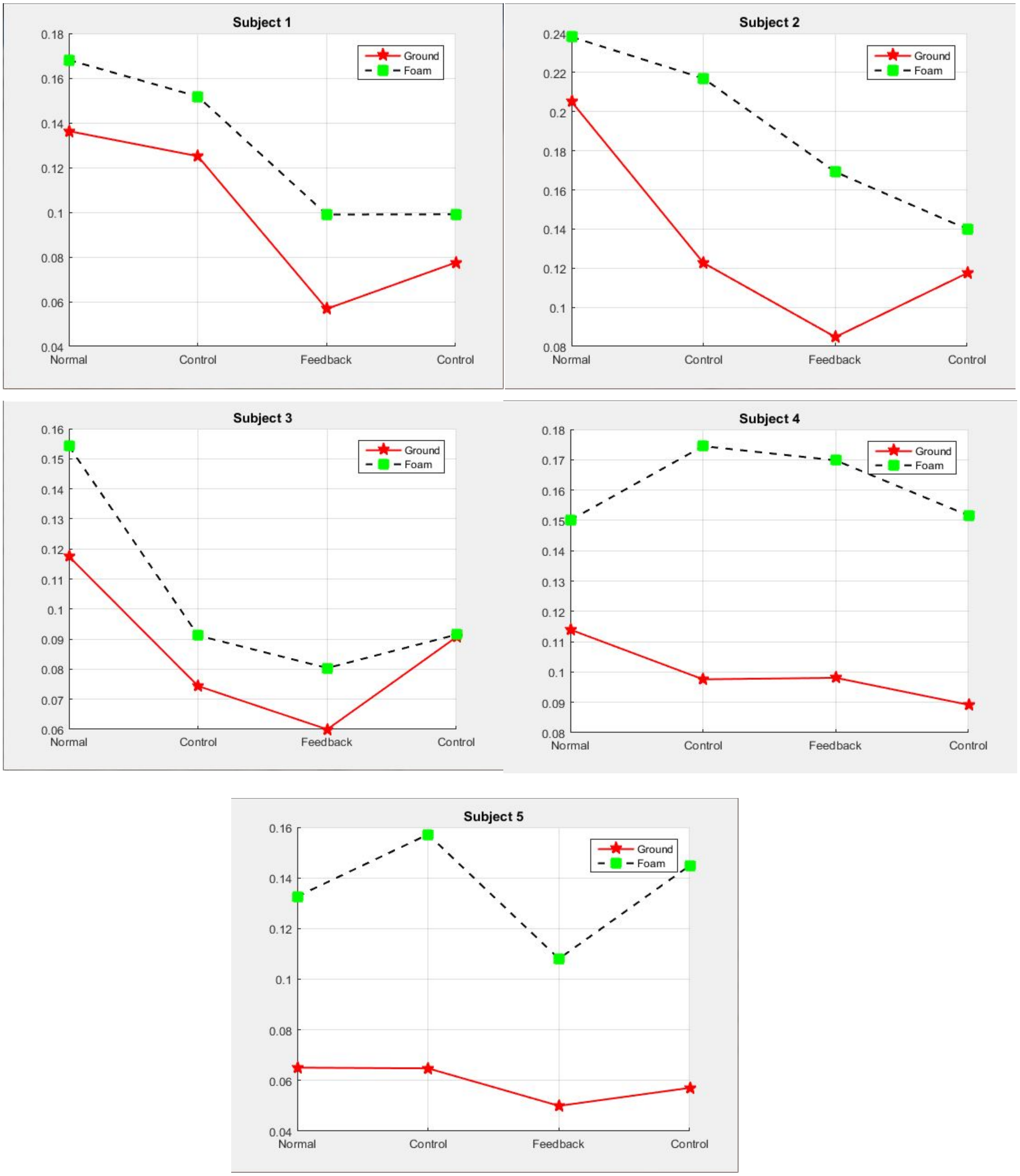
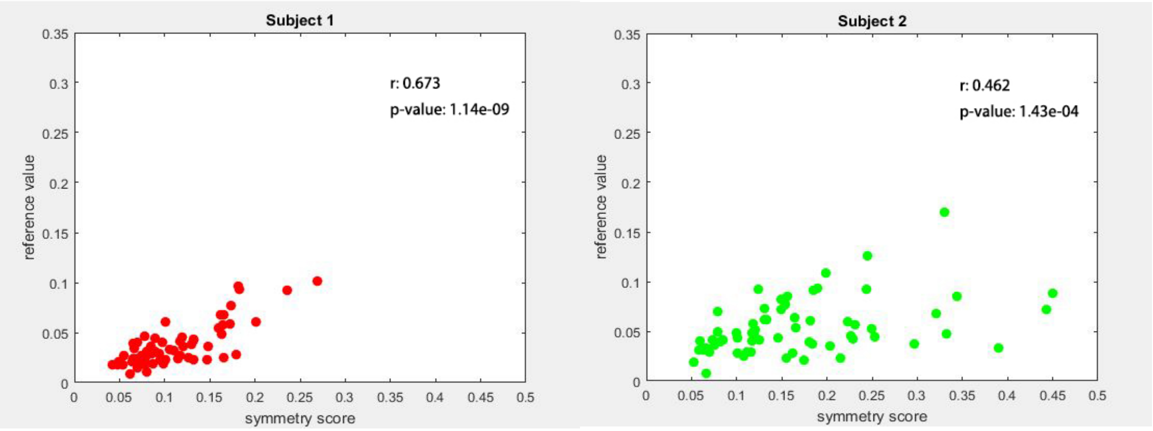
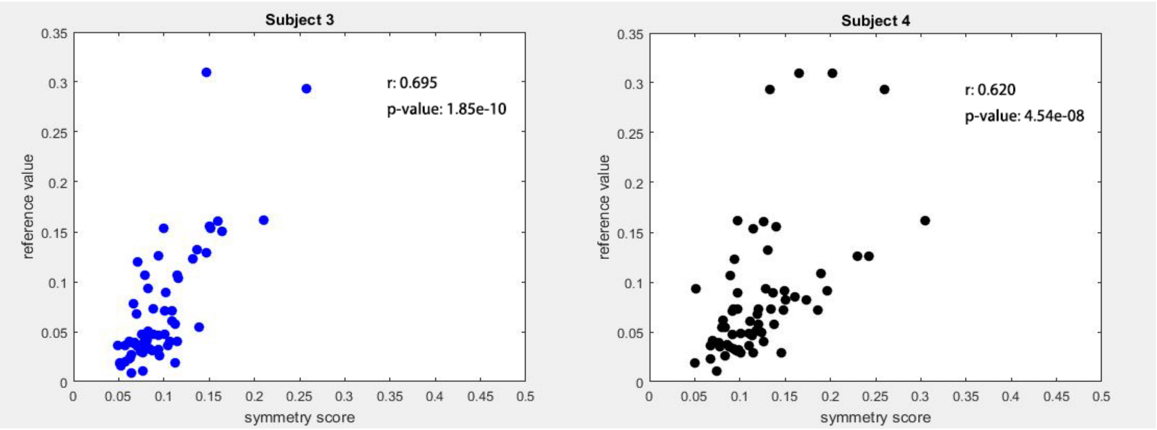


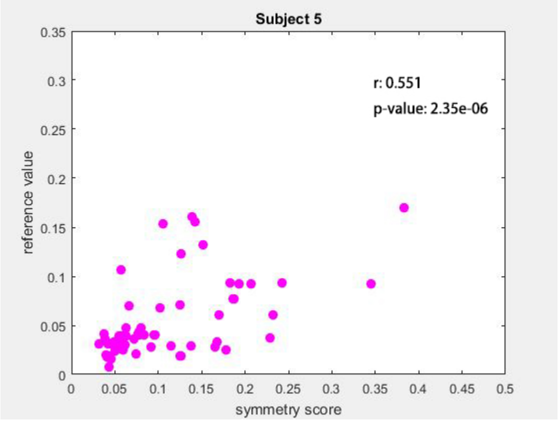
Figure 4.1 The Comparison of the Sub-Sessions Intra-Personally During STS.



(a) r: 0.673 p: 1.14e-09 (b) r: 0.462 p: 1.43e-04



(c) r: 0.695 p: 1.85e-10 (d) r: 0.620 p: 4.54e-08



(e) r: 0.551 p: 2.35e-06

Figure 4.2 (a) - (e): The Scatter Plot of All the Sub-Sessions of Subject 1-5.

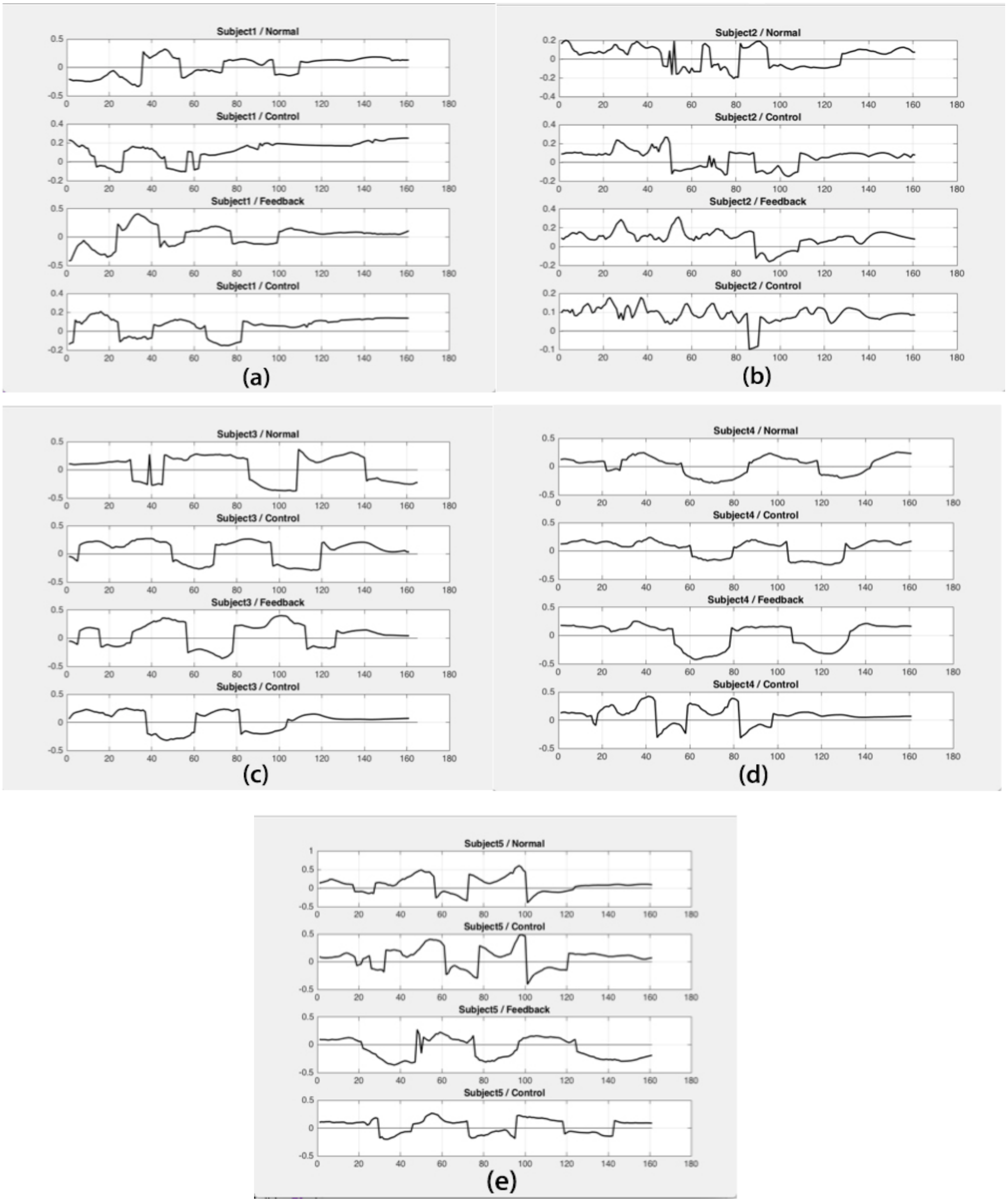


Figure 4.3 (a) - (e) The Comparison of the Sub-Sessions Intra-Personally of Walking

CHAPTER 5

CONCLUSION AND FUTURE WORK

In this thesis, we proposed an easy-setup and low-cost system, using a single Microsoft Kinect depth sensor, to calculate a symmetry score to assess and train the upper body postural symmetry in STS movement. We found that our score was effective in sensitively reflecting the asymmetrical movement in mediolateral direction. The audio feedback performed well in adjusting the degree of postural symmetry during STS movement. Furthermore, from the five participants' feedbacks, they liked the way that they can choose the music type themselves to be their own feedback. Therefore, the promising results of the experiment showed the potential of our Kinect-based system in assessing and training human upper body postural symmetry during STS movement.

However, as the feedback did not make any obvious improvements in walking session, the research points to several interesting directions that our system can be further developed. First, we can resample and align the trajectory of a user's hand swing to reflect the balance of walking, tracking the start and end points of one swing and resample the all the point cloud to get the arm swing trajectory distance, thus create a score to trigger a periodic feedback.

Second, we can test the walking movement on a treadmill in order to ignore the limitation of distance from the user to the camera.

REFERENCES

[1] Cacciatore, Timothy W., Fay B. Horak, and Sharon M. Henry. "Improvement in automatic postural coordination following alexander technique lessons in a person with low back pain." *Physical therapy* 85.6 (2005): 565-578.

[2] Cheng, Pao-Tsai, et al. "Symmetrical body-weight distribution training in stroke patients and its effect on fall prevention." *Archives of physical medicine and rehabilitation* 82.12 (2001): 1650-1654.

[3] Baker, Susan Pardee, and A. H. Harvey. "Fall injuries in the elderly." *Clinics in geriatric medicine* 1.3 (1985): 501-512.

[4] Pisan, Yusuf, Jaime Garcia Marin, and Karla Felix Navarro. "Improving lives: using Microsoft Kinect to predict the loss of balance for elderly users under cognitive load." *Proceedings of The 9th Australasian Conference on Interactive Entertainment: Matters of Life and Death*. ACM, 2013.

[5] Campbell, A. John, et al. "Falls in old age: a study of frequency and related clinical factors." *Age and ageing* 10.4 (1981): 264-270.

[6] Blake, A. J., et al. "Falls by elderly people at home: prevalence and associated factors." *Age and ageing* 17.6 (1988): 365-372.

[7] Sattin, Richard W., et al. "The incidence of fall injury events among the elderly in a defined population." *American Journal of Epidemiology* 131.6 (1990): 1028-1037.

[8] Alexander, Bruce H., Frederick P. Rivara, and Marsha E. Wolf. "The cost and frequency of hospitalization for fall-related injuries in older adults." *American journal of public health* 82.7 (1992): 1020-1023.

[9] Fujimoto, Masahiro, and Li-Shan Chou. "Dynamic balance control during sit-to-stand movement: an examination with the center of mass acceleration." *Journal of biomechanics* 45.3 (2012): 543-548.

[10] Bohannon, Richard W. "REFERENCE VALUES FOR THE FIVE-REPETITION SIT-TO-STAND TEST: A DESCRIPTIVE META-ANALYSIS OF DATA FROM ELDERS 1." *Perceptual and motor skills* 103.1 (2006): 215-222.

[11] Bohannon, Richard W., et al. "Five-repetition sit-to-stand test performance by community-dwelling adults: A preliminary investigation of times, determinants, and relationship with self-reported physical performance." *Isokinetics and exercise science* 15.2 (2007): 77-81.

[12] Runge, Martin, et al. "Is muscle power output a key factor in the age-related decline in physical performance? A comparison of muscle cross section, chair-rising test and jumping power." *Clinical physiology and functional imaging* 24.6 (2004): 335-340.

[13] Hughes, Michael A., and Margaret L. Schenkman. "Chair rise strategy in the functionally impaired elderly." *Journal of rehabilitation research and development* 33.4 (1996): 409.

[14] Hughes, M. A., et al. "Chair rise strategies in the elderly." *Clinical Biomechanics* 9.3 (1994): 187-192.

[15] Mazza, Claudia, et al. "Association Between Subject Functional Status, Seat Height, and Movement Strategy in Sit-to-Stand Performance." *Journal of the American Geriatrics Society* 52.10 (2004): 1750-1754.

[16] Manini, Todd M., et al. "Evaluating task modification as an objective measure of functional limitation: repeatability and comparability." *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences* 61.7 (2006): 718-725.

[17] Winter, David A. "Human balance and posture control during standing and walking." *Gait & posture* 3.4 (1995): 193-214.

[18] Coulthard, Jason T., et al. "Evaluation of an inertial sensor system for analysis of timed-up-and-go under dual-task demands." *Gait & posture* 41.4 (2015): 882-887.

[19] Chaikeeree, Nithinun, et al. "Interaction of age and foam types used in Clinical Test for Sensory Interaction and Balance (CTSIB)." *Gait & posture* 41.1 (2015): 313-315.

[20] Gillette, Jason C., and Catherine A. Stevermer. "The effects of symmetric and asymmetric foot placements on sit-to-stand joint moments." *Gait & posture* 35.1 (2012): 78-82.

[21] Whitney, Susan L., et al. "Clinical measurement of sit-to-stand performance in people with balance disorders: validity of data for the Five-Times-Sit-to-Stand Test." *Physical therapy* 85.10 (2005): 1034-1045.

[22] Cheng, Pao-Tsai, et al. "The sit-to-stand movement in stroke patients and its correlation with falling." *Archives of physical medicine and rehabilitation* 79.9 (1998): 1043-1046.

[23] Cheng, Pao-Tsai, et al. "Symmetrical body-weight distribution training in stroke patients and its effect on fall prevention." *Archives of physical medicine and rehabilitation* 82.12 (2001): 1650-1654.

[24] Winter, David A. "Human balance and posture control during standing and walking." *Gait & posture* 3.4 (1995): 193-214.

[25] Yang, Yang, et al. "Reliability and validity of Kinect RGB-D sensor for assessing standing balance." *Sensors Journal, IEEE* 14.5 (2014): 1633-1638.

[26] Shotton, Jamie, et al. "Real-time human pose recognition in parts from single depth images." *Communications of the ACM* 56.1 (2013): 116-124.

[27] Stone, Erik E., and Marjorie Skubic. "Evaluation of an inexpensive depth camera for passive in-home fall risk assessment." *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2011 5th International Conference on*. IEEE, 2011.

[28] Hg, R. I., et al. "An RGB-D database using Microsoft's Kinect for windows for face detection." *Signal Image Technology and Internet Based Systems (SITIS), 2012 Eighth International Conference on*. IEEE, 2012.

[29] Kitsunezaki, Naofumi, et al. "KINECT applications for the physical rehabilitation." *Medical Measurements and Applications Proceedings (MeMeA), 2013 IEEE International Symposium on*. IEEE, 2013.

[30] Dutta, Tilak. "Evaluation of the Kinect™ sensor for 3-D kinematic measurement in the workplace." *Applied ergonomics* 43.4 (2012): 645-649.

[31] Raptis, Michalis, Darko Kirovski, and Hugues Hoppe. "Real-time classification of dance gestures from skeleton animation." *Proceedings of the 2011 ACM SIGGRAPH/Eurographics symposium on computer animation*. ACM, 2011.

[32] Shotton, Jamie, et al. "Real-time human pose recognition in parts from single depth images." *Communications of the ACM* 56.1 (2013): 116-124.

[33] Zhang, Zhengyou. "Microsoft kinect sensor and its effect." *MultiMedia, IEEE* 19.2 (2012): 4-10.

[34] Pai, Yi-Chung, et al. "Control of body centre of mass momentum during sit-to-stand among young and elderly adults." *Gait & Posture* 2.2 (1994): 109-116.

[35] Colagiorgio, P., et al. "Affordable, automatic quantitative fall risk assessment based on clinical balance scales and Kinect data." *Engineering in Medicine and Biology Society (EMBC), 2014 36th Annual International Conference of the IEEE*. IEEE, 2014.