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SCHOOL OF ENGINEERING, COMPUTING & BUILT ENVIRONMENT

QUANTITATIVE GAIT EVALUATION SYSTEM

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BY

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DECLARATION

I hereby declare that this thesis entitled "QUANTITATIVE GAIT EVALUATION SYSTEM" is the result of my own independent investigation / work, except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature for any other degree.

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ABSTRACT

A gait evaluation is conducted by the physiotherapist before a rehabilitation plan is designed for the patient. The process of gait evaluation requires the patient to walk forth and back under the observation of the physiotherapist. The evaluation takes time from the physiotherapist to interpret based on his/her experience and knowledge. This project presents a quantitative approach for gait evaluation to assist the physiotherapists. To emulate their interpretation, a platform with the Kinect sensor and pre-defined walking path is setup and a set of gait kinematic parameters is identified. 3D skeletal joint data retrieved from Microsoft Kinect sensor is utilised to estimate these parameters. Ten subjects are required to walk forth and back to enable the data collection containing 3D coordinates from skeletal joint points. These coordinates are used to extract kinematic information and estimate joint positions during walk using algorithms created in Microsoft Azure Machine Learning Studio. In obtaining the spatial and temporal factors, an objective, quantitative measurements of the quality and abnormality of the patient's gait can be revealed. Severity level is provided in the system to better classify the gait quality of subject in order to assist physiotherapist in creating rehab plan. The results are compared with actual measurement and showed an overall high rate similarity of 93%. Hence, this quantitative gait evaluation system is a feasible offline tool to assist the physiotherapists in identifying the gait deviation pattern respective to gait parameter deviation and severity level provided the experts identify the associated signs from the recorded gait.

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CHAPTER 1

PROJECT INTRODUCTION

1.1 BACKGROUND

Walking is our most basic method of transportation while gait is the manner, pattern, or style of walking. Gait abnormality can affect the quality of life and limit the independence of the individual affected. An unsteady gait is a disorder in walking that can be caused by diseases of or injury to the legs and feet or to the related nervous system which could be insignificant to be barely noticeable or as severe as, resulting in inability to perform daily tasks. According to the National Health Morbidity Survey (NHMS) 2015 conducted by the Ministry of Health Malaysia (Baharuddin *et al.*, 2015), the prevalence of overall impairment and disability is obtained from adult respondents aged 16 years and above. Among all types of disability, the prevalence of difficulty in walking was the second highest at 11.3%.

Gait can be influenced by many factors either is affected by physical balance or improper footwear. The analysis of quantitative gait data has mainly focused on aspects such as recognition, identification, pattern analysis, animation, attractiveness, etc (Hong, J. and Kang, J., 2012). Gait pattern is interpreted based on the observed patterns of the collected gait parameters such as stride, cadence, angle, etc. Gait evaluation is now more reliable owing to advance of information technology making the ease of measurement and video reviewing in a setup of a laboratory (Switaj, T. and O'Connor, F., 2008). Equipment such as electrogoniometry, EMG, photography with high configuration techniques have been developed for the purpose of gait evaluation.

While gait evaluation becomes measurable with the expenses of equipment cost and analytical time, however, observational method is still preferred by the clinical experts such as physiotherapist owing to the simplicity in setup. Based on the interview with Mr. Chew Kok Hin, a professional physiotherapist in i-Sports Physiotherapy &

Rehabilitation Centre of Island hospital, gait evaluation is related to the biomechanics of body joints, human body movement, and muscle activity (Chew, K.H., 2019). Dysfunction in any of these will results in people walking in an ‘abnormal’ way producing a gait deviation pattern. Associated signs can be helpful in identifying underlying conditions and narrowing the differential diagnosis of gait deviation pattern (Salzman, B., 2011). Gait evaluation with associated signs are the essentials to design a rehabilitation plan for the patient in aligning the gait of patient. Therefore, a physiotherapist must first ascertain the gait deviation opposes to the normal gait pattern along with associated signs and the related causes.

1.2 PROBLEM STATEMENT

In order to restore a patients’ normal gait, physiotherapists are required to work closely with the patients. However, compared to the high rise number of patients in Malaysia, acute shortage of professional include occupational therapist and physiotherapist is reported as the ratio of therapist to patients is 1:17,777 in 2016 (National News Highlights the High Demands for Therapist, 2016). This ratio is more than three times below the global average of therapist-to-population ratio of 1:5,000. This has also led to a long queueing list of treatment appointment and causing the degrade in treatment outcome owing to delays inn treatment. Besides, observer-based gait clinic visits can be conducted instantaneously without specific equipment, but it requires interpretation of the physiotherapists which consumes more time for them. Though, this method has limited validity, reliability and precision as it is qualitative and subjective to experience of individual expert while it could not be quantified and visualised the previous gait activity performed.

1.3 AIM AND OBJECTIVES

In this project, it is aimed to present a gait evaluation system which provides quantitative information on the gait quality of a user. The objectives are listed in the following to achieve the aim:

- To setup a video acquisition module to capture the gait and obtain the skeletal joint data.
- To identify the features in gait evaluation and develop the respective data processing module in enabling the data collection of these features.

- To develop a gait quality evaluation module with the accuracy of at least 90% to evaluate the quality of the gait performed.
- To develop a gait categorisation module to categorise the gait severity level based on the results of features and selected associated sign.
- To design a graphical user interface (GUI) to enable the gait recording and displaying of the gait parameter and gait quality result.

1.4 PROJECT SCOPE

This project is designed to make gait analysis with less hardware logistic and assist the physiotherapist/physician in the clinic to reduce the observation time. A laptop with Kinect sensor will capture the gait and analyse the gait. A graphical user interface (GUI) is created to assist the experts in gait evaluation while a platform is setup to enable the video capturing on the gait activity along with a set of procedure.

In this project, ten volunteers are approached to obtain their consents (See Appendix E) in the participation of the gait creation. Owing to the difficulties to obtain people with abnormal gait, the volunteers may be asked to act the gait with the reference to the videos found in YouTube. These volunteers are aged between 20 to 23 years old as it is easier to approach the classmates by the availability.

1.5 PROJECT SPECIFICATION

The suitable video acquisition hardware for the usage of this project is the Microsoft Kinect. The justification will be presented in Chapter 3. Consequently, some of the specifications of the project are based on the product specification of Kinect sensor as shown in Table 1.1.

Table 1.1 - Specification of the project

Specification	Value
1. Video Capturing	
Operating Space	Minimum : 5metres (length) x 3metres (width) x 2.5metres (height)
Device Placement	0.7 metres off the ground
Tracking target	1 user per session
Allowable Distance to the user	2.8 metres to 3.5 metres
Walking Path Line	2.4 metres (length) x 0.5 metres (width)
Required Resolution	640 x 480 pixels
Frame Rate	30 frames per second
Recording Time (Or required walking time)	6 to 8 seconds per session
2. Gait Evaluation and Processing	
Measurement Tolerance of Gait Parameter	±10%
Root Mean Squared Error of Feature Segmentation	0.10
Similarity of Gait Evaluation System	90%
Processing Time (from data extraction to the results publication)	7 Minutes
Severity Level	• Normal • Abnormal - Low • Abnormal - Medium • Abnormal - High

CHAPTER 2

LITERATURE REVIEW

2.1 GAIT

Gait is a pattern or style of a person walking. Walking is one of the most trivial but most important forms of the movement of individuals. The gait cycle is a repetitive pattern involving steps and strides (Gait, 2019). Gait cycles mainly consist of two major phases, namely stance phase and swing phase. Stance refers to the time when the foot is on the ground and stance phase begins with initial contact (Kharb, A. *et al.*, 2011). Swing is the term used to describe the period during which the foot is in the air for limb advancement and it begins when the foot is lifted from the ground (toe-off). A gait cycle started with the right limb as reference is illustrated in Figure 2.1. The stance phase takes 60% of the gait cycle as there are several periods where both grounds are situated on ground which knows as double support whereas the remaining 40% is the swing phase. A detailed of normal gait is categorized to eight subphases with classic and new terms as shown in Figure 2.1.

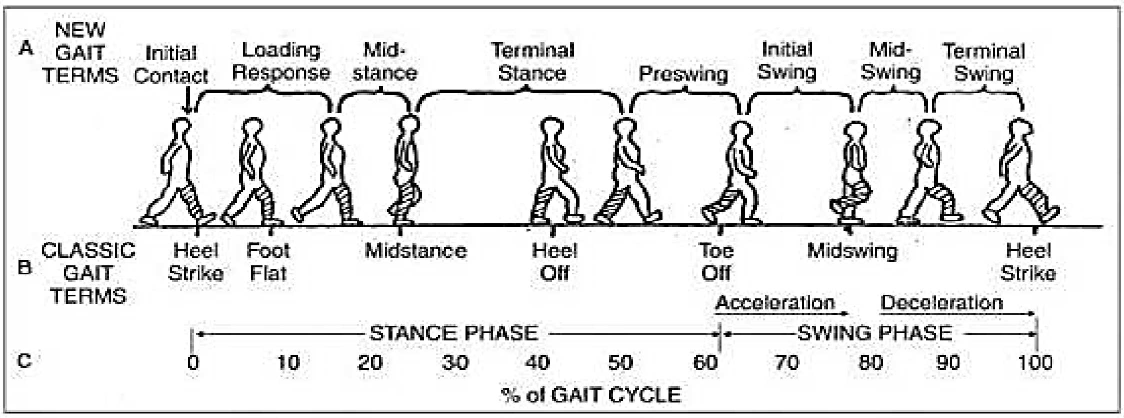


Figure 2.1 - Gait Cycle (Gait, 2019)

2.1.1 THE PHYSIOLOGY OF GAIT

Normal gait requires a delicate balance between various interacting systems, namely three major afferent sensory systems, a locomotor efferent and the strict surveillance by several structures of the central nervous system (Dietz, V., 2013). Cardiovascular system provides the ability to stand erect without collapsing. Normal walking rely not solely on sensorimotor structures, but also critically rely on the interaction between the executive control dimension (integration and call of action) with the cognitive aspect (e.g., navigation, visuospatial perception, or attention) and the affective aspect (mood, cautiousness, and risk-taking) (Snijders, A., *et al.*, 2007). Walking also consist of three major components : locomotion (including initiation and maintenance of rhythmic stepping), balance and ability to adapt to the environment. Malfunction in any of these systems can affect gait.

2.1.2 BIOMECHANIC OF GAIT

Gait evaluation is related to the biomechanics of body joints, human body movement, and muscle activity. As shown in Figure 2.2, muscles generate forces that acted directly on the skeleton during ordinary walking. These forces affect the motion of the entire body as joint contact forces and ground responses cause the impacts of muscle force to be transferred to sections away from muscle contraction.

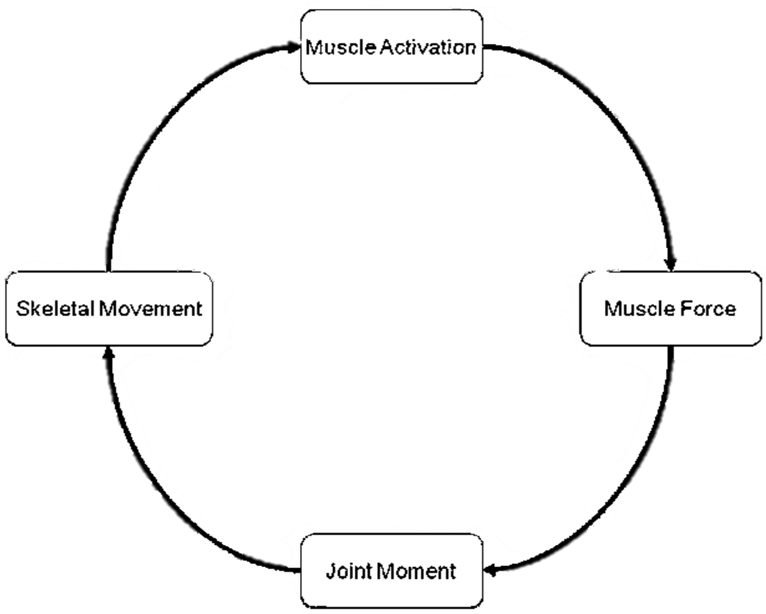


Figure 2.2 - Steps Required in Musculoskeletal System of Gait (Stewart, C. & Shortland, A., 2010)

1. <u>Muscles Activity</u>

Muscle activity is typically studied using electromyography (EMG). EMG documents differ between individuals and differ for each individual according to factors like speed. Overall, during the gait, the calf muscles are the main contributors to the walking action, it is known to be active during the stance phase with rising activity to peak in the terminal phase before the muscle becomes inactive during the swing phase. (Stewart, C. & Shortland, A., 2010). The activation of the component muscle makes a subtle differences at a self-selected walking speed. The calf muscles, for example, which includes of three component muscles, namely the medial and lateral head of gastrocnemius and soleus, are common contributors to the development of knee extension. Figure 2.3 (a) shows the operations of these three muscles when walking at self-selected speed (ORLAU data, 2010) while Figure 2.3 (b) shows the effect of fast walking speed on the amplitude of EMG signals in different subjects. As shown in Figure 2.3, a tight relationship is present between the parameters of Kinematic events with the muscle activity where the time-shift patterns of gait cycle with increasing walking speed parallels the corresponding changes of the muscle activity (Lacquantiti, F. *et al*., 2012).

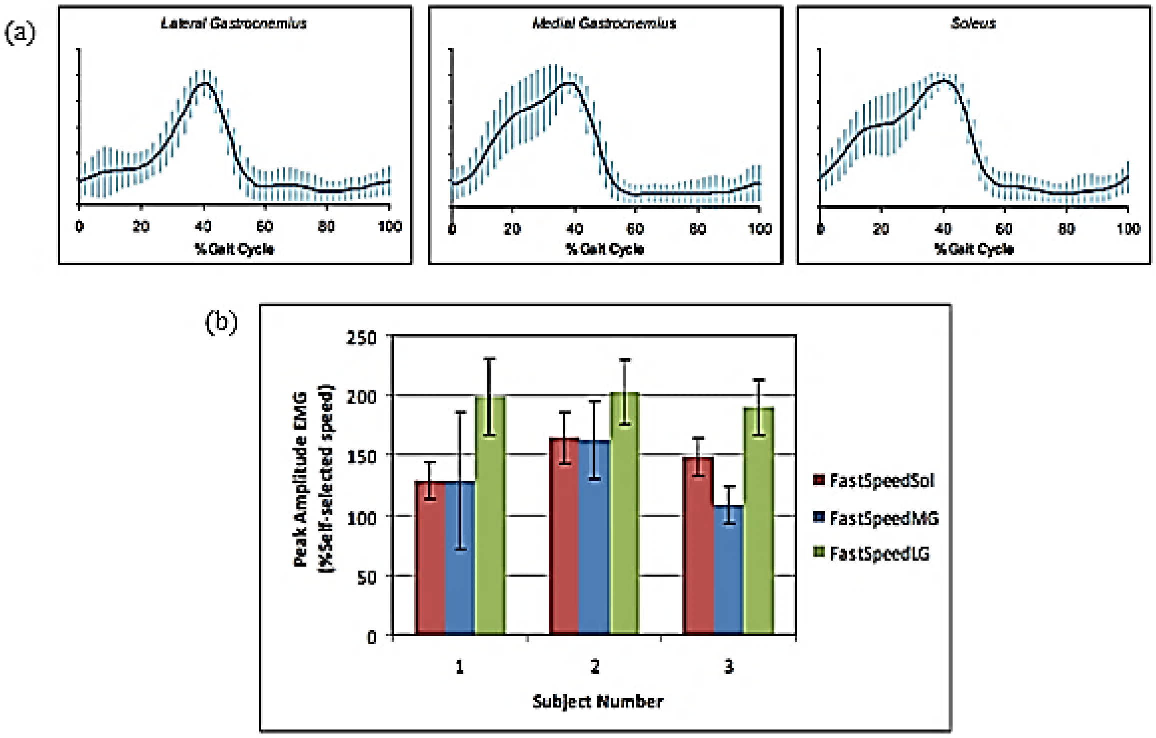


Figure 2.3 - EMG Data of Activities of Muscles when Walking

2. Joint Movement

A joint or articulation (or articular surface) is the bone-to-body connection that links the skeletal system into a functional whole. The muscle force produces a joint motion and it spans the joint axis. The muscle's motion arm gives the link between the force and the resulting joint moment. A muscle with a long moment arm will generate a higher moment for a specified force, but if the position of the joint changes, it will also experience a greater shift in its length.

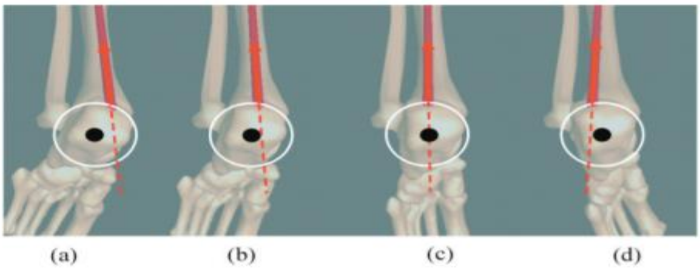


Figure 2.4 - Position of Ankle Joint influenced by Gastrocnemius Muscles (Stewart, C. & Shortland, A., 2010)

Figure 2.4 illustrates the position of ankle joints influenced by the stabilizing action of gastrocnemius muscles which is shown as a single line of action. The joint location is marked with a black dot for positions shown, i.e. (a) 15º eversion, (b) 0º or neutral, (c) 15º inversion and (d) 30º inversion. Due to the correlated relationship between muscle and joint movement, the movement will be affected if there’s a muscle weakness. For examples, spasticity due to weak muscles leads to inadequate joint positions at particular moments in time (too flexed, too extended), which may be absolute (limited motion) or relative (delayed motion). All of these factors will reduce the stability of the legs, which again deteriorates gait function.

3. Skeletal Movement

Muscles, joints and bones contributes the principal mechanics for the skeletal movement, all coordinated by the nervous system while the skeleton helps transmit that movement. The skeleton and muscles work together as the musculoskeletal framework. Musculoskeletal system (often treated as two separate systems, the muscular, and skeletal) plays an important homeostatic role: allowing the skeletal movement to be more favourable external conditions. To put it in a simple term, many skeletal muscles are attached to joints which allows the muscle contraction to move the bones across the joint which leads to skeletal movement.

2.2 GAIT EVALUATION

In everyday clinical area, experienced physiotherapist can make many perceptive diagnoses based on medical history, physical examination or observation alone. In the research made by Rubino, F. (2002), most of the clinicians and neurologists consider the instrumented gait analysis/gait evaluation to be the best tool for assessing gait performance. Instrumented gait evaluation is a method for evaluating the gait quality which studies the gait parameters and then interprets the parameters by constructing conclusions based on the gait parameter obtained (Laxman Chavan, Y., 2011). It involves measurements, where measurable parameters such as biomechanics of the body joints, human body motion and muscle's activity are analysed and further interpreted. Kinematic gait assessment generally takes advantage of different types of laboratory equipment and sensors to capture gait information. This type of gait evaluation is the study of the angles, positions, accelerations, and velocities of a human body, limbs, and joints that occurs during movement and it provides a non-invasive way of collecting data of joint and limb motion from the patients (Ganea, D. *et al.*, 2013). As described in a paper, the kinematic system is used in gait evaluation to capture the human gait data in video and further analysis and calculations are done to obtain all the required data for the evaluation of gait quality, including the joint angle and position during each gait cycle (Ganea, D. *et al.*, 2013).

2.2.1 GAIT PARAMETERS

Gait parameters can be obtained from the gait cycle and it's taken into account for gait evaluation. The basic parameters that mainly used for gait evaluation are spatial, temporal and kinematics, as proposed by Prakash, C. *et al.* (2015) may be summarised as follows.

<u>Spatial Parameters (Distance parameters):</u>

1. Stride length
    - Distance between two successive placements of heel contact of the same foot (Prakash, C. *et al.*, 2015). The term of 'Stride' is defined as one step by each foot. Stride length consists of two step lengths, left and right, which also forms a complete git cycle. It can be measured from the point of one heel strike of one lower extremity to the point of the next heel strike of the same extremity as shown in Figure 2.5.

2. Step length
    - Distance between successive contact point on opposite feet. In normal gait, the step length for both left and right legs should be equal and the summation of right step length and left step length should make a stride length as shown in Figure 2.5.

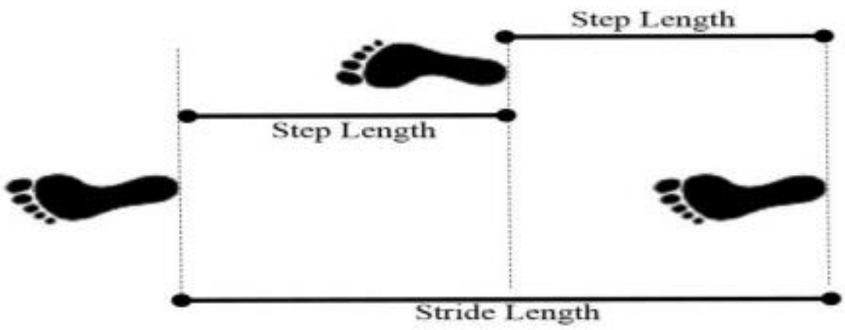


Figure 2.5 - Spatial-temporal Parameters (Prakash, C. et al., 2015)

3. Step Width
    - The distance between the two feet at perpendicular axis to the walking direction of steps (Dietz, V., 2013).

<u>Temporal Parameters (Time parameters):</u>

1. Cycle Time or Stride Time
    - Duration of one complete gait cycle. The amount of time taken to complete one stride/ gait cycle.
2. Step Time
    - Duration of the point of heel strike of one leg and the point of heel strike of the opposite leg.
3. Walking/Gait speed
    - Distance covered in a gait cycle time which can be presented as follows:

      Speed (m/s) = stride length (m) / cycle time (s)
    - Gait speed is the most often reported reference value for gait performance as it depends on two gait parameters, namely stride length and stride time (also referred as ‘cycle time’) which makes it more accurate (Hollman, J.H. *et al.*, 2011).

Kinematic Parameters:

The Kinematic parameters focused in Prakash's study (Prakash, C. *et al.*, 2015) are joint position containing critical information for the calculation of stride length, cycle time, etc. These parameters are very important in the identification and classification of gait kinematics of human. Since gait is approximately cyclic, the pattern of data can be calculated using the temporal and spatial variables as they vary constantly with time (Baker, R., 2013). A sample of gait pattern of both right foot and left foot is presented in a graphical form which is divided into a number of discrete gait cycles as shown in Figure 2.6.

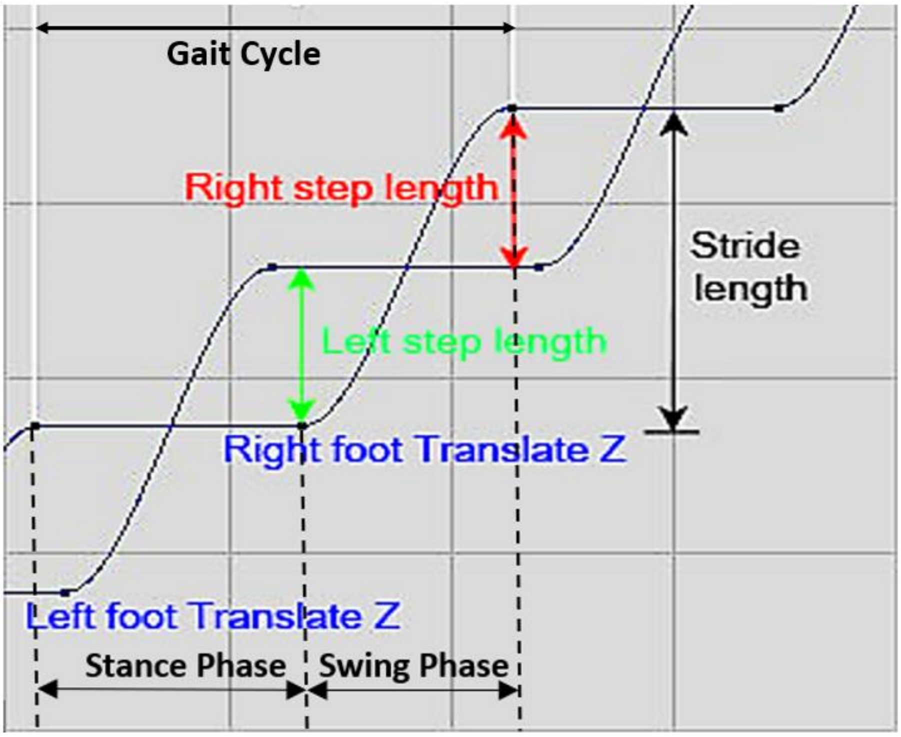


Figure 2.6 - Foot Movements in Graphical Form (Utdallas.edu. (n.d.).)

The data acquired, including the temporal/spatial parameters of gait such as stride and strep lengths, the duration of stance and swing phases of the gait cycle and gait speed can be interpreted either in numerical or graphical forms as presented in Figure 2.6. When the foot is in a stance phase, the joint location of foot should not be changing as the curve of the graph will remain completely flat. If the foot is in a swing phase, the joint location of the foot will be changing as the curve of the graph increase with ease-in and ease out. By referring to the graph, it can be seen that the durations of stance phases are slightly longer than swing phases throughout a neutral walking pattern due to the stance phase takes 60% of the gait cycle while the swing phase takes the remaining 40% as mentioned in Section 2.1.

2.2.2 NORMAL GAIT

There are requirements for a person to have a stable gait when walking (Rubino, F., 2002):

1. Balance must be maintained, either dynamically or statically, during in the phase of single leg stance.
2. The body remains erect and have an upright posture with the head straight.
3. Arms should be hanging loosely at the sides, swinging in rhythm with equal motion of the opposite leg.
4. Step length and time should be symmetrical thus forming a base with about 6 inches (15.24 cm) apart between the feet.
5. Walking in a straight line without waddling or staggering.
6. Turning should be no problem and can be perform smoothly and continuously.

Table 2.1 - Normal ranges for gait parameters by normal female subjects of different ages (Whittle, M., 2007; Item, G. et al., 2014).

Age (years)	**Cycle time (s)**	**Stride length (m)**	**Speed (m/s)**
13-14	0.99-1.55	0.80-1.17	0.57-0.96
15-17	1.03-1.57	0.83-1.20	0.59-0.98
18-49	1.06-1.58	0.87-1.22	0.62-1.02
50-64	1.04-1.56	0.88-1.24	0.60-1.01
65-80	0.94-1.46	0.88-1.25	0.52-0.89

Table 2.2 - Normal ranges for gait parameters by normal male subjects of different ages (Whittle, M., 2007; Item, G. et al., 2014).

Age (years)	**Cycle time (s)**	**Stride length (m)**	**Speed (m/s)**
13-14	1.06-1.64	0.81-1.20	0.62-1.01
15-17	1.15-1.75	0.85-1.25	0.63-1.09
18-49	1.25-1.85	0.89-1.32	0.78-1.18
50-64	1.22-1.82	0.95-1.46	0.65-1.06
65-80	1.11-1.71	0.96-1.48	0.53-0.98

A person with a normal gait would accomplish them without any difficulty. However, if even one of these conditions not met, the subject can be considered as having abnormalities in movement or is unable to walk. Although some deviations exist in normal gait, 'normal pattern' of walking leading to 'normal range' of parameters can be measured and obtained (Whittle, M., 2007). Table 2.1 and 2.2 show the approximate range for general temporal/spatial gait parameters in walking for both normal female and male subjects from different age groups (Whittle, M., 2007; Item, G. *et al*., 2014).

2.2.3 FACTORS INFLUENCING GAIT

<u>Age</u>

Studies made by Salzman, B. (2011) examine the effect of advanced age on gait condition by comparing healthy persons in their 70s with healthy persons in their 20s. The results demonstrate a 10% to 20% reduction in stride length or step length in the older population which resulting the age-related decline in gait speed. Other characteristics of gait features that commonly change with aging include increased stance phase and shorter swing phase, bent posture, ankle range of motion, diminished arm swing, etc which can be presented in Figure 2.7. Some speculate that these changes may represent adaptations to alterations in musculoskeletal function and locomotion system to produce a safer and more stable gait pattern.

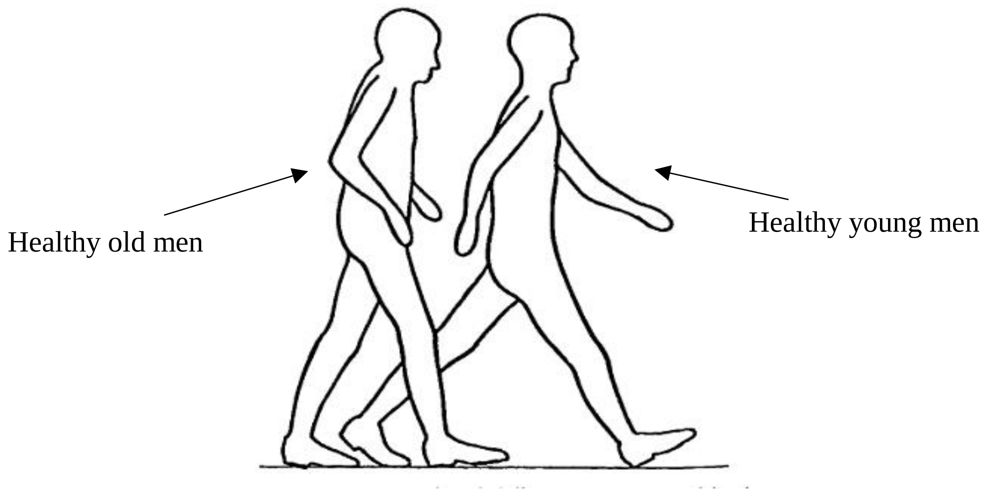


Figure 2.7 - Age-related Differences in Sagittal Body Position (NB, A., 1996)

<u>Anthropometry and Gender</u>

Subject features may confound the decrease in gait speed associated with age. Height is also associated with age-independent gait speed as it is known that taller subjects have bigger step and step lengths (NB, A., 1996). However, the proportion of variation described by height (12%) or leg length (6%) is overshadowed by the age (33%) impact, at least in some research (Dobbs, RJ *et al*., 1992). As for the gender factor, elderly females may walk more slowly than males, but the age-related decline in speed after age

63 may accelerate more in males (16.1% per decade) than in females (12.4% per decade) (NB, A., 1996). Compared to young adults, speed decreases in healthy old women but not in healthy old men when controlling for leg length, note that the old women were somewhat older than the old men.

2.2.4 ABNORMAL GAIT

Determining that whether a gait is “abnormal” or “disordered” is actually very difficult because there are many contributors that needs to be taken into consideration. Gait abnormalities may cause from a system disorder, including the nerves, brain, spinal cord, skeleton, joints and muscles. It may also come from the presence of pain at the critical joints making the subject feeling more comfortable to walk in ‘abnormal’ way. Some of these pathological and abnormal gaits can be identified by just using eye, but others can only be determined by using a specific measurement system or gait evaluation. Gait abnormalities may be revealed by evaluating the aspects of gait during evaluation of gait including, body posture, length of stride, base width, velocity, instability, fluidity of movements, etc.

Murray, *et al*. (1978) had collected the gait data from 44 men that are diagnosed with parkinsonism and concluded the abnormalities which can be identified by temporal/spatial and kinematics measurement as follows:

- Stride length and gait speed were decreased greatly even though the cycle remained normal.
- The walking base was enlarged insignificantly.
- The ROM (range of motion) at the hip, knee, and ankle were all reduced, especially in the joint extension.
- The swinging of the arms decreased greatly.
- Most of the patients rotated the trunk in phase with the pelvis, instead of twisting it in the opposite direction.
- The vertical trajectories of the head, heel, and toe were all decreased.

Most experts in the field of gait analysis and gait disorders have accepted Nutt, Marsden, and Thompson’s system (1993) which identifies gait disturbances as “Lowest-level,” “Middle- level,” and “Highest-level” disorders (Figure 2.8). This scheme is based on the hierarchy of lowest, middle, and highest sensorimotor levels. It should also be taken into account that the characteristics of an abnormal gait are usually a combination of the underlying pathologic process, compensatory mechanisms, and potential development of secondary musculoskeletal abnormalities.

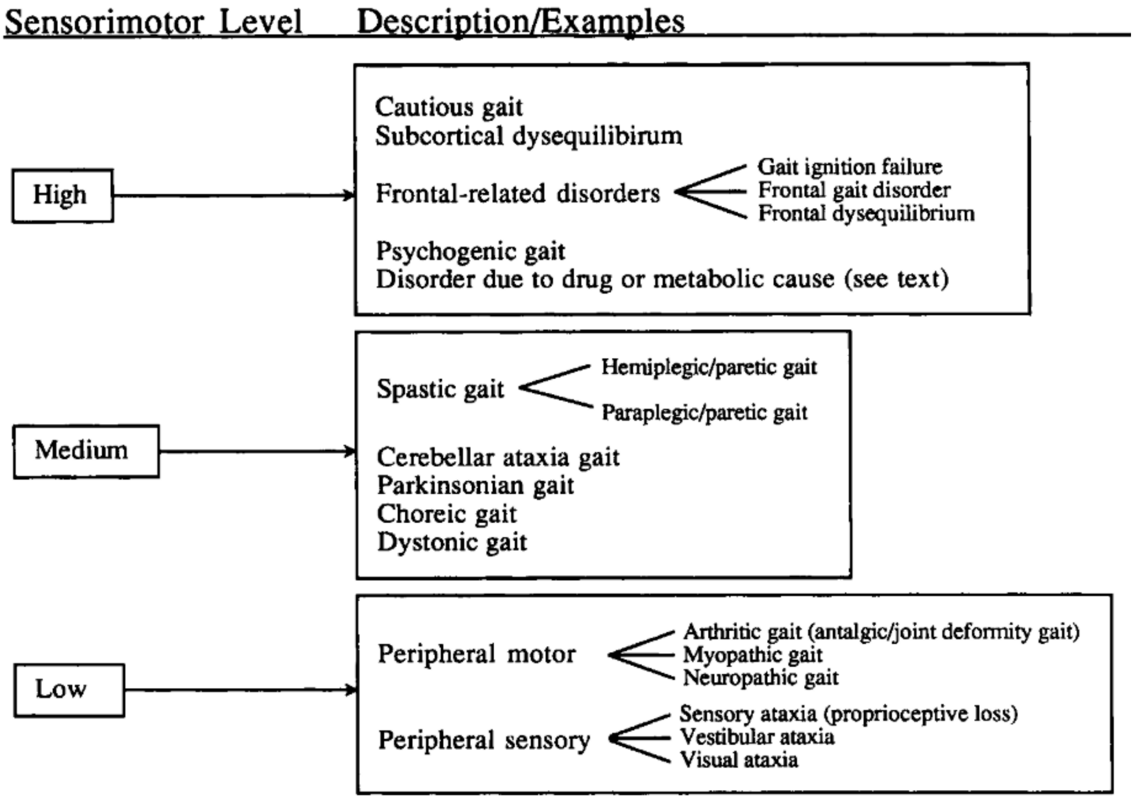


Figure 2.8 - Gait Disorder Classification Scheme (Nutt, JG., 1993)

Lowest-level disorders are because of musculoskeletal problems or impairment of afferent systems, including proprioceptive, vestibular, and visual systems. Middle-level disorders are characterized by abnormal walking, gait is initiated without any problem but the gait pattern is abnormal. At the Highest-level, the categorisation is confusing and disorders of this level type may be overlap considerably. The main reason is because the gait characteristics can be non-specific and caused by a number of disease entities. The Highest-level gait disorders are a result of damage to the cerebral hemispheres or psychogenic problems and are characterized by significant disequilibrium on a cortical or subcortical basis as well as Isolated gait ignition or initiation trouble.

Table 2.4 shows the summary of eight common gait deviation patterns encountered by patients, along with associated sign and related causes, which can be categorised as shown in Table 2.3 using the scheme developed by Nutt and their anatomical correlates which mentioned in Section 2.1.1.

Table 2.3 - Middle- and Lowest-level Gait Deviation Pattern with Their Anatomical Correlates (Rubino, F., 2002; NB, A., 1996)

Sensorimotor Level	Anatomical Level	Gait Deviation Pattern
Lowest	Skeleton	• Antalgic
	Muscle	• Trendelenburg • Waddling • Steppage
Middle	Cerebellum	• Cerebellar ataxia
	Spinal Cord	• Hemiparetic • Scissors
	Basal Ganglia	• Parkinsonian

Table 2.4 – Common Gait Deviation Pattern (Dietz, V., 2013; Salzman, B., 2011; Chew, K.H., 2019)

<table>
<tr><th rowspan="3">No.</th><th rowspan="3">Abnormal gait</th><th colspan="12">Parameter</th><th rowspan="3">Associated signs</th><th rowspan="3">Causes</th></tr>
<tr><th colspan="3">Temporal</th><th colspan="4">Spatial</th><th>Sp-T</th><th colspan="2">Gait Features</th></tr>
<tr><th>CT</th><th>LST</th><th>RST</th><th>SL</th><th>LSL</th><th>RSL</th><th>SW</th><th>S</th><th>BP</th><th>AS</th></tr>
<tr><td colspan="16">Lowest-level Gait Disorders</td></tr>
<tr><td>1.</td><td>Antalgic</td><td>↑</td><td>↑</td><td>↑</td><td>↓</td><td>↓</td><td>↓</td><td>=</td><td>↓</td><td>=</td><td>=</td><td>Pain worsening with movement and weight bearing; Reduced knee flexion; Reduced stance phase on affected limb (limping).</td><td>Degenerative joint disease; Trauma.</td></tr>
<tr><td>2.</td><td>Trende-lenburg</td><td>=/↑</td><td>=/↑</td><td>=/↑</td><td>↓</td><td>↓</td><td>↓</td><td>↑/=</td><td>↓</td><td>=/↓</td><td>=</td><td>Unilateral weakness of hip abductors (difficult to support the body weight on affected side);
Sways from side to side;
Hip hiking (when one leg swings forward and the hip drops down and moves outward).</td><td>Can also appear after a total hip replacement surgery (Surgeon will have to make incisions in the gluteus medius muscle. This can weaken the muscle and cause you to walk with this gait.).</td></tr>
<tr><td>3.</td><td>Waddling</td><td>↑</td><td>↑</td><td>↑</td><td>=/↓</td><td>=/↓</td><td>=/↓</td><td>↑/=</td><td>=/↓</td><td>=/↓</td><td>=/↓</td><td>Bilateral weakness of hip abductors; Wide-based;
Trouble staring balance movement: rising off chair or starting to stand up straight;
Swaying; Toe walk.</td><td>Muscular dystrophy; Myopathy.</td></tr>
<tr><td>4.</td><td>Steppage</td><td>↑</td><td>↑</td><td>↑</td><td>↑↓</td><td>↑↓</td><td>↑↓</td><td>=</td><td>=/↓</td><td>=</td><td>=</td><td>Foot drop (weakness or paralysis of the dorsiflexor muscles due to an injury to the muscles);
Excessive flexion of hips and knees when walking; Slapping quality.</td><td>Caused by neuropathies Motor neuropathy.</td></tr>
</table>

Middle-level Gait Disorders													
5.	Cerebellar ataxia	=/↑	=/↑	=/↑	↓	↓	↓	↑↑	↓	=	=/↓	Lacks balance; Irregular, jerky, weaving and staggering; Wide-based; Turning can cause instability; Trouble staring balance movement: rising off chair or starting to stand up straight.	Cerebellar degeneration; Drug or alcohol intoxication; Multiple sclerosis; stroke; Thiamine and vitamin B12 Deficiency.
6.	Hemiparetic	↑	↑	↑	↓	↓	↓	↑/=	↓	=	↓	Inability to “shorten” swing leg (possibly due to reduced active or passive hip or knee flexion or as a result of wearing a “straight-leg” brace at knee); Extension and circumduction of weak and spastic limb; Flexed arm.	Hemispheric or brainstem lesion.
7.	Scissors	=/↑	=/↑	=/↑	↓	↓	↓	↑/=	↓	=	=	Bilateral leg weakness; Scissoring of both legs; Stiffness.	Spinal cord or bilateral cerebral lesions.
8.	Parkinsonian	↑	↑	↑	↓	↓	↓	=/↓	↓	↓↓	↓	Bradykinesia; Muscular rigidity; Postural instability; Reduced arm swing; Shuffling; Foot drop; Hard to turn body.	Parkinson disease; Damage to brain nerve cell (basal ganglia).

↓ = decreased; = = normal; ↑ = increased; , ↑↓= variable; ↑↑= markedly increased; ↓↓ = markedly decreased;

CT = Cycle Time
LST = Left Step Time
RST = Right Step Time

SL = Stride Length
LSL = Left Step Length
RSL = Right Step Length

SW = Step width
S = Gait Speed
BP = Body Posture
AS = Arm Swing

2.3 METHODS OF GAIT EVALUATION

Gait dysfunction in humans can be assessed using standardized clinical measurements, timed measurements, patient-based measurements, observational gait analysis (OGA), instrumented walkways, or 3-D gait evaluation. The optimal technique for assessing gait dysfunction relies on the knowledge of the examiner, the available time and facilities, and the evaluation objectives.

2.3.1 OBSERVATIONAL GAIT ANALYSIS

OGA is the most frequently used clinical instrument for assessing the quality of the gait. OGA includes watching an individual walking and analysing the kinematic and spatio-temporal parameters of their gait pattern. OGA may be performed during a clinical visit, during standardized gait testing, or under walking circumstances that best suit the patient's complaints. Figure 2.9 shows an example of an individual performing the Timed 25-Foot Walk Test (T25FWT) while the clinician conducts OGA.

Figure 2.9 - Observational Gait Analysis - Timed 25-Foot Walk Test (Cameron, M. & Wagner, J., 2011).

Expanded disability status scale (EDSS) (Kurtzke JF., 1983) and the Hauser Ambulation Index (AI) (Hauser, SL. *et al.*, 1983) are also used to assess walking in gait evaluation scale. The EDSS shown in Figure 2.10 is a frequently used disability score that ranges from 0 (no impairment) to 10 (death from MS). The AI is a rating used to assess mobility by evaluating the time and degree of assistance required to walk 25 foot (7.62 metres). The patient is asked to walk a marked 25-foot course as quickly and safely as possible and the examiner records the time and type of assistance (e.g., cane, walker, crutches) needed.

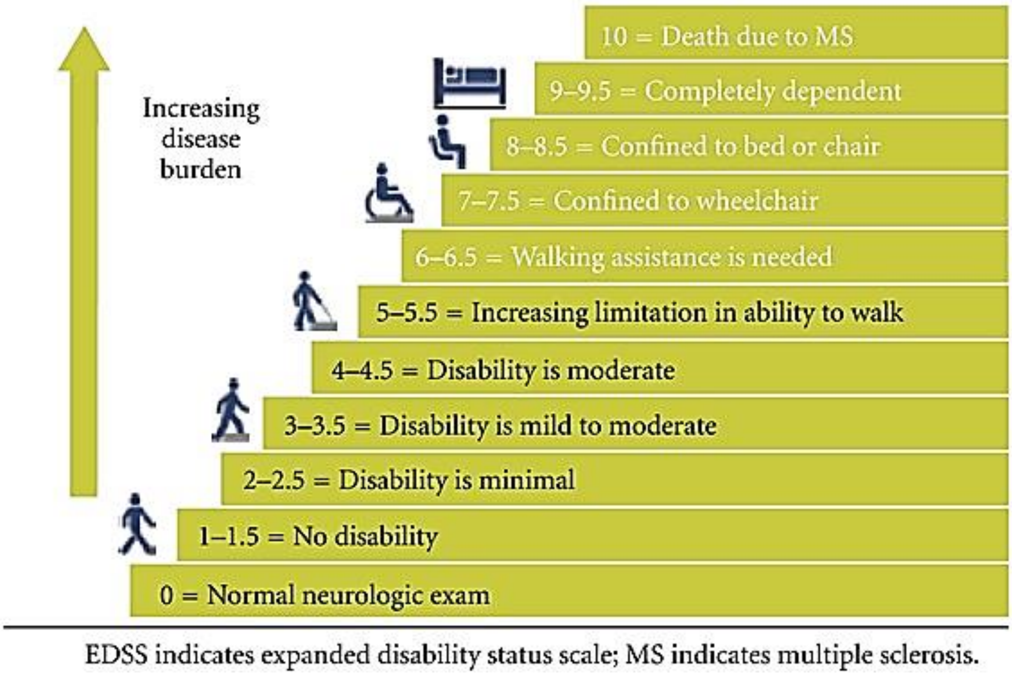


Figure 2.10 - The Expanded Disability Status Scale (EDSS) (Kurtzke JF., 1983)

Another OGA technique would be the patient-based measures used to evaluate their walking disability viewpoint from the patient. A patient-based measure of the effect of multiple sclerosis on walking is the 12-item Multiple Sclerosis Walking Scale (MSWS-12). Each item is scored between 1 (not restricted) and 5 (highly restricted) scales. A complete score is produced and converted into a scale of 0 to 100. The MSWS-12 is a valid and reliable standardized measurement of self-perceived walking constraints owing to multiple sclerosis (Hobart, JC., 2003).

2.3.2 INSTRUMENTED EVALUATION

One of the instrumented way for gait evaluation would be the instrumented walkways shown in Figure 2.11. It is portable, inexpensive and requires minimal training and offers a valid and accurate evaluation of clinically appropriate kinematic parameters of the gait, including gait velocity, step length, single support time, swing time and support base. (van Uden, C. & Besser, MP., 2004). The spatio-temporal parameters of the gait can be exactly quantified by instrumented walkways. An instrumented walkway can be used during standardized clinical testing such as the T25FWT or during OGA to obtain thorough measurements.

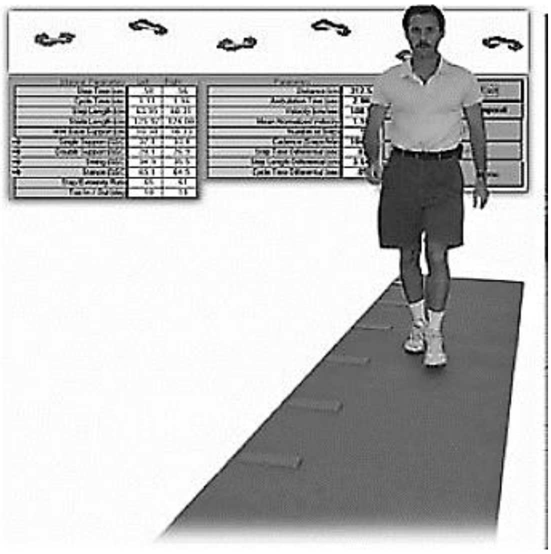


Figure 2.11 - Instrumented Walkway Test (Cameron, M. & Wagner, J., 2011).

3-D gait evaluation is the gold standard for gait evaluation. 3-D gait evaluation is conducted by putting reflective markers on an individual and recording their motion with infrared cameras while walking (Figure 2.12(a)). Computer software then reconstructs the markers to create the moving person's 3-D picture (Figure 2.12(b)). This technique offers comprehensive quantitative measurements of kinematic, kinetic, and spatio-temporal gait parameters and can therefore provide information on the mechanisms underlying the gait dysfunction as well as accurate spatio-temporal data. This sort of gait evaluation can be used to detect subtle gait impairments (Martin, CL, *et al*. 2006) and unusual postural control strategies (Remelius, JG., 2008) that are not captured by other gait assessment techniques.

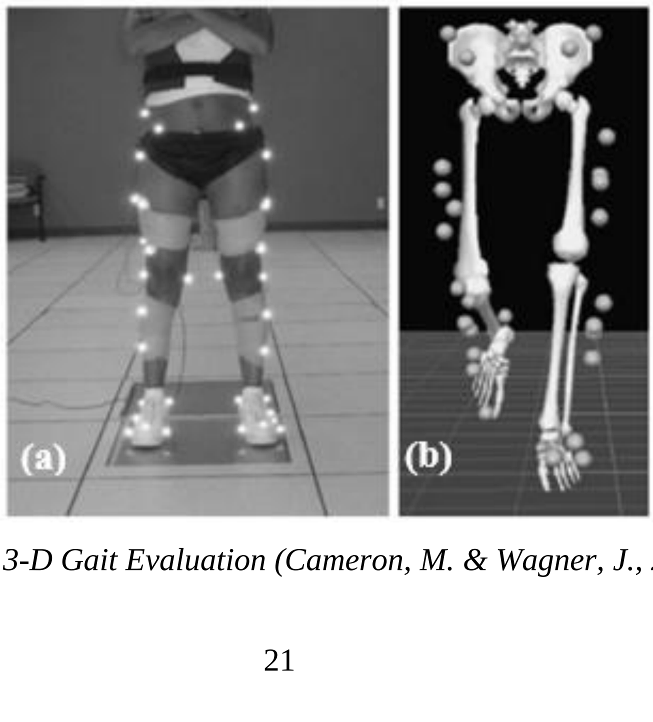


Figure 2.12 - 3-D Gait Evaluation (Cameron, M. & Wagner, J., 2011).

2.3.3 COMPARISON BETWEEN METHODS OF GAIT EVALUATION

Table 2.5 - Comparison of Gait Evaluation between Different Methods

Methods	Advantages	Disadvantages
Observational Gait Analysis (OGA)	• Consider the use of assistive tools • EDSS : directly associated with neurological examination; used in clinical studies • AI : simple and quick • Required limited time and equipment	• Require a skilled examiner • Mechanisms underlying gait disorder not identified • EDSS and AI have limited precision and responsiveness • No normative data • Limited validity, reliability, and precision
Instrumented Evaluation	• Identify mechanisms underlying gait disorder • Provide precise kinematic, kinetic, and spatio-temporal data	• Required skilled examiner and expensive equipment

Each gait evaluation technique has different advantages and disadvantages. Although OGA can be fast and needs little room and no particular machinery, this technique of analysing gait needs a high amount of expertise and has been criticized for its restricted precision and reliability (Krebs, DE, *et al.* 1985) owing to the validity, reliability and responsiveness of the above measures (Sharrack, B., *et al.* 1999 ; McGuigan, C. & Hutchinson M., 2004). These techniques provide restricted data, if any, on the quality of the gait and the processes underlying the dysfunction of the gait. Compared to instrumented gait assessment, they also have restricted accuracy.

The accuracy of gait parameters given by an instrumented assessment can be useful for guiding therapy and evaluating the effect of gait disorder procedures. These gait parameters can be used to define the functional system(s) that contribute to the gait dysfunction of a person. For instance, some spatial-temporal gait parameters may distinguish patients with pyramidal dysfunction gait disorder from patients with cerebellar dysfunction gait disorder. However, instrumented gait evaluation is time-consuming and may require extremely qualified and experienced staff, such as in 3-D gait evaluation. This gait evaluation technique may be a useful instrument for studies, but it has a restricted function in clinical practice.

2.4 INSTRUMENTED GAIT EVALUATION TECHNIQUES

Instrumented gait evaluation requires measurement, assessment, and analysis of the biomechanical features that are associated with the walking task. Due to the recent development of more advanced gait evaluation techniques, it can be summarised that gait evaluation technology which utilises the said temporal/spatial and kinematics parameters can be grouped into three major categories, i.e. machine vision (MV), floor sensor (FS) and wearable sensor (WS) (Gafurov, D., 2007). The following literature survey is conducted to further discuss the three categories.

2.4.1 MACHINE VISION (MV-BASED)

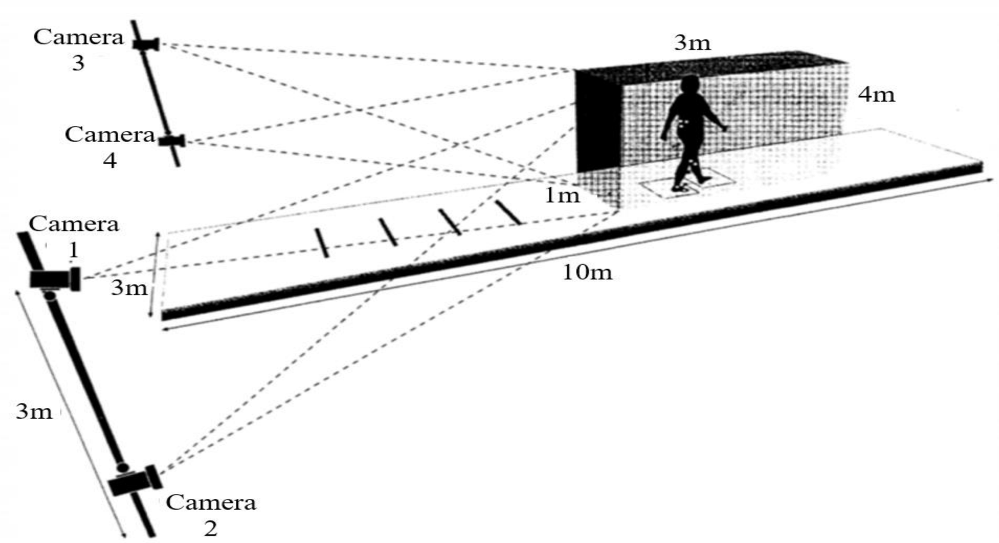


Figure 2.13 - General layout of the gait laboratory (Frigo, C. et al., 1998)

Frigo, C. had developed a gait capturing laboratory by an arrangement of four TV cameras and implementing video and image processing techniques to extract gait features by obtaining the skeletal data of the subjects (absolute movements of vital limbs and location of joint centres) using skeletal tracking. Figure 2.13 shows the general layout of the laboratory where two cameras are placed in a posterolateral position on each side of the subject and two force plates are trailed along the walking pathway. Subjects are attached with markers on the specific locations as shown in Figure 2.14. From the experimental test conducted, 3D movements of pelvis and lower limbs are acquired that matches the expected functional anatomy. The MV-based gait recognition studies shows accurate results, however the high cost of setup impacts the affordability and ease of use of this service.

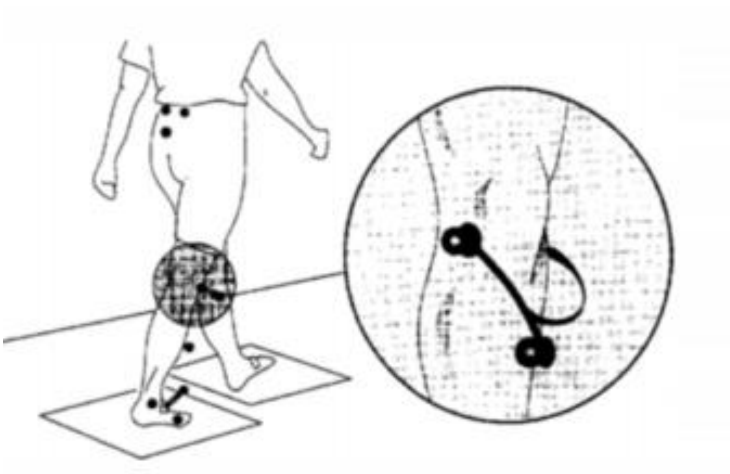


Figure 2.14 - Locations of the markers on the subject (Frigo, C. et al., 1998)

Figure 2.15 - Existing MV-based Gait Evaluation Product in Market (zebris, 2019)

The basic system FDM-T developed by a Germany Company – zebris Medical, employs the MV (machine vision) based approach as it records the video data on the treadmill using the optional camera module equipped with video camera which linked with EMG amplifiers or inertial sensors which enable the FDM-T system to perform an analysis on the kinematic motion.

2.4.2 FLOOR SENSOR (FS-BASED)

Lee, M. *et al.* (2005) describes the development of a prototype floor sensor with low cost materials which is inspired from a computer keyboard. A data set of 15 individuals is collected by having them walk on the floor sensor. The design of the floor sensor mat is simple with the implication of switch made of wires. The final prototype as shown in Figure 2.16 is built with two layers of sensors and the additional four isolated grids to avoid the effect of ghosting and increase the resolution. The overall construction materials are affordable and readily available as the control can be achieved by merely using three PIC microcontroller and a USB driver chip. With three extracted features, i.e. stride length, stride cadence, and time on toe to time on heel ratio, 80% of gait normality recognition rate is achieved. The FS-based approach is better in terms of efficiency and cost comparing to MV-based approach as it is easier to set up and less equipment to prepare.

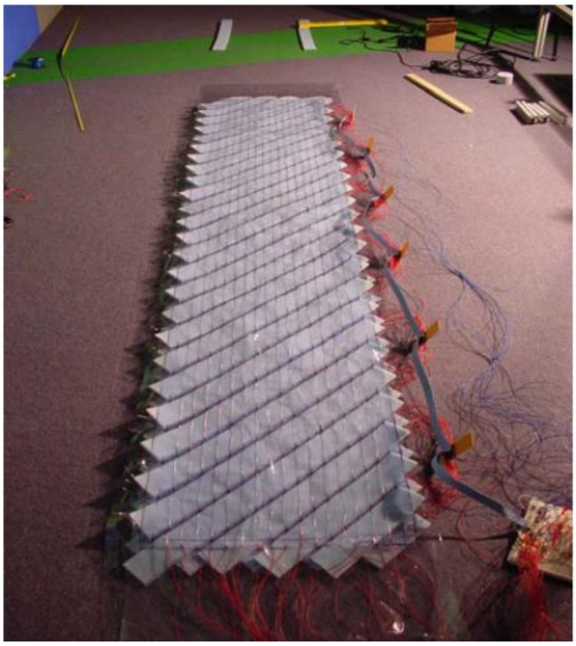


Figure 2.16 - Final Prototype Floor Sensor Mat (Lee, M. et al., 2005)

2.4.3 WEARABLE SENSOR (WS-BASED)

According to Tao, W. (2012), the measurement of gait is obtained using a wearable sensor, WS-based. One of the main reasons of this WS-based gait analysis is preferred compared to several other methods is its unobtrusive data collection as it is proposed as portable electronic devices which makes it much easier and more convenient for the data measurement purpose. Attachment of motion sensors in the specific location of the subject's body by using a wearable sensor method for the gait analysis. The devices are attached on the thigh, foot or shank to measure angular rate of foot and acquire the joint angle. As illustrated in Figure 2.17, a kinematic measurement using accelerators and gyroscopes was implemented.

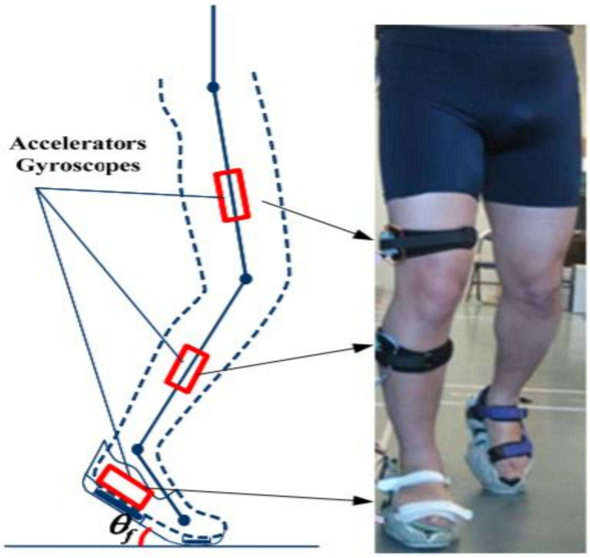
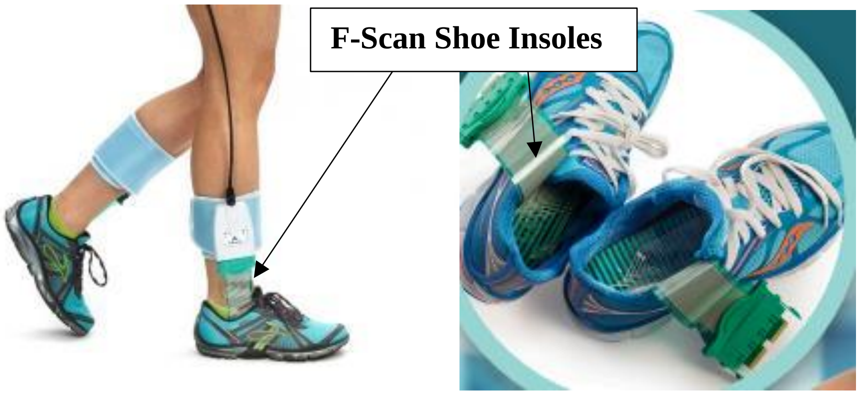


Figure 2.17 - Kinematic measurement based on accelerators and gyroscopes (Tao, W., 2012)



(a) F-Scan In-Shoe System

(b) Stridalyzer INSIGHT Smart Insoles

Figure 2.18 – Existing WS-based Gait Evaluation Product in Market (F-Scan System, 2019; ReTiSense, 2019)

These two products perform real-time gait analysis which implements the WS (wearable sensor) based approach by having client wear them and walk/run and gather measurements of various parameters of interest and provide useful information for diagnosing pathologies, evaluating treatments and educating patients or assessing users.

2.4.4 COMPARISON OF THE THREE APPROACHES

Table 2.6 - Comparison of Gait Analysis from Research Papers

No.	Approach	Strengths	Limitations	Remarks
1	Machine Vision (MV-based)	• High accuracy • Real-time motion tracking	• High cost • Inconvenient setup procedure	Required specific laboratory with particular arrangement and setup of many cameras.
2	Floor Sensor (FS-based)	• Low cost • Simple construction	• Low resolution	Required huge amount of sensors to increase the resolution.
3	Wearable Sensor (WS-based)	• Low cost • Portable	• Inaccuracy caused by marker occlusions or displacement of markers	Relies on attach markers/sensors to capture human motion, which can be extremely time consuming

2.5 MARKERLESS-BASED MOTION CAPTURE TECHNOLOGY

As this instrumented gait evaluation using MV-based based is costly and requires a laboratory environment while FS-based and WS-based are reported to be able to carry out the gait evaluation without the need of platform, but a few limitations are still discovered as stated in Table 2.6. Consequently, markerless-based methods were suggested that it could be used in biomechanical research and gait evaluation which can provide solutions to overcome all of the limitations stated above (Tao, W., 2012; Muro., A. *et al*., 2014 ; Caseracciu, E. *et al*., 2014).

Markerless motion capture technology has shown promise to assess both gait and postural control (Clark *et al*., 2012, 2013; Corazza *et al*., 2006; Mentiplay *et al*., 2013; Stone and Skubic,v2011). The precision of marker-based schemes was analysed (Holden *et al*., 1997; Kiran *et al*., 2010; Miranda *et al*., 2013; Richards, 1999) whereas the accuracy of markerless motion capture methods was not so widely studied. The accuracy of markerless systems has been assessed using marker-based measures as ground-truth (Clark *et al*., 2012, 2013; Mentiplay *et al*., 2013; Mündermann *et al*., 2005; Steele *et al*., 2009; Stone and Skubic, 2011) One of the most frequently used markerless motion captured systems for gait evaluation is the Microsoft Kinect Sensor (Caseracciu, E. *et al*., 2014; C. Granata. *et al*., (n.d.);Andersson, V. *et al*., 2014). Microsoft Kinect is a cost-efficient mobile technology capable of capturing human movement without the need for a complicated set-up of tools and without attaching markers / sensors to the body of the subject. (Stone, E. and Skubic, M., 2013).

The use of 3D skeleton data extracted from Microsoft Kinect sensor to obtain gait kinematic parameters from human walk for gait identification has been discussed and further investigated for the validation of result. Comparison between markerless-based captured data by Kinect and the data determined by the traditional marker-based system have been made in several studies (Skals S.L. *et al*., 2013; Andersson, V. *et al*., 2014). Although the systems showed discrepancies, the markerless-based system is proved to have potential contribution in the gait analysis/evaluation.

2.6 CHAPTER SUMMARY

This chapter delivers information about the different phases of the gait cycle, physiology of gait, critical parameters of gait, and various gait evaluation methods. Gait evaluation is a study of how an individual performs the movement of a human body and specific measurement is required for the data acquisition and interpretation of gait. Temporal/spatial and Kinematics are the measurements carried out to obtain the relative parameters required for the gait evaluation. Normal and abnormal gait also can be distinguished and classified by referring to the normal ranges of the specific gait parameters. Methods of gait evaluation can be divided into observational-based and instrumented-based. From a technological perspective, instrumented-based gait evaluation techniques can be further classified into three main categories: Machine Vision (MV) based, Floor Sensor (FS) based and Wearable Sensor (WS) based where three of these methods have applied the temporal/spatial and kinematics measurement respectively. Several gait evaluation systems that are already available in the market also introduced for reference purpose. Markerless-based motion capture technique such as Kinect sensor is introduced to overcome the limitations of the techniques mentioned.

CHAPTER 3

PROJECT METHODOLOGY

3.1 GAIT IDNETIFICATION USING SKELETON-BASED TRACKING

The human skeleton is made out of many bones and the skeletal system of a human includes all of the bones and joints in the body. The skeletal system also provides attachment points for muscles to allow the movements of joints (Kar, A., 2010). Different movements are performed by human skeleton via joints and hence enable human to move in every directions and activities. Gait evaluation using markerless-based method is performed to obtain the skeletal information and identify the capability of these joints thus determine the gait quality.

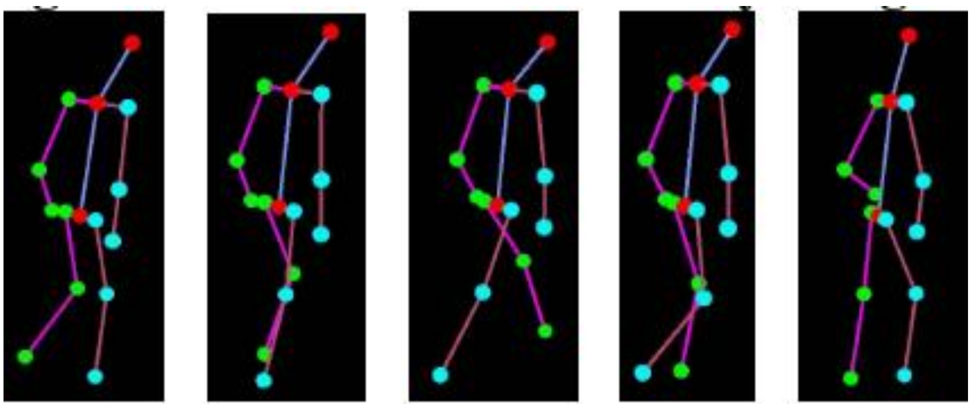


Figure 3.1 - Gait Tracking and Stick Figure Simulation (Zhao G. et al., 2006)

The use of anatomical human skeleton model has been experimented and analysed in order to perform accurate data acquisition of gait (Orrite-Urunuela, C. *et al*., 2004; Zhao G. *et al*., 2006; Gianaria. E. *et al* ., 2013). 3D model of stick figure shown in Figure 3.1 is generated to represent human body and fundamental joint points are selected to define human motion. In recognition, static parameters and dynamic feature obtained by determining joint positions are combined together for the identification of gait.

Kinect, a markerless-based motion capture technology developed by Microsoft, is used in several studies (Ondrej, Tupa. *et al*., 2015; Preis, J. *et al*., 2012; Gianaria. E. *et al* ., 2013) to characterize walking gait using three-dimensional skeleton information. Kinect sensor is capable of capturing 30 frames per second which include the colour, depth, body and infrared frames. A 3-dimensional mapping of environment can be produced using these frames to help tracking the desired body and position of joint (25 points for Kinect V2; 20 points for Kinect V1 to be exact) precisely (Laxman Chavan, Y., 2011). The joints of each skeleton captured by the body frames are all critical joints in the skeleton and its essential for the purpose of gait evaluation as spatio-temporal gait parameters can be extracted by using the location of joints provided by Kinect sensor. Figure 3.2 shows the various joints that are tracked by the Kinect sensor.

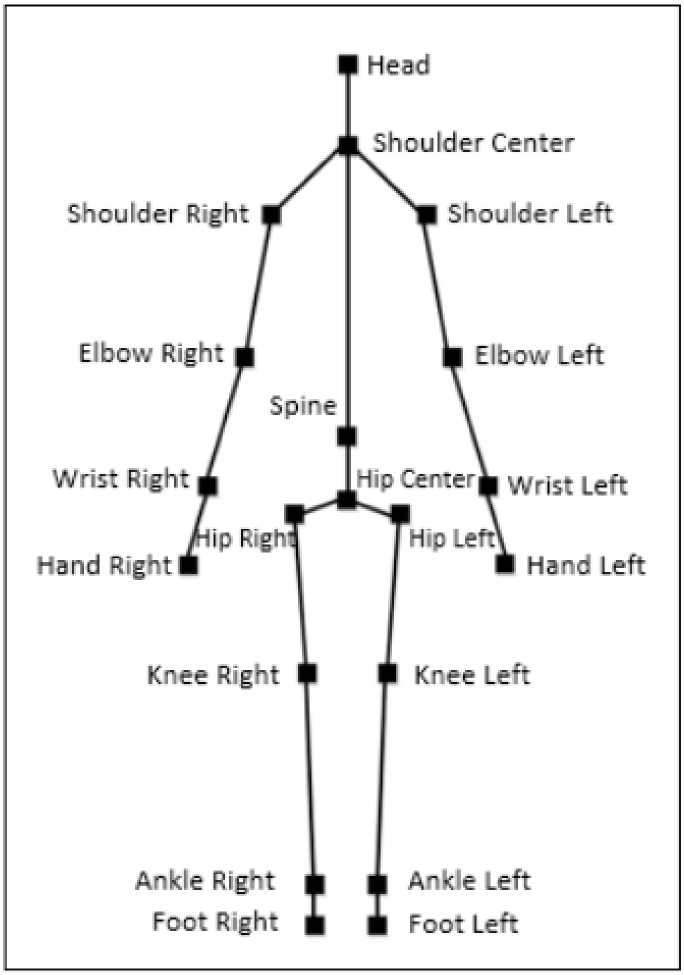


Figure 3.2 - Skeletal joints tracked by Kinect (Laxman Chavan, Y., 2011).

3.2 SELECTION OF HARDWARE AND SOFTWARE

3.2.1 KINECT FOR WINDOWS V1 SENSOR

Section 3.1 reveals the skeletal approach is the potential solution for quantitative gait evaluation. One of the distinguishing factors that makes this Kinect sensor (Figure 3.3) standing out among others in this genre is the detection of user's body position and motion. Kinect sensor provides two data channels which allow the capturing of colour and depth images with a skeleton tracking functionality developed by Microsoft for the video capture of body motion. The major components of Kinect sensor are its colour sensor, IR depth sensors, IR emitter, microphone arrays, and a stepper motor that can be tilted to change the Kinect camera angles. To most of the public knowledge, it is a motion-sensing device which was originally developed for the Xbox 360 gaming console (Jana, A.,2012).

Figure 3.3 - Kinect for Xbox 360 (Birbilis, G., 2015).

Along with the bundled software, the Kinect sensor unwrap a new opportunity for the developer to build a wide range of applications which has a level of similarity to this project as follows.

- Capturing real-time video using the colour sensor
- Tracking a human body and then responding to its movements and gestures a natural user interface
- Measuring the distances of objects
- Analysing 3D data and making a 3D model and measurement
- Generating a depth map of the tracked objects

3.2.2 KINECT FOR WINDOWS SDK

The Microsoft Kinect SDK (Software Development Kit) works as an interface between Microsoft Kinect Device and applications created. It provides the tools and APIs (Application Programming Interfaces) that needed to develop Kinect-enabled applications for Microsoft Windows which allow the fetching of sensory data and various frame data (LLC), T., 2014). With the installed Kinect driver, controls access to sensor data which helps to stream the video and audio data from the sensors and return it to the application. It also provides for the features of the Kinect to build application with the programming language of C++, C# or Visual Basic in the environment of Microsoft Visual Studio. This includes depth images, colour images, skeletal data, and audio input. The samples and examples provided inside the SDK establish good practices for using a Kinect sensor (Download Kinect for Windows SDK 2.0 from Official Microsoft Download Center, 2019).

3.2.3 MICROSOFT VISUAL STUDIO

Microsoft Visual Studio is a fully featured integrated development environment (IDE) from Microsoft. It enables the rapid application development (RAD) of graphical user interface (GUI) applications (Overview of Visual Studio, 2017). With the Kinect sensor used for this project, Microsoft Visual Studio is used as the main programming and GUI creation software using the programming language of C# (Download Kinect for Windows SDK 2.0 from Official Microsoft Download Center, 2019). This will ease the task of development of video acquisition module and gait categorisation module as shown in Figure 3.4.

3.2.4 MICROSOFT AZURE MACHINE LEARNING STUDIO

To obtain a set of gait parameters, the raw data of skeletal joint's position is required to be processed and following by exporting the output results back to Microsoft Visual Studio. Microsoft Azure Machine Learning Studio is a collaborative, visual drag-and-drop tool that can use to build, test and develop predictive or non-predictive analytics solutions on data where no coding is necessary (Docs.microsoft.com., 2019). It publishes models as web services that can easily be consumed by custom apps or tools such as Microsoft Excel. In this project, dataset acquired from Kinect is transformed and analysed through various data manipulation and statistical functions provided in the studio to determine the desired output results. Algorithm or analytics model can be created in an experiment and deployed as an Azure Machine Learning web service to make predictions using new data. Web services provide an interface between an application and a workflow scoring model of Machine Learning Studio. A call to a web service from Machine Learning Studio returns the results of the prediction to an external application via the API key created when deploying the web service. Consequently, the output results can be returned to Microsoft Visual Studio to further perform gait categorisation.

Azure Machine Learning Studio has two types of web services, Request-Response Service (RRS) and Batch Execution Service (BES). While RES acquires the data by call request, BES reads a block of records from a variety of HTTP sources. BES is chosen for the web service of this project to manage and evaluate a whole batch of dataset received from the Kinect sensor.

3.2.5 PROCESSING UNIT

The processing unit is used to perform the data acquisition and processing. Conventionally, this require a computer such as laptop. Since Microsoft Visual Studio along with Kinect SDK and the driver are chosen in this project, therefore, the laptop used must fulfil the following minimum requirement of the application software (*Download Kinect for Windows SDK v1.8 from Official Microsoft Download Center*, 2019):

- 32-bit (x86) or 64-bit (x64) processor
- At least Windows 7 or above
- Dual-core 2.66-GHz or faster processor
- Dedicated USB 2.0 bus
- 2 GB RAM

Fortunately, a self-owned HP brand, Pavilion model, laptop with 4.00 GB RAM, 64-bit (x64) based processor which runs on operating system of Windows 10 fulfils all the requirements as listed above.

3.3 PROJECT OVERVIEW

3.3.1 OVERALL BLOCK DIAGRAM

To develop a motion capturing system that is easy to set up, flexible with different data streams of the sensors, a Microsoft Kinect is used to create a system model for the skeletal tracking and video acquisition. To extract a set of gait parameters, data processing, and gait categorisation process will be conducted in the processing unit.

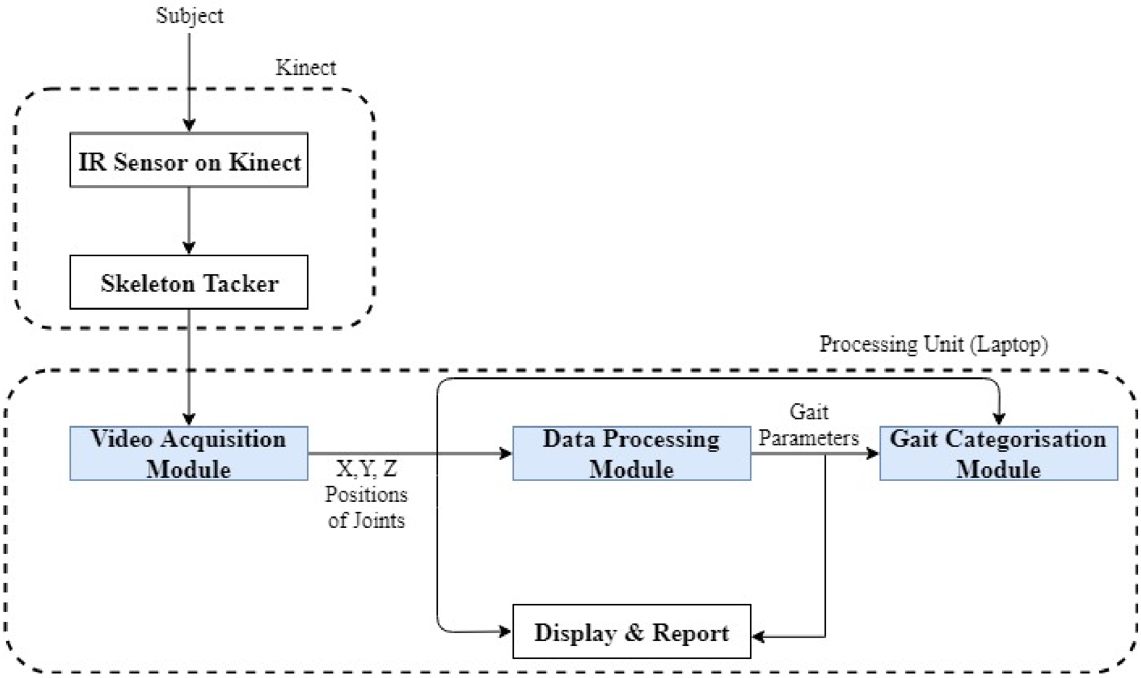


Figure 3.4 - Block Diagram of overall Gait Evaluation System

As per illustrated in Figure 3.4, a sequence of walk by the subject is captured and input through the video acquisition tool of this project, Kinect sensor. The video data is then processed and the joint location for the vital joints of user is detected. Feature extraction is implemented in data processing module for the purpose of calculation of the necessary gait parameter. Based on the features obtained, the parameter of the subject's gait is evaluated and the abnormality of the gait is identified based on the parameter value and the associated sign. The evaluation results are stored in Microsoft Excel file marked with Date and Time for revise purpose in future by the patient or physiotherapist.

3.3.2 SKELETON TRACKER

The skeleton tracker shown in Figure 3.5 is built on the depth data processing, internal machine learning and colour vision algorithm. In the initial steps of the skeletal-tracking, Kinect sensor uses a rendering pipeline to identify the human body object, from the incoming data (raw depth data from sensor) (Jana, A., 2012). To start recognizing a human body, the sensors start matching each individual pixel of incoming depth data with the data the machine has learned. The human pose recognition algorithm uses several base character models that varied with different height, sizes, clothes, and several other factors. Kinect uses a Decision tree structure to match the data for a specific part of human body. Kinect will then starts creating body segments once there is matched data labelled with individual body parts as shown in Figure 3.6.

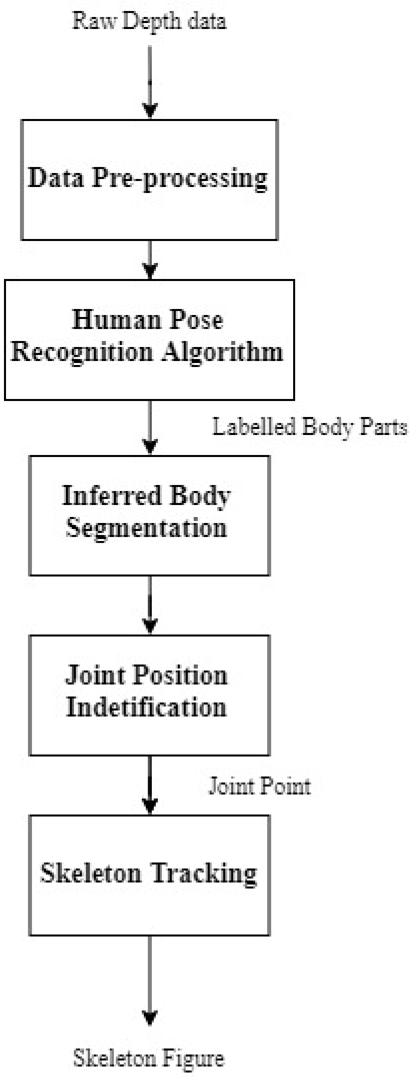


Figure 3.5 - Block Diagram of Skeleton Tracker

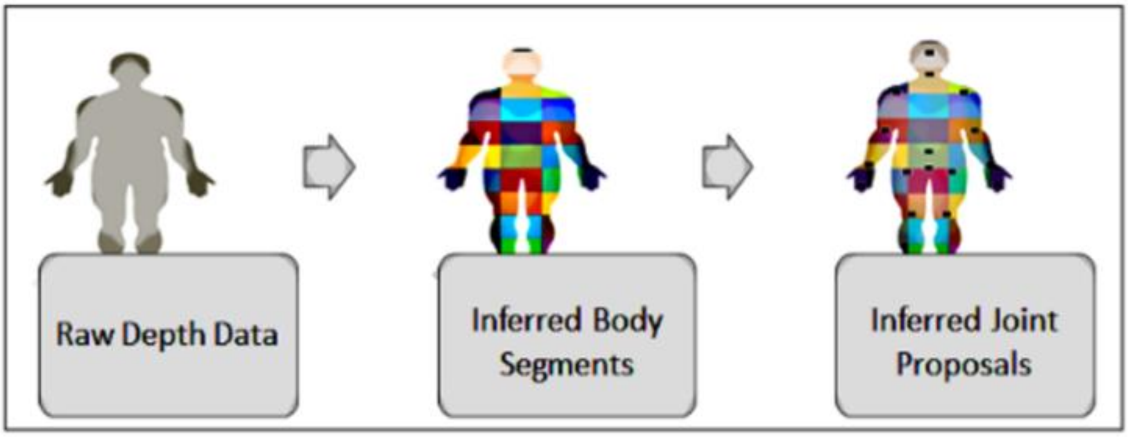


Figure 3.6 - Overall Process Flow of Skeleton Tracking (Jana, A., 2012).

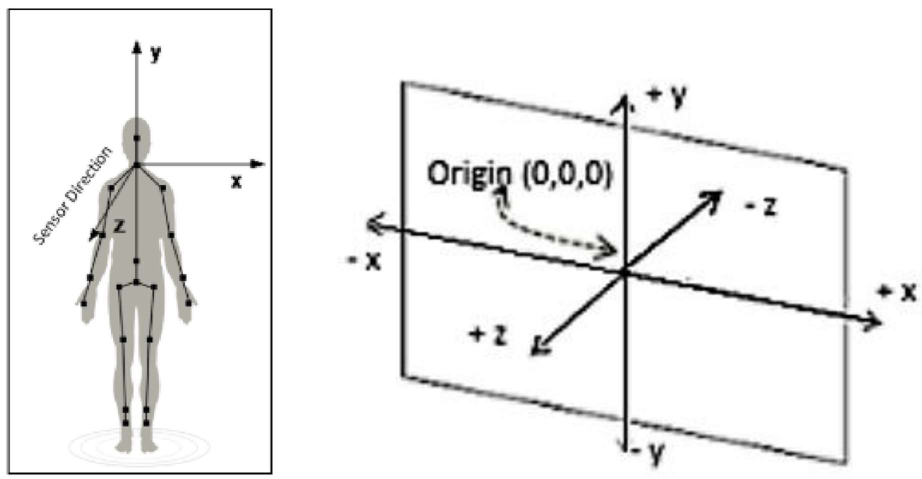


Figure 3.7 - Skeleton Joint Coordinate Systems (Jana, A., 2012).

Joint position identifications will be performed once the different body parts are identified where the joint positions are measured by three coordinates (X, Y and Z). All the joints are represented as three dimensions (X, Y, Z) and the right-handed coordinate system is used which indicates that the Z axis is the positive cross product of the X and Y axes, with X pointing to the right, Y pointing up, and Z pointing at the viewer as illustrated in Figure 3.7. Kinect will then start tracking the human skeleton and the movement of the complete body with the proposed joint points and the movement of those joints.

3.3.3 VIDEO ACQUISITION MODULE

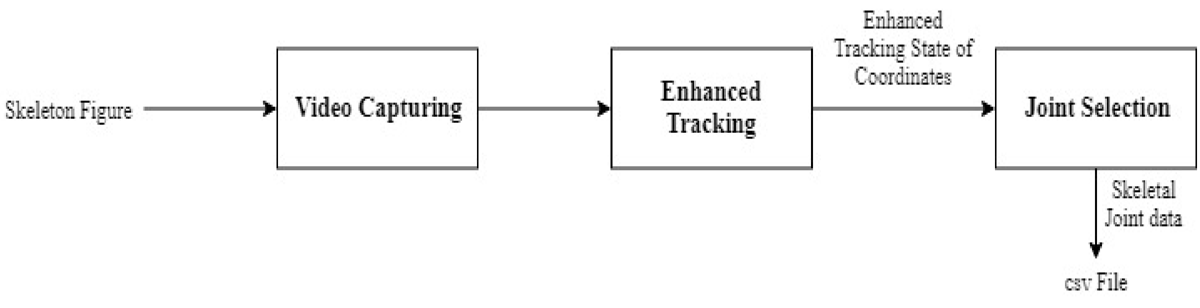


Figure 3.8 - Block Diagram of Data Acquisition Module

When the skeleton stick figure is shown with the successful detection of every joint positions and skeleton coordinates, the module will be activated to start the video recording of gait performed. The structure of every joint is represented using three main properties, namely ‘JointType’, ‘Position’ and ‘TrackingState’ (Jana, A., 2012). 'The ‘JointType’ property has the name of all 20 joints and each and every joint position indicates an object of Skeleton Point. The ‘Position’ property is a type of Skeleton Point, which represents the X, Y and Z values of Joint. All the skeleton joints are associated with the property ‘TrackingState’ which returns the tracking state for the current joint tracked.

Table 3.1 - Joint Tracking State Enumeration

Name	Description
Tracked	When the tracking state is ‘Tracked’, the sensor has a clear vision of the joint position which indicates that all the three coordinates (X, Y, Z) have been captured properly.
Inferred	‘Inferred’ means that the sensor made some calculations for the joint positions based on other tracked joints when the sensor does not have the actual joint position data.
NotTracked	‘NotTracked’ will be returned when the joints are not visible to the sensor, making the sensor hard to track.

After the data is extracted from the video frames and fed into the system, there are chances where the data might be redundant or irrelevant due to various factors such as overlaps of joints or the fast movement resulting to the inconsistency of the position data. To overcome the said problem, Kinect is embedded with an enhanced motion tracking system. As shown in Table 3.1, ‘Inferred’ value will be used if the joints overlapped or the motion is too fast to capture whereby the ‘NotTracked’ data will be rejected. The time-streamed pre-filtered joint data consists of the X, Y and Z position values will be used and extract the desired joints only. It will be exported and saved in comma separated value (.csv) file format for data processing.

3.3.4 DATA PROCESSING MODULE

Skeleton joint data which exported in csv file is uploaded to cloud-based storage in Azure whenever there’s a new gait video acquired. Jittering of skeleton joints may occurred and lower the detection accuracy of the joint’s movements. A moving average filter is introduced to suppress the potential noise and jitters in skeletal joint data by applying a special weighting function on data to create a new smooth baseline for modelling. The gait parameters especially the temporal patterns will be revealed easily.

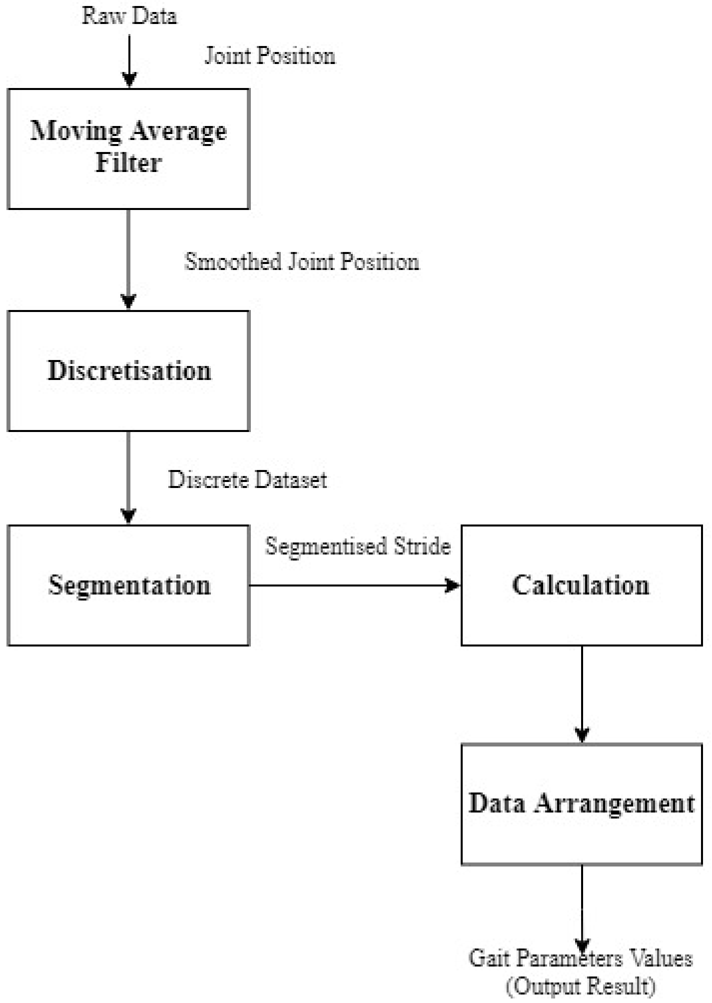


Figure 3.9 - Block Diagram of Data Processing Module

Since the subject is requested to walk a round trip (forth and back) which one complete stride will be performed in each trip, therefore feature extraction is performed on each stride to obtain the average gait parameter value. Discretisation is performed on the filtered data for binning and flattening the distribution of continuous data. Only the last 70% is used to extract the useful gait parameters because the beginning 30% is the initialization phase which can be neglected. After smaller set of discrete ranges are obtained, the data is split into partitions again according to changing points revealed by the discretised level for the segmentation of gait cycle. The segmented gait cycle is used to proceed to extract each gait parameters as listed in Table 3.2. When all of the gait parameters are obtained, the output data are concatenate to create a single dataset to be saved and exported into cloud storage destinations. Snapshots of working experiment in Microsoft Azure Machine Learning Studio are presented in Appendix C.

Table 3.2 – Equation of the Spatio-Temporal Gait Parameters

	Parameter	Estimation Equation
Spatio-Temporal Parameter	**Stride Length**	$\Delta X\ of\ (ReferenceFoot_{i+1} - ReferenceFoot_i)$
	Step Length	$Stride\ Length\ /\ 2$
	Step Width	$\Delta Z\ of\ (ReferenceFoot_i - Opposite\ Foot_i)$
	Cycle Time	$\Delta time\ of\ (ReferenceFoot_{i+1} - ReferenceFoot_i)$
	Step Time	$Cycle\ Time/2$
	Gait Speed	$Stride\ Length/CycleTime$
Other Gait Feature	**Body Posture**	$\Delta X\ of\ (Head_i - Hip\ Center_i)$
	Arm Swing	$\Delta X\ of\ (Shoulder_i - Hand_i)$

3.3.5 GAIT CATEGORISATION MODULE

The gait parameters determined in Microsoft Azure are exported in csv file format and imported to Microsoft Visual Studio to perform comparison between measured parameter values with pre-defined normal range (referred to Table 2.1 and Table 2.2 in Section 2.2.2) as listed in Table 3.3 and Table 3.4.

Table 3.3 - Normal ranges for gait parameters for female subjects of different age group

Age	Stride Length (m)	Step Length (m)	Step Width (m)	Cycle Time (s)	Step Time (s)	Speed (m/s)
13-14	0.80-1.17	0.40-0.59	0.10-0.15	0.99-1.55	0.49-0.78	0.57-0.96
15-17	0.83-1.20	0.42-0.60		1.03-1.57	0.51-0.79	0.59-0.98
18-49	0.87-1.22	0.43-0.61		1.06-1.58	0.53-0.79	0.62-1.02
50-64	0.86-1.20	0.43-0.60		1.07-1.60	0.53-0.80	0.60-1.01
65-80	0.76-1.10	0.38-0.55		1.07-1.61	0.53-0.81	0.52-0.89

Table 3.4 - Normal ranges for gait parameters for male subjects of different age group

Age	Stride Length (m)	Step Length (m)	Step Width (m)	Cycle Time (s)	Step Time (s)	Speed (m/s)
13-14	0.81-1.20	0.40-0.60	0.10-0.15	1.06-1.64	0.53-0.82	0.62-1.01
15-17	0.85-1.25	0.42-0.63		1.15-1.75	0.57-0.88	0.63-1.09
18-49	0.89-1.32	0.44-0.66		1.25-1.85	0.62-0.93	0.78-1.18
50-64	0.86-1.29	0.43-0.65		1.31-1.95	0.65-0.98	0.65-1.06
65-80	0.75-1.18	0.37-0.59		1.32-1.98	0.66-0.99	0.53-0.98

Equation 3.1 - Deviation Percentage of Gait Parameter

$$\%Deviation = \frac{|Predefined\ Normative\ Value - Measured\ Parameter\ Value|}{Predefined\ Normative\ Value} \times 100\%$$

Deviation is applied using the formula above to obtain the deviation percentage of measured parameter value. Determining the deviation in patient's gait parameter is helpful to quantify the current impairment, as well as the patient's recovery level. Severity level is provided in the system to better classify the gait quality of subject in order to assist physiotherapist in creating rehab plan based on different level of the patient's severity. The system will categorise the severity level of gait parameter based on the deviation percentage calculated as shown in Table 3.5. Owing to the small tolerance and latency introduced in several phases of methodology, deviation percentage of all gait parameter that below or equal 10% will be considered as 'Normal'. The computed outcome is used to identify any abnormalities present in the gait. Overall deviation percentage is presented by using the Equation 3.2 where the mean average value of deviation percentage of the eight spatio-temporal gait parameters (excluding gait features, i.e. body posture and arm swing) is calculated to further determine the severily level of gait performed by subject.

Table 3.5 - Severity Level and the Corresponding Deviation Percentage

Severity Level	**Deviation of Gait Parameter**
Normal	0% <= Deviation < =10%
Abnormal – LOW	10% < Deviation <= 20%
Abnormal – MEDIUM	20% < Deviation <= 50%
Abnormal – HIGH	Deviation > 50%

Equation 3.2 - Overall Deviation Percentage of Gait

$$\%Overall\ Deviation = \frac{\sum \%\ Deviation}{8}$$

Although quantitative gait parameter may be able to provide valuable information about the quality of patient's gait, but gait deviation pattern could not be revealed if depends solely on the gait parameter. Reviewing the associated symptoms/signs is a critical aspect of a gait evaluation. Therefore, in this system, a checker box function with a list of associated sign which listed in Table 3.6 is provided to ease the identification of gait deviation pattern for rehabilitation purpose. A professional observer such as a physiotherapist is required to observe any associated sign present in the gait performed by the subject. Gait deviation pattern is categorised based on the deviation of the specific gait parameters (referred to Table 2.4 in Section 2.2.4) and associated sign selected. The data computed is presented to the application via user interfaces where the users will be able to view the results of their gait status and their gait parameters as well as the gait deviation pattern, if any.

Table 3.6 - Gait Deviation Patterns with the respective Associated Sign

No.	**Gait Deviation Pattern**	****Associated Sign**												
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1	Antalgic Gait				√						√			
2	Trendelenburg Gait								√	√				
3	Waddling Gait							√	√					
4	Steppage Gait			√		√								
5	Cerebellar Ataxia Gait	√					√						√	
6	Hemiparetic Gait				√									√
7	Scissors Gait			√								√		
8	Parkinsonian Gait	√	√	√										

**Associated signs as indicated in Table 3.6:

1. Hard to turn body
2. Shuffling gait pattern
3. Foot drop
4. Reduced knee flexion
5. High stepping (over hip flexion)
6. Drunken gait pattern
7. Hard to balance when walking
8. Tight hip abductors
9. Hip hiking
10. Poor weight transfer / weight shifting
11. Scissors gait pattern
12. Irregular, jerky or involuntary movements
13. Circumduction gait pattern

3.4 SETUP AND PROCEDURE OF THE PROJECT

An initial platform to enable the subjects performing the gait and the recording of gait is designed as shown in Figure 3.10. The Kinect sensor is placed at a height of 70 centimetres above the floor and perpendicular to the 2.4 metres long and 50 centimetres wide path line that beyond 2.8 metres away. This setting is owing to the optimum full body capture area of Kinect sensor is between 2.8 metres to 3.5 metres. During system setup, a subject is required to walk forth and back at his/her normal pace. For each time, subject is asked to walk in one complete stride. Right foot is selected as the reference point to determine the precision of joint tracking in Kinect sensor. Three dimensional skeleton data in Kinect is acquired by the laptop to further perform gait evaluation.

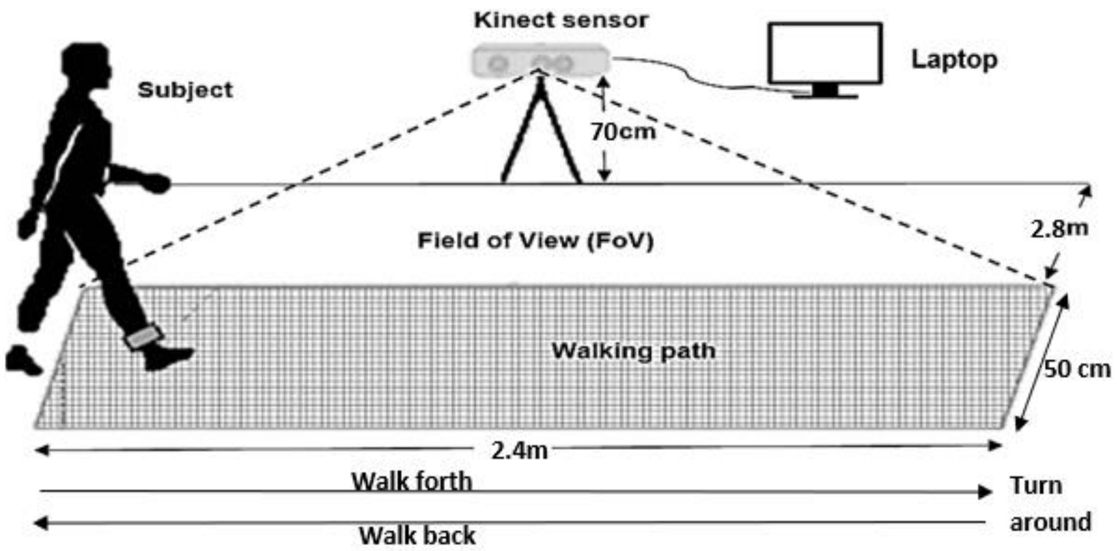


Figure 3.10 - Setup of the Gait Performing Platform

A series of experiments is conducted to determine the optimum setup of the project where the results could be viewed in the Appendix D.1. The height to place Kinect, maximum tracking range of Kinect, walking path line and Kinect tracking view are investigated and analysed. Kinect sensor has a vertical field of view of 43 degrees, horizontal field of view of 57 degrees with the elevation angle that can be shifted upwards or downwards by 27 degrees. The following figure shows an illustration of the angle being changed when the motor of Kinect sensor is tilted:

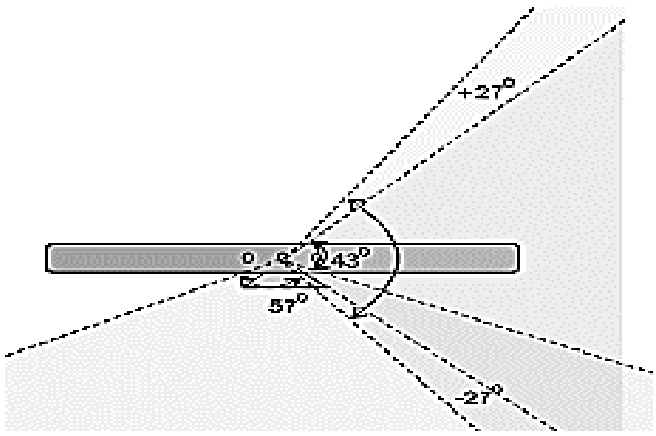


Figure 3.11 - Field of View of Kinect Sensor

The default elevation angle of Kinect sensor is 0 degrees, which indicates that the sensor is pointing to a perpendicular gravity. According to Jana, A (2012), changing the sensor frequently will result in an error code, hence the elevation angle of Kinect sensor is set at 0 degrees at all time throughout the project.

3.5 FLOW CHART

3.5.1 SYSTEM SETUP

First of all, the Kinect is placed at 0.7 metres off the floor for an efficient skeleton tracking. After ensuring the Kinect placement is stable, the Kinect is connected to the laptop through USB adapter, both laptop and Kinect are then powered on. When the Windows operating system is ready, the Kinect driver is detected and the GUI can now be launched. Then, wait 5 seconds for the Kinect driver to synchronize with the GUI. When Kinect is ready, a message showing "Kinect is ready" is displayed at Status Box of the GUI. Since only IR depth sensor is used to capture depth image for skeleton tracking in this system, IR sensor on Kinect is turned on in the background. Once the IR sensor is turned on, the distance of patient is measured and patient is requested to stand within optimum detection range of 2.8m to 3.5m directly in front of the IR sensor on Kinect device. If patient does not stand within the detection range, calibration and the following process will not be carried out. If patient is within the detection range, patient is requested to stand at one point in the centre of field of vision of Kinect device where the coordinate X of patient should be at the origin for the skeleton tracking as shown in Section 3.3.2. If the skeleton stick figure is tracked, the distance between subject and Kinect sensor will be adjusted to make sure that full body of patient is covered by the field of view of Kinect IR sensor.

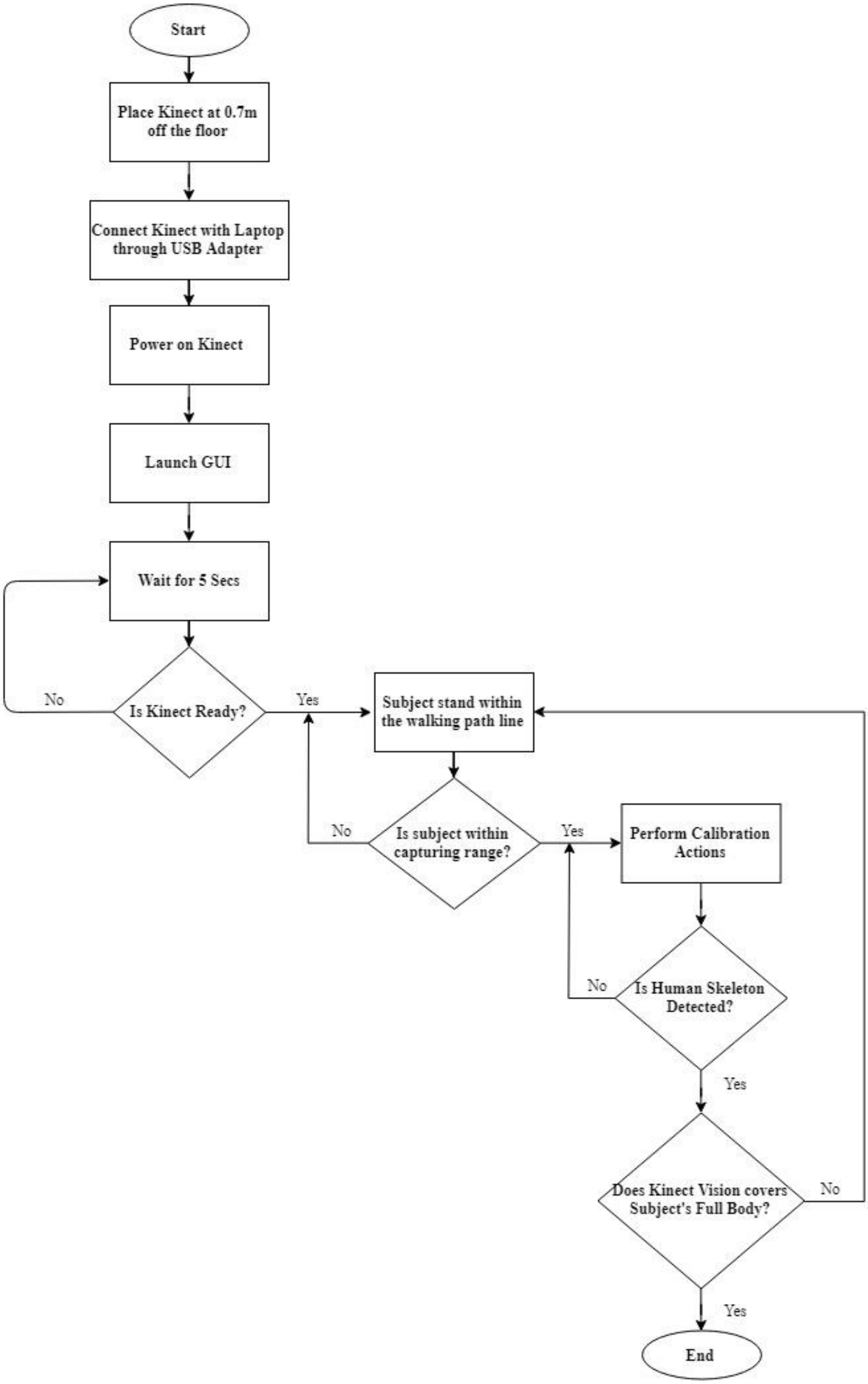


Figure 3.12 - Flow Chart of System Setup

3.5.2 SYSTEM PROGRAMMING

Figure 3.13 to Figure 3.15 illustrate the flow charts of applying Gait Evaluation System by using the Microsoft Kinect sensor. After system setup is done, the gait evaluation system is ready to be operated by user through GUI. User is requested to key in the respective age and gender of the subject and the file name as well. Once the acquisition inputs have been developed, user shall press ‘Start Recording’ button to start capture the gait performed by the subject. A series of walk or motion pattern of the user is captured from the Kinect sensor and the acquisition of the skeletal joint data is performed.

The extracted joint data is saved in the form of CSV in local file. Assuming the input is present in local file, the web service of Azure Machine Learning Studio will accept the input and upload the input file to Azure Blob Storage. Batch Execution Service is called to process a batch of data records. Running time for the whole data-processing takes approximately 6 to 7 minutes. Once the batch execution has finished running, the output blob is exported in CSV file format and downloaded to the local file.

The system performs calculation and comparison on the gait parameter received. Abnormality of gait will be categorized based on the deviation calculated and gait features measured in subject as described in Section 3.3.5. If subject’s gait is detected to be abnormal, the system will led the user to select the associated sign that can be observed in the subject using checkbox function to further categorize the gait deviation pattern of subject, which will display in graphic interchange format (GIF) for a better idea of the gait deviation pattern. The gait status and gait parameter values will be displayed on the GUI and stored in Microsoft Excel file. The user will have the option to start over again by recapturing another gait to perform a new gait evaluation when the system has done displaying all the outcome result.

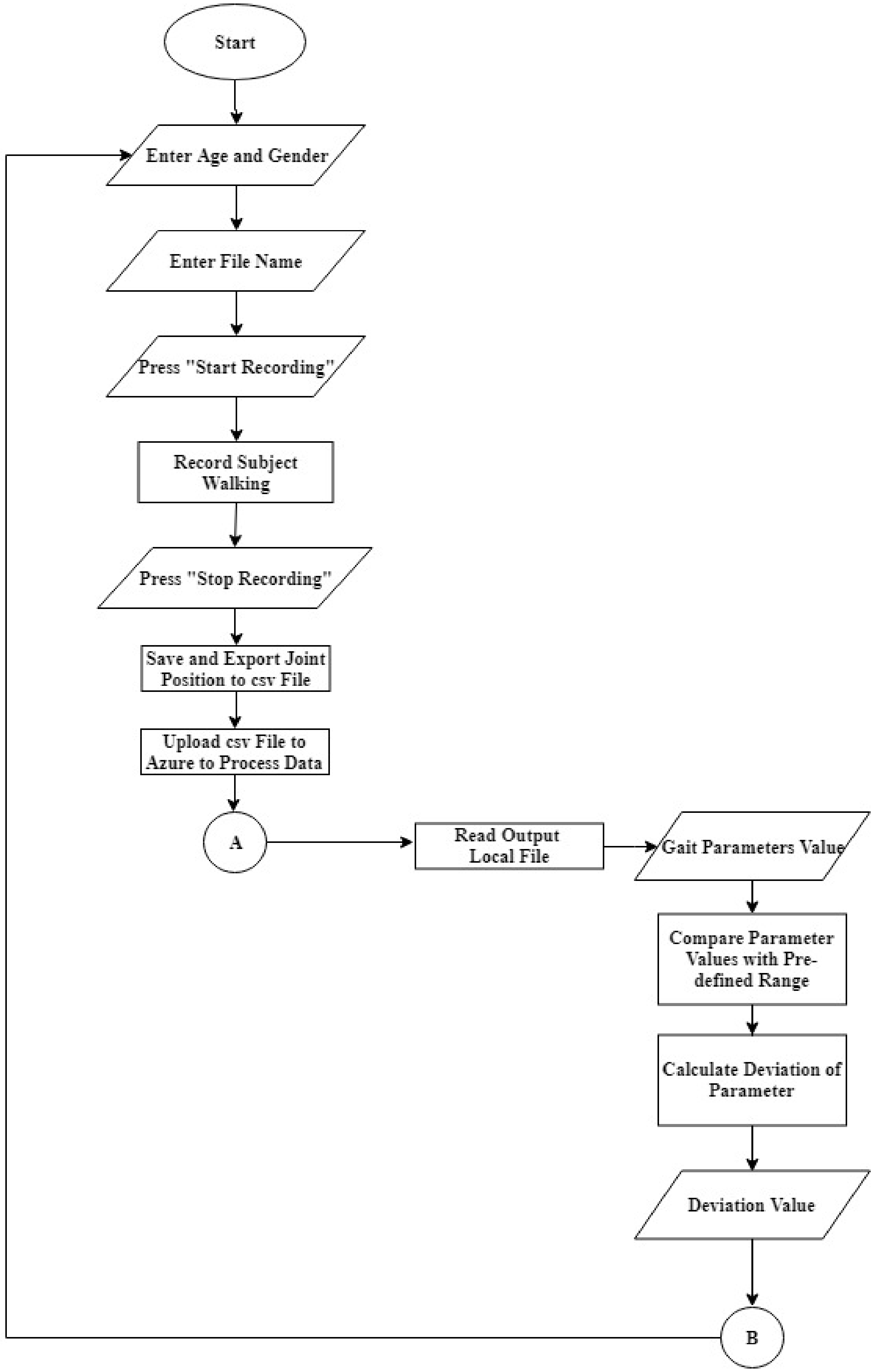


Figure 3.13 - Flow Chart of System Programming

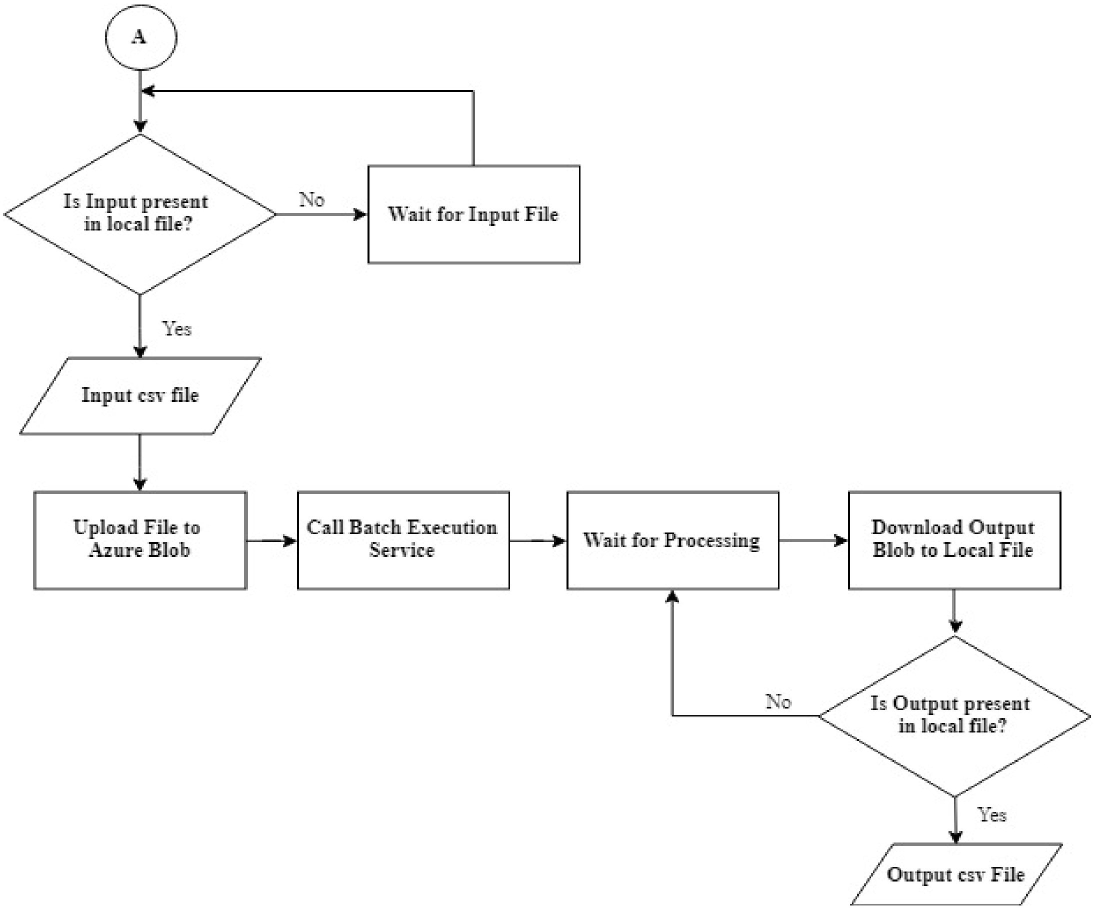


Figure 3.14 - Flow Chart of System Programming (Continued)

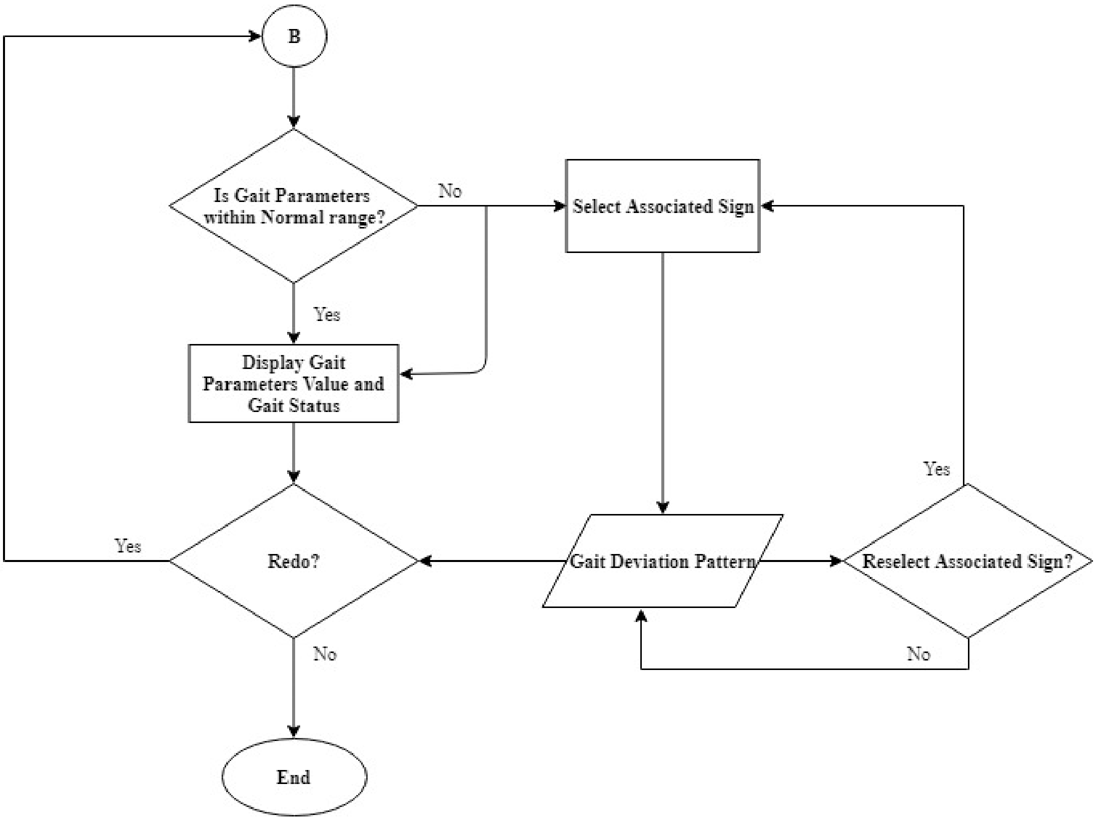


Figure 3.15 - Flow Chart of System Programming (Continued)

3.6 GRAPHICAL USER INTERFACE (GUI)

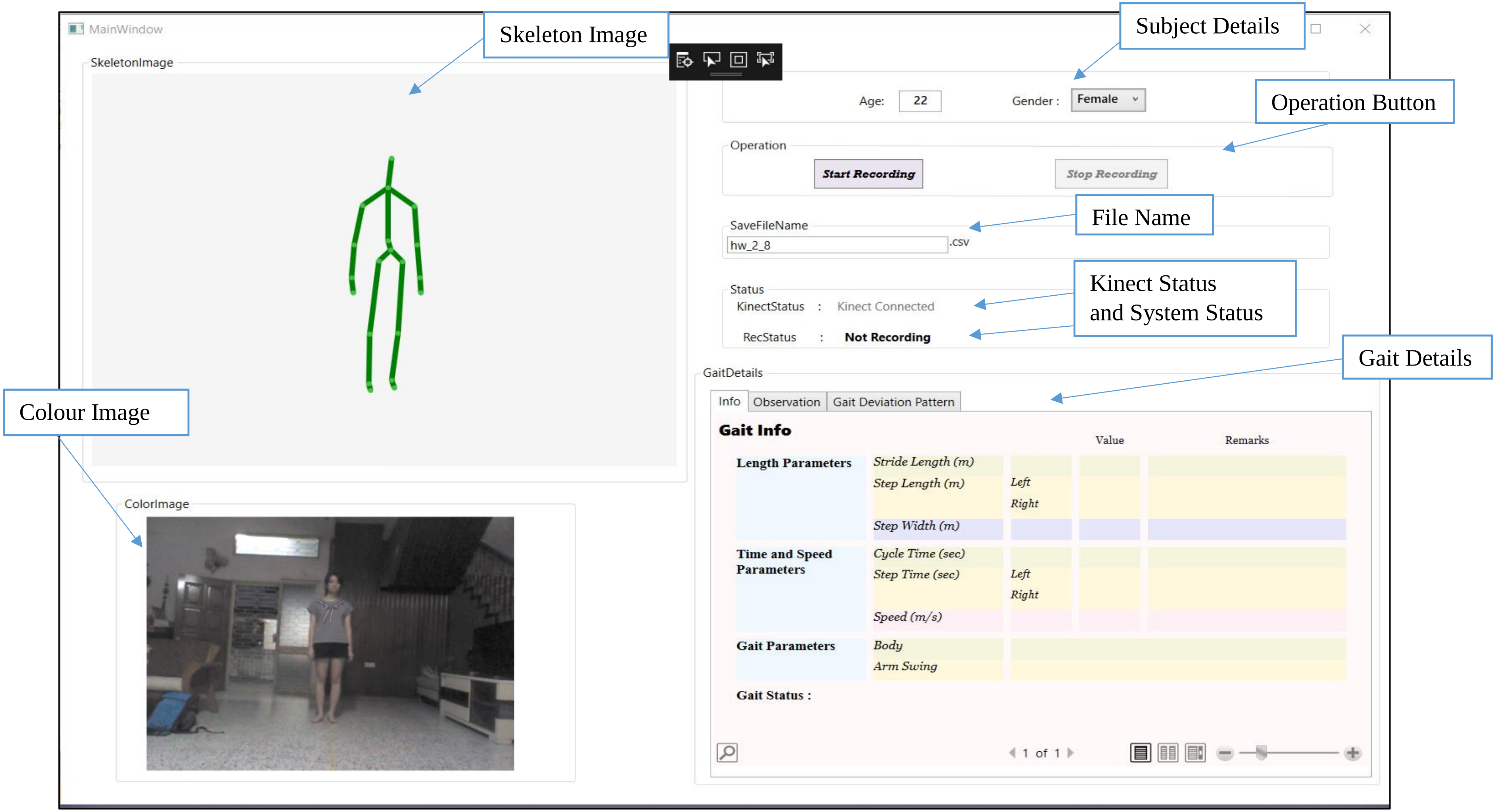


Figure 3.16 – GUI of Gait Evaluation System

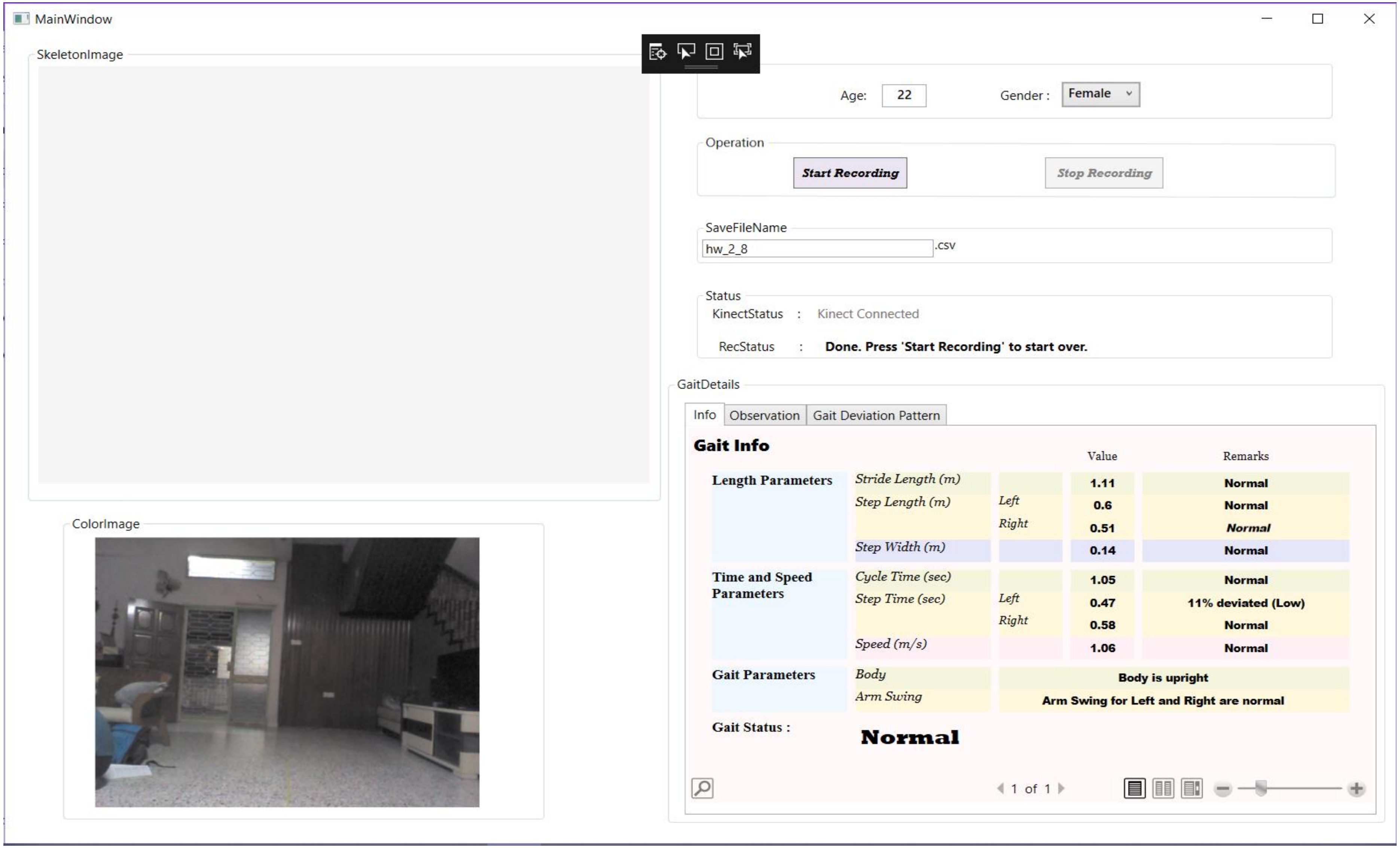


Figure 3.17 – Outcome Result of Gait Evaluation System

A simple Graphical User Interface (GUI) is designed to allow the user to record the gait performed and view the output result. The overall GUI is shown in Figure 3.16. The status of Kinect sensor and the application system are shown in the Status Box. Before recording the gait, user is required to key in the personal details of the subject, namely age, gender and the file name as well. To capture the gait performed by subject using Kinect sensor, the push button ‘Start Recording’ will activate the recording of the movement of skeletal joint and the recorded skeletal data will be saved to a destination folder after ‘Stop Recording’ is pressed. After approximately 7 minutes of processing time, the Gait Details Box will display the subject’s gait parameter value and gait status in the ‘Info’ tab. If the gait status shown ‘ABNORMAL’, user will be led to the ‘Observation’ tab to select the associated sign of subject’s gait as shown in Figure 3.19. Lastly, after pressing the ‘Continue’ button, the gait deviation pattern that matches both the deviation of gait parameter and selected associated sign will be displayed in the form of graphic interchange format (GIF) in the ‘Gait Deviation Pattern’ tab as shown in Figure 3.20.

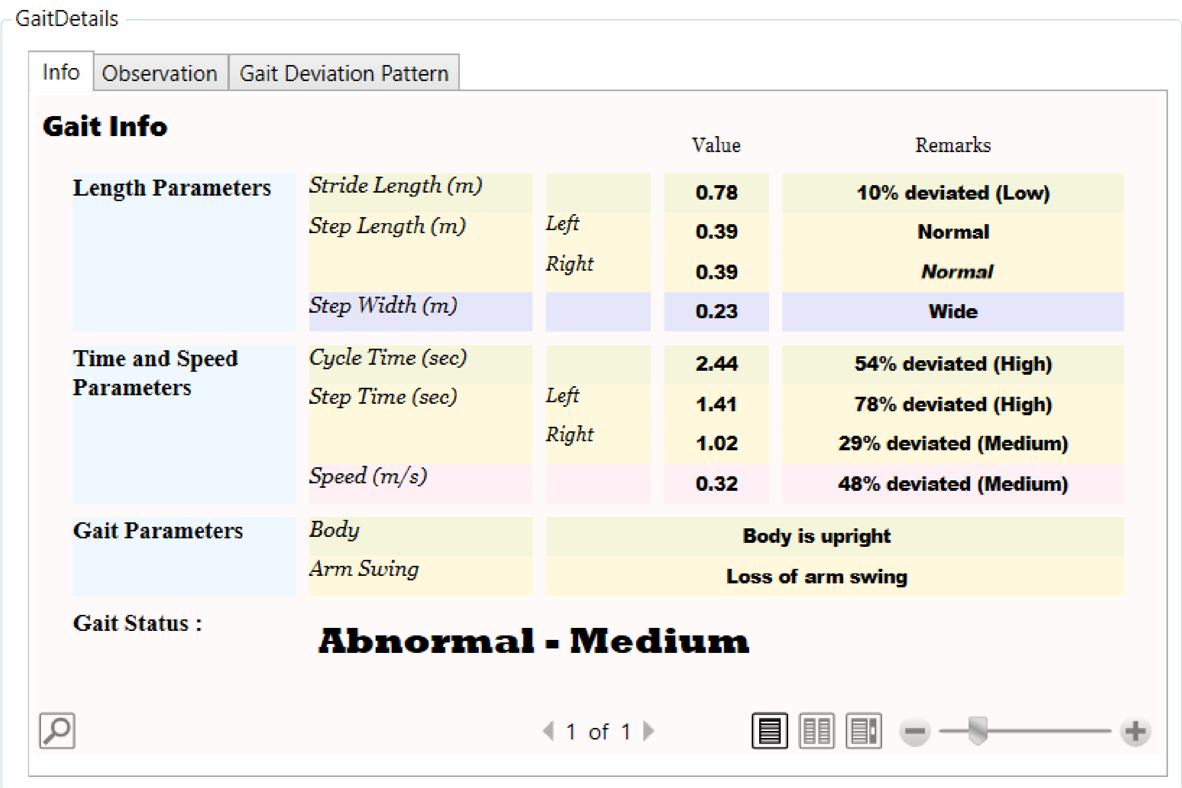


Figure 3.18 – Gait Info when ‘Abnormalities’ Detected

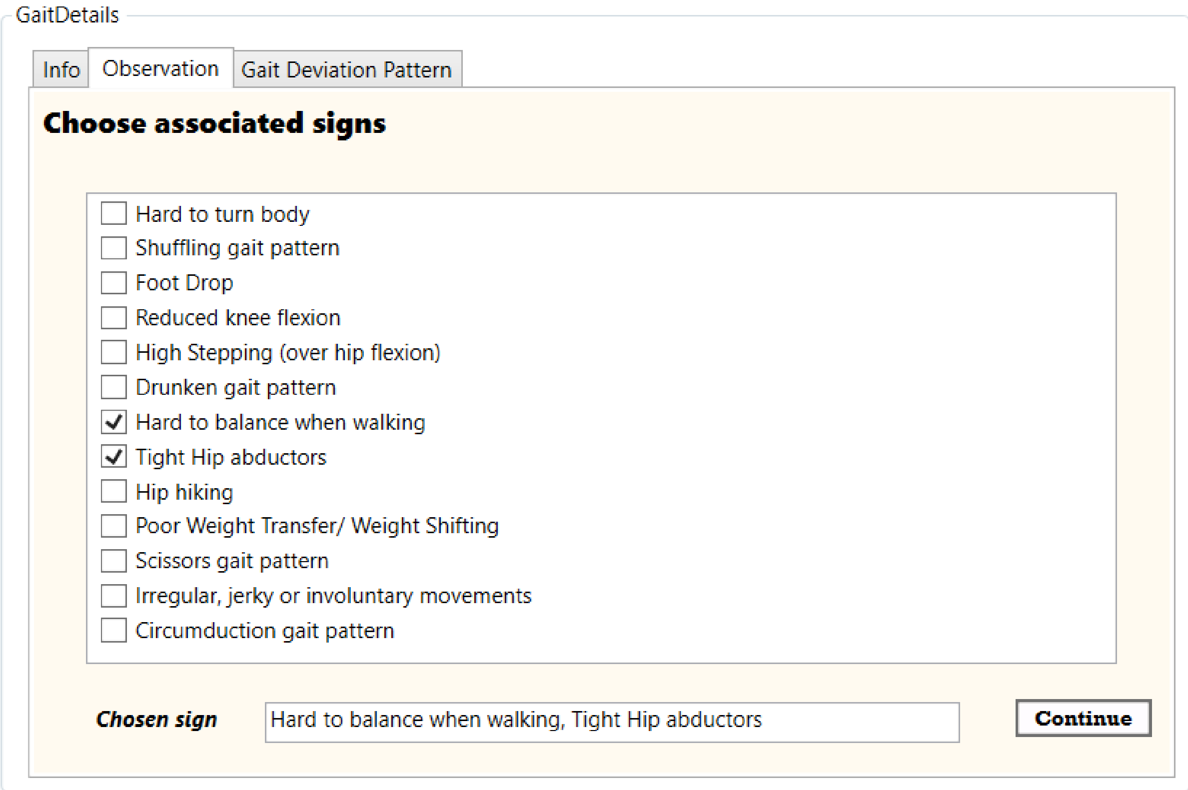


Figure 3.19 – Selection of Associated Sign

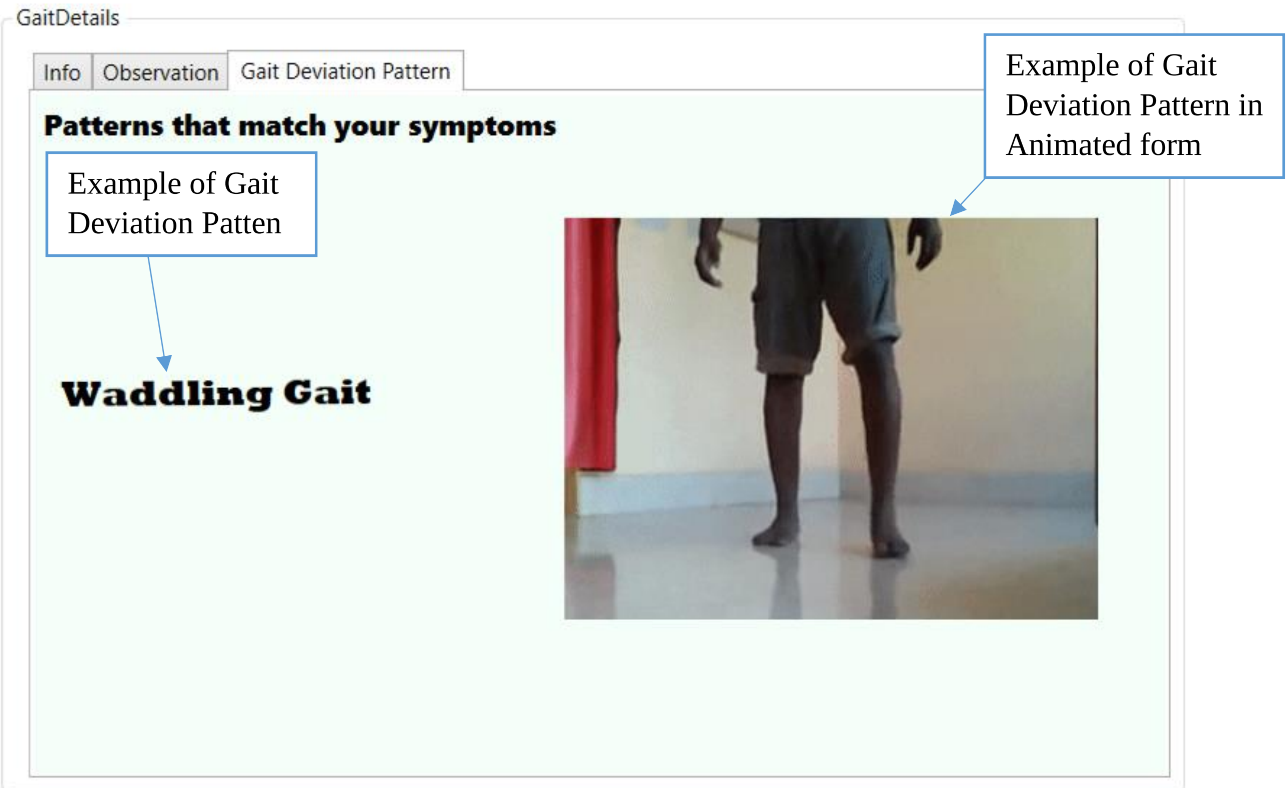


Figure 3.20 – Gait Deviation Pattern

3.7 CHAPTER SUMMARY

This chapter describes the methodology used to develop the project. The chapter begins with a review of gait evaluation using skeletal-based tracking, followed by the chosen hardware and software of the project where Kinect sensor is used as the recording and skeletal tracking of walking gait. The chapter then continues with the descriptions of block diagram where the choice methods of data analysis and processing are discussed. Next, a detailed setup and procedure of the project is included, focusing on the platform with the Kinect sensor and walking path. Flow chart of project setup and system programming are discussed as well. Finally, this chapter provides a detail explanation of the Graphical User Interface (GUI) of the system.

CHAPTER 4

EXPERIMENTAL RESULTS AND DISCUSSION

Participants

Ten healthy participants were approached to carry out the experiments of this project. All the participants had provided their main physical information regarding the age, weight and height. Table 4.1 has presented the data anonymously. They were between 20 and 23 years old and are split almost equally between genders.

Table 4.1 – Participants' physical characteristics for the experiments

Participants	Gender	Age	Weight (kg)	Height (m)
Subject 1	F	22	53	1.69
Subject 2	M	22	75	1.78
Subject 3	F	22	56	1.63
Subject 4	F	22	56	1.55
Subject 5	M	23	59	1.55
Subject 6	M	20	60	1.80
Subject 7	F	22	45	1.52
Subject 8	M	23	52	1.70
Subject 9	M	22	65	1.70
Subject 10	M	22	85	1.75

To evaluate the relevance of each feature for the identification task, the following experiment is carried out: ten participants had to walk from right to left then left to right in front of the Kinect sensor as depicted in Section 3.4. They had been told to walk at their ordinary velocity in their common gait. Each person walked through the field of view, while the Kinect recorded a sequence of frames capturing their side view.

4.1 EXPERIMENT ON PERFORMANCE OF KINECT SENSOR IN MEASURING DYNAMIC JOINT POSITION

4.1.1 EVENT AND PHASE CHANGE OF NORMAL PACE WALKING AND NORMAL GAIT

Theoretical Background:

When performing a dynamic action, the changes of joint position over time can be viewed in 3D space as represented by X, Y, Z coordinates which indicates the joint point movement. The movement towards left or right is represented by X-axis, the movement towards up or down is represented by Y-axis and the movement toward back and front is represented by Z-axis in 3D coordinate system. Since gait is approximately cyclic, the pattern of gait data can be calculated using the temporal and spatial variables which can be determined through the movement of joint position as they vary constantly with time. Gait pattern of both right foot and left foot should be presentable in a graphical form which will be divided into a number of discrete gait cycles as mentioned in Section 2.2.1.

Objectives:

- To determine the changes of X, Y, Z coordinates over time when normal pace walking and normal gait is performed.
- To determine the ability of Kinect in capturing the movement of joint position.

Hypothesis:

The changes of joint point in terms of X, Y, Z coordinates over time can be used to determine and identify discrete gait cycle.

Apparatus required:

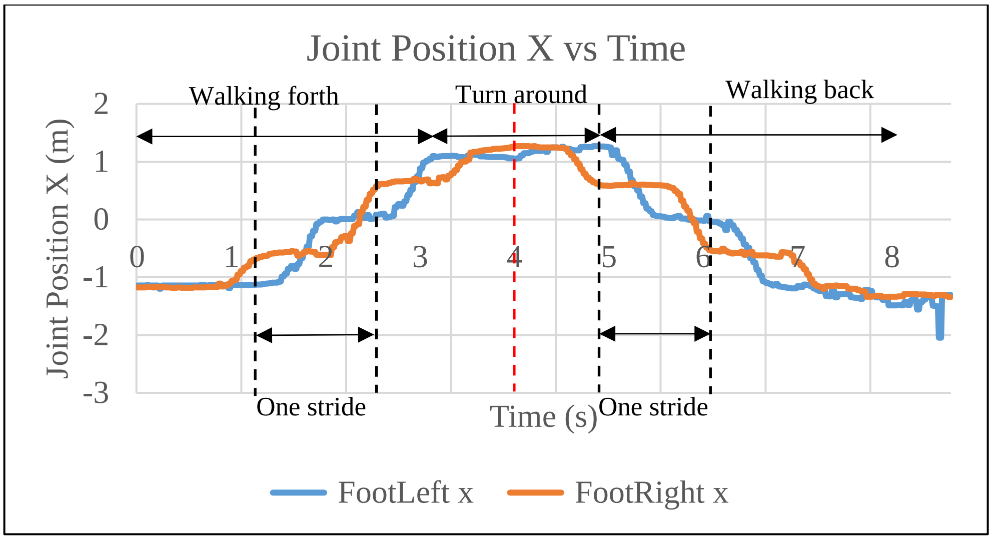
- Kinect device
- Subject 1

Procedure:

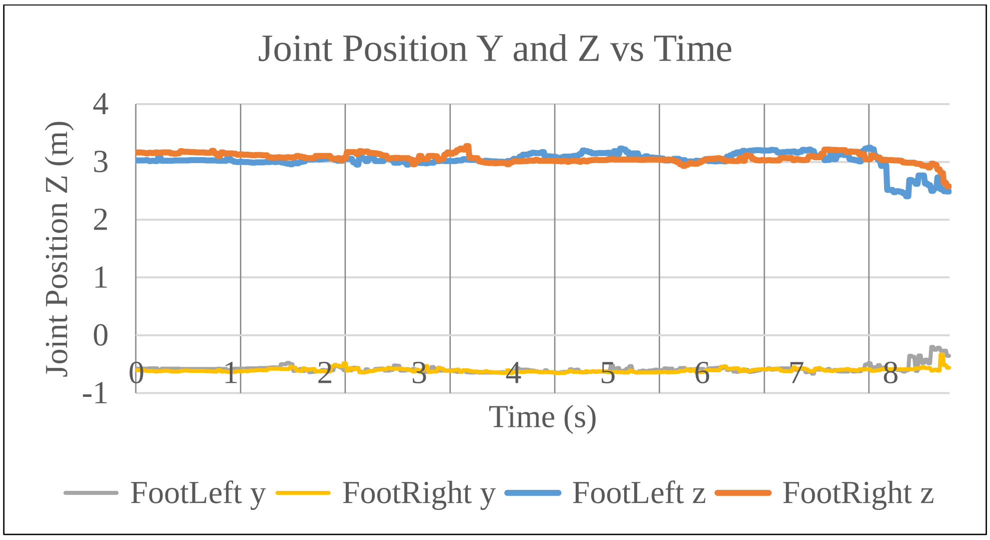
1. Kinect is setup as mentioned in Section 3.4.
2. Subject will be required to walk forth and back at his/her normal pace in the designated walking path line with right foot as starting foot.
3. The whole operation is recorded with frame rate of 30 samples/second.

4. The readings of left foot and right foot coordinates are taken to be compare with the theoretical normal gait cycle phases.
5. Two complete strides and the gait cycle phases are identified from the graph.

Results:



(a) Position X of Right Foot Joint



(b) Position Y and Position Z of Right Foot Joint

Figure 4.1 - Movement of Coordinates of Right Foot Joint in Normal Pace Walking

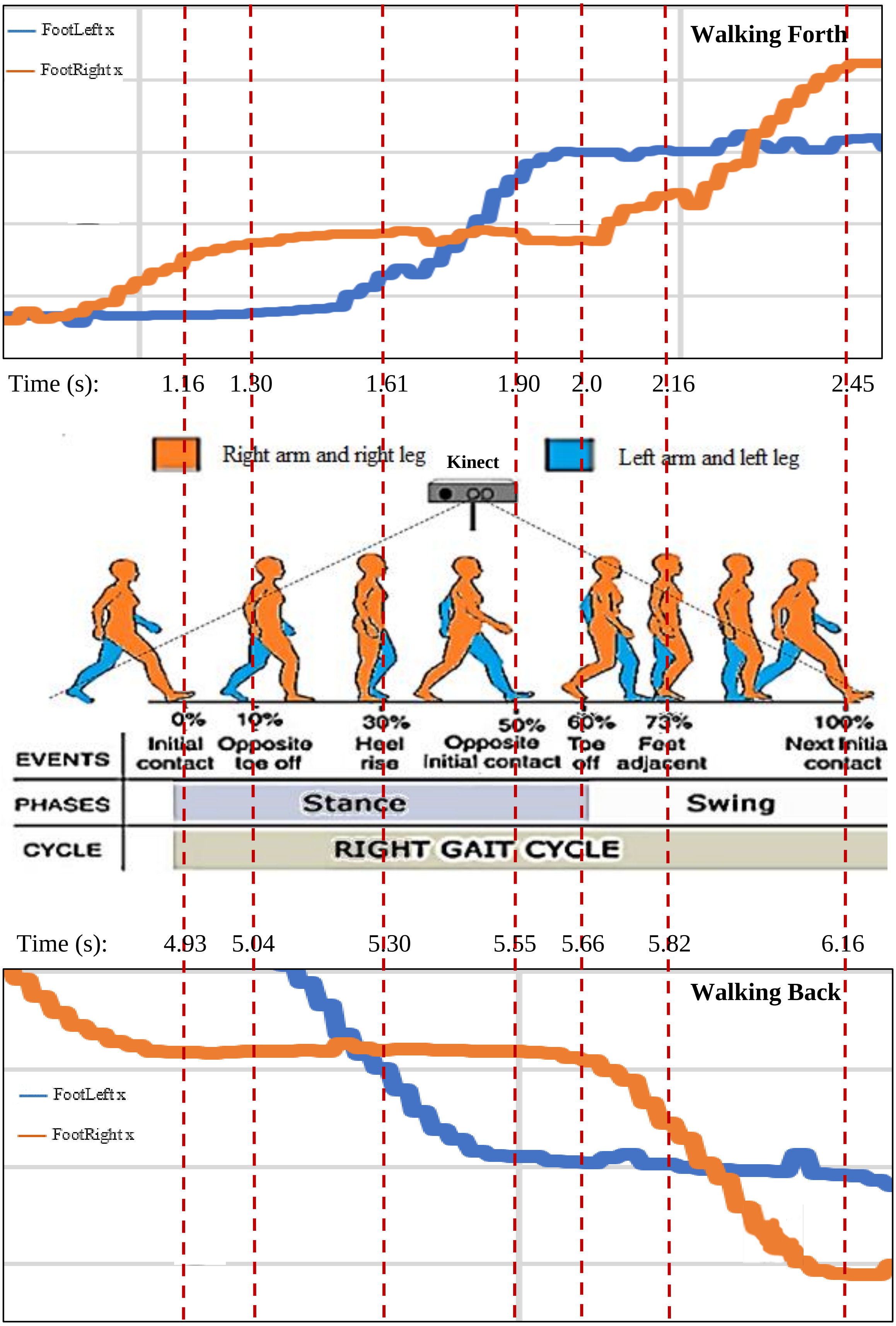


Figure 4.2 - Magnified Portion of Phases of Normal Gait Cycle

Discussion:

The changes of foot joint position which represented by X, Y, Z coordinates are observed and the flow pattern of the coordinates when normal pace walking has been revealed. The Y-coordinates and Z-coordinates remain unchanged while X-coordinates are varied constantly with time. Right foot is set as reference foot. When the foot is in a stance phase, position X of foot should not be changing as the curve of the graph shown in Figure 4.2 remains completely flat. If the foot is in a swing phase, the position X of the foot joint is changing as the curve of the graph increases when subject walks forth and decreases when walking back. One complete stride is identified in each trip when walking forth and walking back in the designated walking path line.

Conclusion:

The event and phase changes of gait performed can be determined using joint coordinates captured by Kinect.

4.1.2 EVENT AND PHASE CHANGE OF ABNORMAL PACE WALKING AND ABNORMAL GAIT

Theoretical Background:

Similar to Section 4.1.1, when performing a dynamic action, the changes of joint position over time (X, Y, Z coordinates) can be observed and further deduce the gait pattern. Since the walking path line is fixed, a normal gait person usually will only walk in one complete stride at each time when walking forth and walking back again. However, it will be different case for the abnormal pace, if the subject walks with a faster pace and smaller step, it will take more strides for the subject to finish the walking path line. On the other hand, if subject walks with a slower pace but bigger step, a longer time will required to complete a stride.

Objectives:

- To determine the changes of X, Y, Z coordinates over time when abnormal pace walking and abnormal gait is performed.
- To determine the ability of Kinect in capturing the movement of joint position.

Hypothesis:

The changes of joint point in terms of X, Y, Z coordinate over time when performing abnormal gait and abnormal pace walking will different from that of the normal gait and normal pace walking.

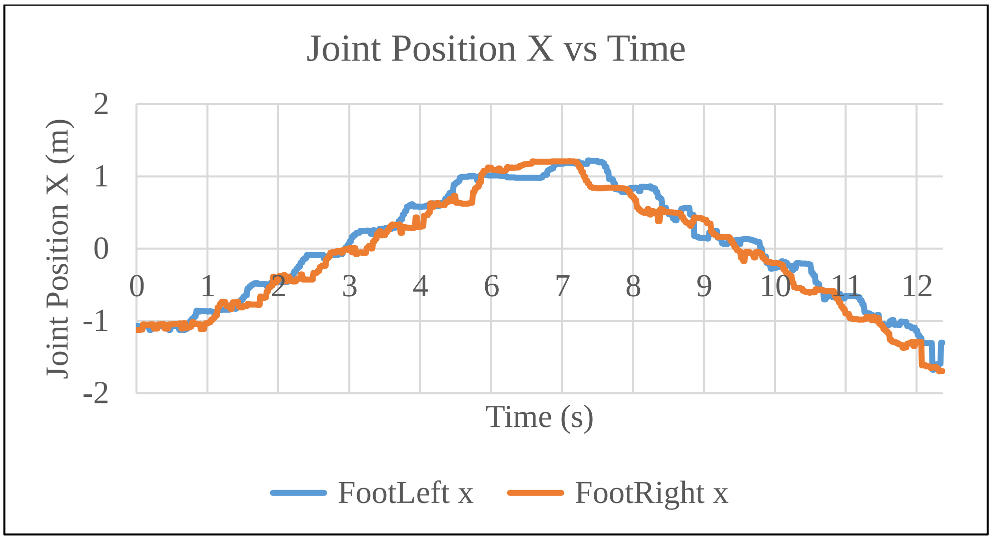
Apparatus required:

- Kinect device
- Subject 1

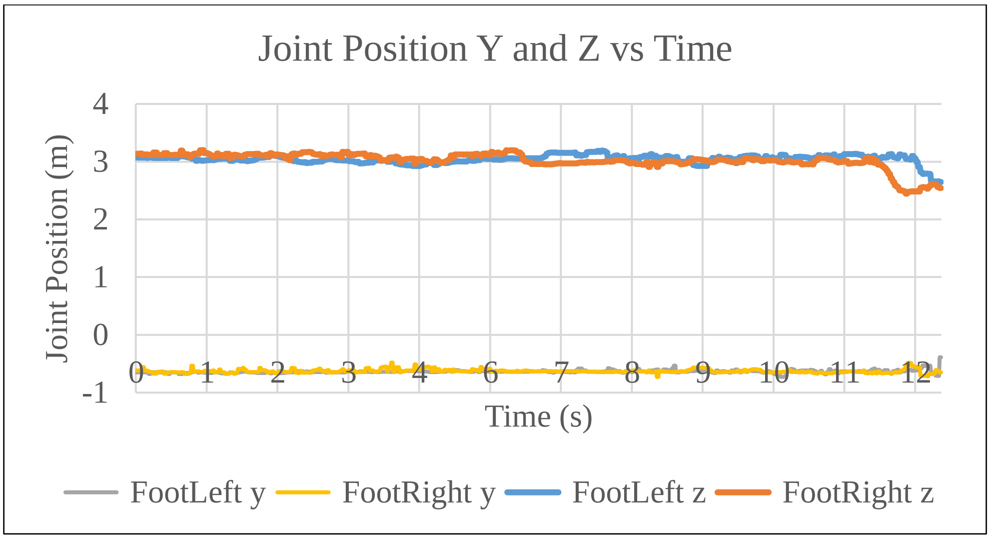
Procedure:

1. Kinect is setup as mentioned in Section 3.4.
2. Subject will be required to walk forth and back with a faster pace and shorter step in the designated walking path line with right foot as starting foot.
3. The whole operation is recorded with frame rate of 30 samples/second.
4. The readings of left foot and right foot coordinates are taken to be compare with the results of the normal pace walking obtained in Section 4.1.1.
5. Step 2 to 4 is repeated but with the subject walking in a slower pace and larger step.

Results:

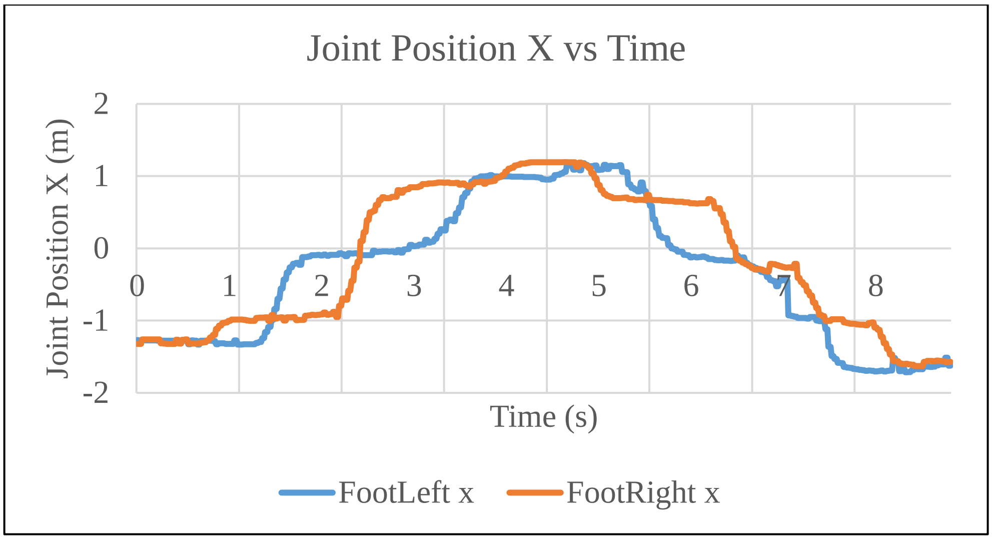


(a) Position X of Right Foot Joint

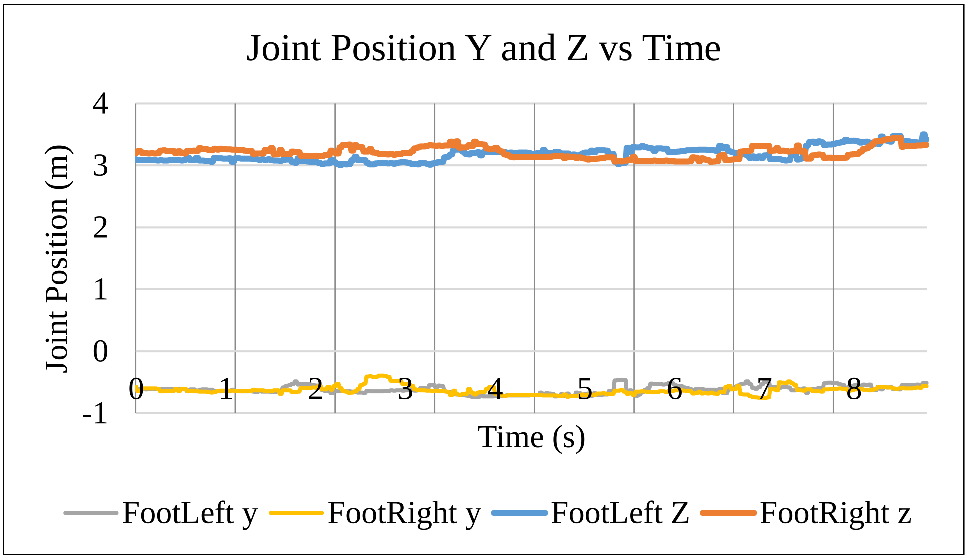


(b) Position Y and Position Z of Right Foot Joint

Figure 4.3 - Movement of Coordinates of Right Foot Joint in Faster Pace and Smaller Step Walking



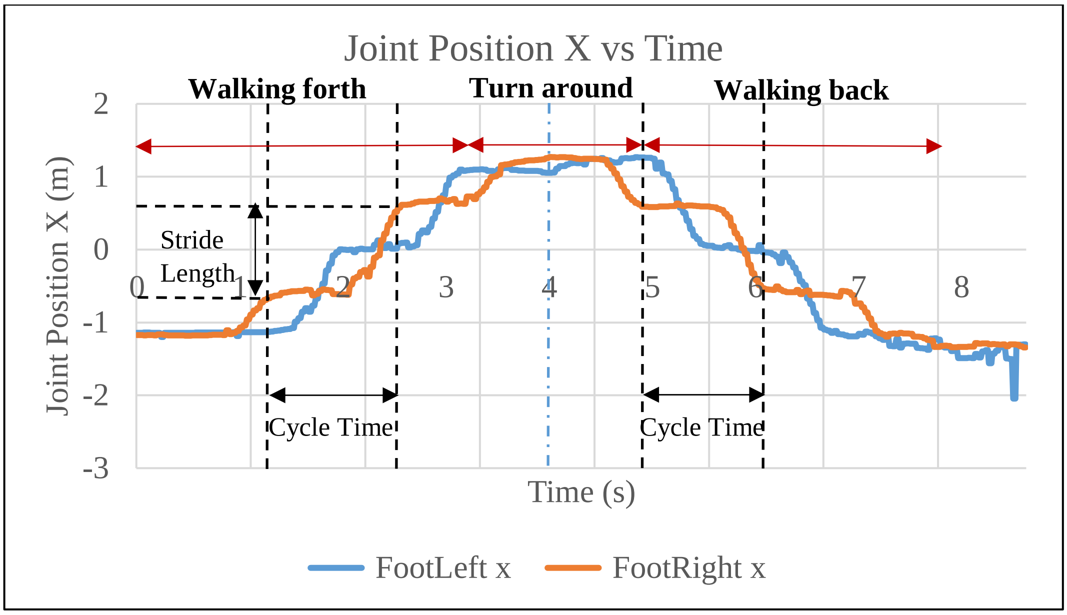
(a) Position X of Right Foot Joint



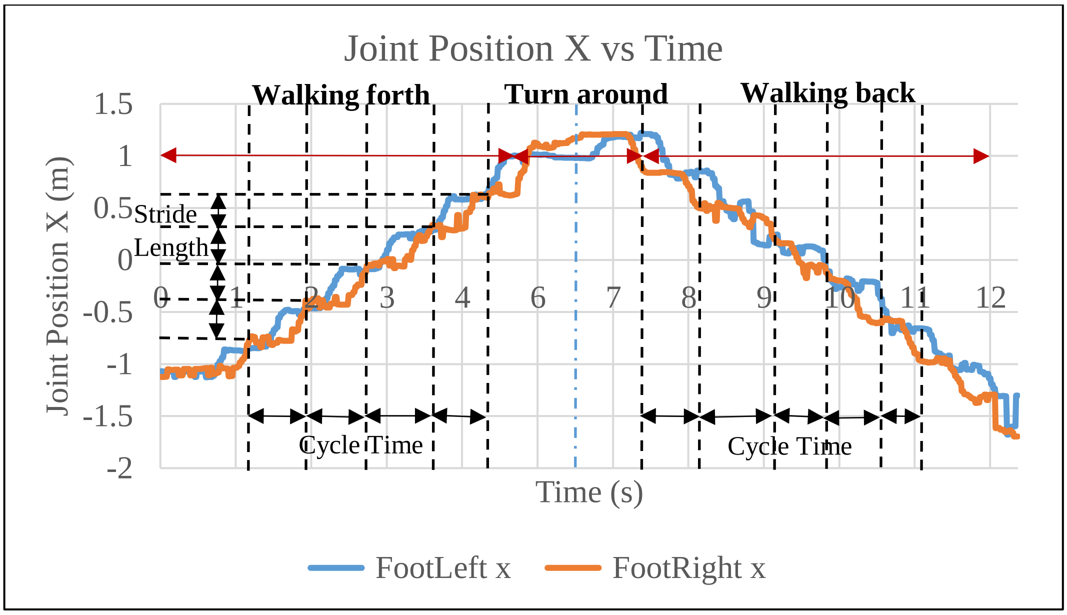
(b) Position Y and Position Z of Right Foot Joint

Figure 4.4 - Movement of Coordinates of Right Foot Joint in Slower Pace and Larger Step Walking

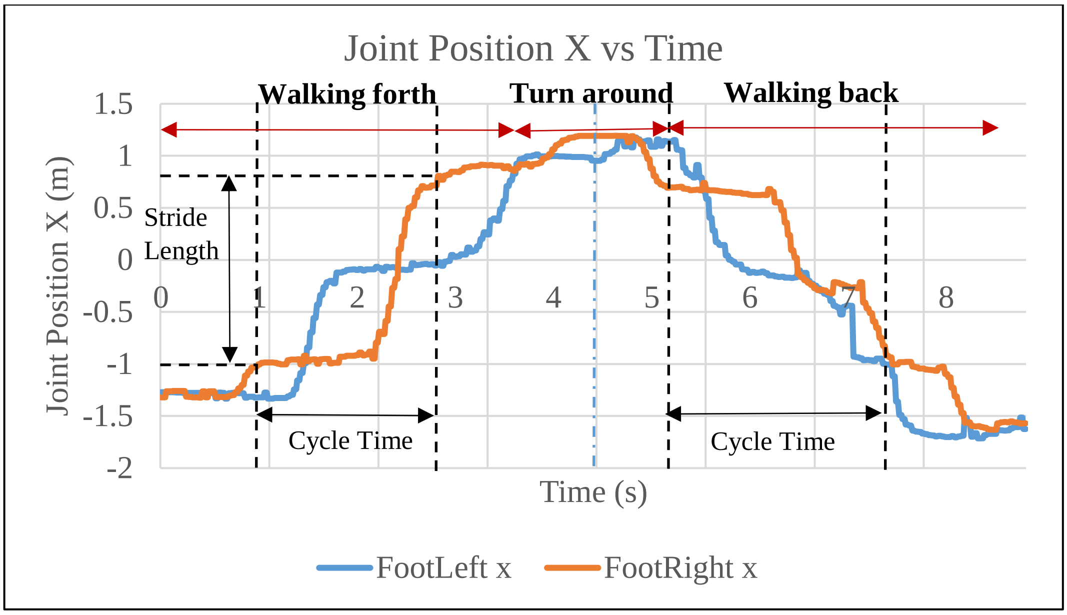
Discussion:



(a) Normal Pace and Normal Gait



(b) Faster Pace and Smaller Step



(c) Slower Pace and Larger Step

Figure 4.5 - Movement of Position X of Right Foot Joint in Different Gait

The changes of foot joint position which represented by X, Y, Z coordinates are observed and the flow pattern of the coordinates in abnormal pace walking has been revealed. The Y-coordinates and Z-coordinates remain unchanged while X-coordinates varied constantly with time, similar to when in normal pace walking. For normal pace walking with normal gait in Figure 4.5 (a), only one complete stride is identified in each trip when walking forth and walking back in the designated walking path line and approximately 1 second is used to perform a complete stride. However, when the subject walks with faster pace and smaller step in Figure 4.5 (b), there are more than one stride found in each trip and the stride length is considerably shorter than in the normal pace walking and shorter cycle time is spent to complete a stride. As for another case in Figure 4.5 (c) which is the total opposite of the previous one, a longer stride length and cycle time are presented in the graph when subject is requested to walk in a slower pace but bigger step.

Conclusion:

The changes of movement of Position X of foot joint over time when performing abnormal pace walking will different from that of the normal pace walking, in terms of stride length and cycle time.

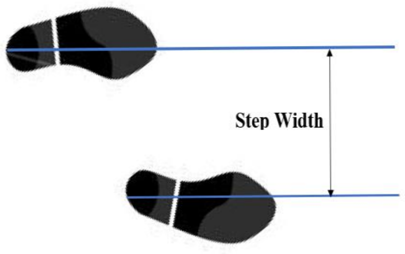
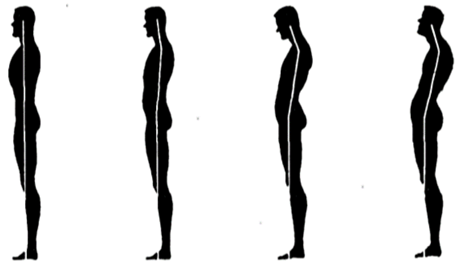
4.2 EXPERIMENT ON SETTING OF DATA PROCESSING

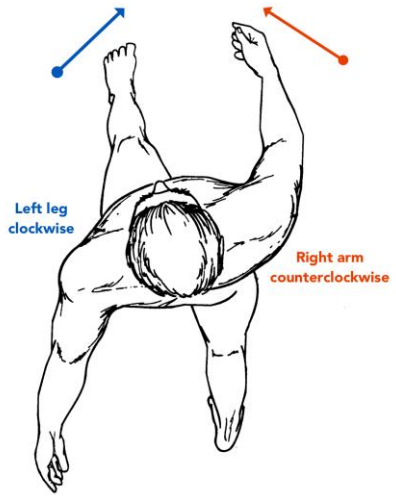
4.2.1 THRESHOLD VALUE OF GAIT FEATURE

Theoretical Background:

Unlike other spatio-temporal parameters, namely stride length, cycle time and speed, a proper normative range of different age group for these parameters are provided and analysed by Whittle, M (2007) and Item, G. *et al*. (2014). However, step width doesn't have a reference data for a normative range. Gait features such as body posture and arm swing also not given a quantitative value as the usual observational gait analysis only depends on the judging of how well a subject is walking by using observation and experience of physiotherapist. Step width can be measured by calculating the distance between Z coordinates of left foot joint and right foot joint. As mentioned in Section 2.2.2, body should remain erect and have an upright posture with the head straight when walking, hence coordinate X of head and hip centre should be on the same position during walking. For a person with normal gait, arms should be hanging loosely at the sides, swinging in rhythm with equal motion of the opposite leg and the hands should be away from the shoulder joint, else the moving direction of coordinate X of the hand joint and shoulder joint would be the same for both left and right respectively.

Table 4.2 – Extraction of Gait Parameter and Feature

Gait Feature	Definition and Method of Extraction
Step Width 	Distance between centres of the feet Step width $= \left\lvert \begin{matrix} \text{position Z of left foot joint} - \\ \text{position Z of right foot joint} \end{matrix} \right\rvert$
Body Posture  *(Illustration by Fruzsina Kuhári., 2016)*	Position in which body are held while standing $\text{Differences} = \left\lvert \begin{matrix} \text{position X of Head} - \\ \text{position X of Hip Centre} \end{matrix} \right\rvert$

Arm Swing  *(Illustration by Fauntine Lariba., 2018)*	Arm swings with the motion of the opposing leg $\text{Differences} = \lvert \text{position X of Shoulder} - \text{position X of Hand} \rvert$

Objective:

- To determine the thresholding value of the step width, body posture and arm swing for the gait evaluation.

Hypothesis:
The optimum threshold value can be determined by using the joint point which can be represented by X, Y, Z coordinates.

Apparatus required:

- Kinect device
- 10 Subjects as listed in Table 4.1

Procedure:

1. Kinect is setup as mentioned in Section 3.4.
2. Subject will be required to walk forth and back at his/her normal pace in the designated walking path line with right foot as starting foot.
3. The whole operation is recorded with frame rate of 30 samples/second.
4. The readings of left foot and right foot coordinates, head and hip centre coordinates, shoulder and hand coordinates (both left and right) are taken to calculate the mean value and standard deviation in order to determine the optimum threshold value.

Results:

Table 4.3 – Gait Parameter Values Collected in 10 Subjects

	Gait Parameter for Gait Evaluation			
	Spatial Parameters	Gait Features		
	Step Width (m)	Body Posture (m)	Left Arm Swing (m)	Right Arm Swing (m)
Subject 1	0.12	0.05	0.12	0.12
Subject 2	0.09	0.06	0.12	0.20
Subject 3	0.10	0.05	0.12	0.15
Subject 4	0.16	0.05	0.17	0.17
Subject 5	0.13	0.03	0.09	0.08
Subject 6	0.17	0.10	0.09	0.09
Subject 7	0.08	0.03	0.08	0.07
Subject 8	0.10	0.11	0.11	0.13
Subject 9	0.15	0.14	0.08	0.13
Subject 10	0.16	0.06	0.13	0.18
MAX **MIN**	0.17 0.08	0.14 0.03	0.17 0.08	0.20 0.07
MEAN (Standard Deviation)	**0.13 (0.03)**	**0.07 (0.03)**	**0.11 (0.03)**	**0.13 (0.04)**

Discussion:

Table 4.3 includes the outcomes of the assessment averaged to 10 participants as listed in Table 4.1. Small standard deviation is discovered and appears to be closely compatible between all these measures. For the body posture to be upright, the difference between head and hip centre needs to be as small as possible. The average mean obtained for the difference is 0.07 m with a standard deviation of 0.03m, hence the optimum threshold value is set to be 0.1m, meanings the subject will be said not having an upright body if the difference of position X of head joint and hip centre joint is greater than 0.1m. Same concept goes to arm swing, but for having a normal gait, arm swing is required to swing in rhythm with equal motion of the opposite leg. According to the result, it is found that a mean average value of approximately 0.12m gap with a small standard deviation will be present between shoulder joint and hand joint for the arm swing of normal gait. The optimum lower boundary for this difference will be set as 0.1m as well where the subject will be identified as ‘Loss of arm swing’ if the difference is lower than 0.1m. As for the step width, according to the analysis of gait made by Kau.edu.sa. (n.d.)., the standard normative value for step width is ranged between 0.10m to 0.15m. From the result obtained in Table 4.3, a promising result with having a high similarity with the analysis by Kau.edu.sa (n.d.) is shown. Therefore, the optimum normative range for the step width is set to 0.10m to 0.15m.

Conclusion:

The optimum thresholding values for step width, body posture and arm swing are successfully determined from this experiment.

4.2.2 EFFECT OF MOVING AVERAGE FILTER ON STRIDE INDENTIFICATION

Theoretical Background:

Jittering of skeleton joints may happen due to the processing of large amount of data over a period of time which make it very difficult to identify stride. Moving Average Filter is used to generate a moving average of joints, which reduces the noise thus getting a smoother skeleton data in enabling the identification of stride.

Azure Machine Learning Studio provides the following types of moving average calculations (Docs.microsoft.com., 2019) :

- **Simple**: A simple moving average (SMA) is calculated as an unweighted rolling mean.
- **Triangular**: Triangular moving averages (TMA) are averaged twice for a smoother trend line. The word triangular is derived from the shape of the weights that are applied to the data, which emphasizes central values.
- **Exponential Simple**: An exponential moving average (EMA) gives more weight to the most recent data. The weighting drops off exponentially.
- **Exponential Modified**: A modified exponential moving average calculates a running moving average, where calculating the moving average at any one point considers the previously computed moving average at all preceding points.
- **Cumulative**: Given a single point and a current moving average, the cumulative moving average (CMA) calculates the moving average at the current point.

The root-mean-squared error (RMSE) is a measure of how well the model performed by measuring difference between predicted values and the actual values which is defined as follows (Goswami, R., 2018):

Equation 4.1 - Root Mean Squared Error (RMSE)

$$\boldsymbol{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}(\boldsymbol{Predicted_i} - \boldsymbol{Actual_i})^2}{\boldsymbol{N}}}$$

Objective:

- To determine the most optimum type of moving average calculations to use in enabling the ease of the identification of stride.

Hypothesis:

Moving Average Filter can provide a smoother skeleton data to reduce fluctuation for the ease of data-processing.

Apparatus required:

- Kinect device
- 10 Subjects as listed in Table 4.1

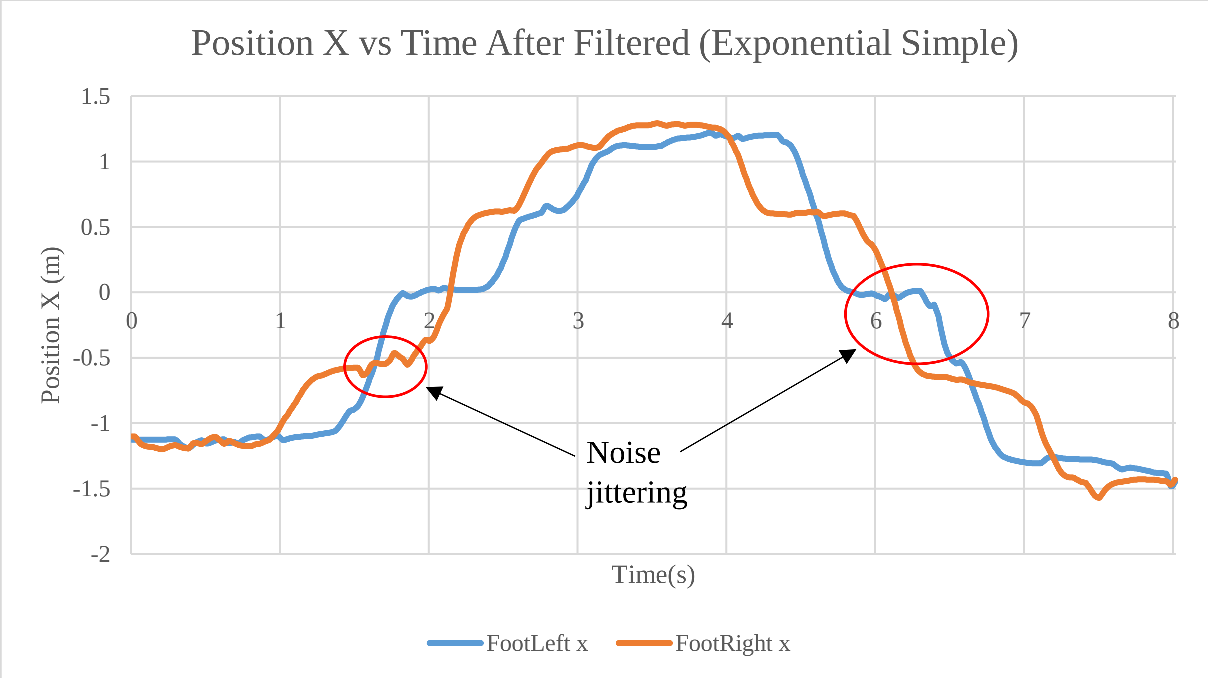
Procedure:

1. Kinect is setup as mentioned in Section 3.4.
2. Subject will be required to walk forth and back at his/her normal pace in the designated walking path line with right foot as starting foot.
3. The whole operations is recorded with frame rate of 30 samples/second.
4. The readings of left foot and right foot coordinates are taken with respect of time measured.
5. The dataset is fed into Azure Machine Learning Studio and moving average filter is applied.
6. The length of the moving average window is set to default value.
7. The type of moving average calculation is set to ‘Simple’.
8. The output dataset is converted to csv file and exported for analysis.
9. Step 6 to 8 is repeated by changing the type of moving average calculations (Triangular, Exponential Simple, Exponential Modified and Cumulative) for comparison.
10. RMSE is calculated with predicted value obtained using Moving Average Filter and actual value from raw data.

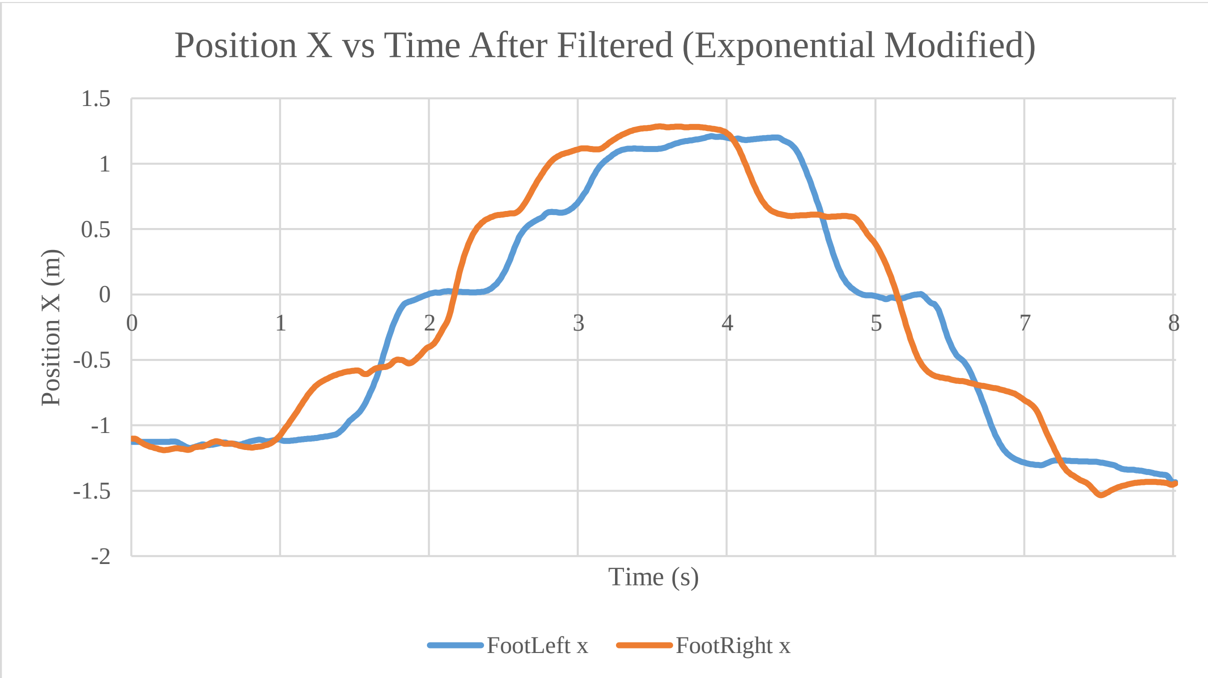
Results:

Table 4.4 - RMSE Calculated for Different Moving Average Calculation Method

Participants	Moving Average Calculation Method									
	Simple		Triangular		Exp-Simple		Exp-Modified		Cumulative	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Subject 1	0.066	0.067	0.069	0.071	0.035	0.037	0.047	0.051	0.865	0.886
Subject 2	0.076	0.077	0.081	0.081	0.040	0.042	0.056	0.059	0.952	0.980
Subject 3	0.071	0.072	0.075	0.076	0.038	0.036	0.055	0.061	1.010	0.958
Subject 4	0.076	0.073	0.080	0.078	0.041	0.038	0.061	0.056	0.915	0.799
Subject 5	0.057	0.056	0.061	0.059	0.029	0.026	0.047	0.045	0.644	0.766
Subject 6	0.060	0.060	0.063	0.063	0.032	0.031	0.057	0.054	0.881	0.841
Subject 7	0.059	0.058	0.062	0.062	0.035	0.034	0.057	0.055	0.812	0.797
Subject 8	0.092	0.096	0.098	0.101	0.035	0.041	0.062	0.060	1.064	1.130
Subject 9	0.059	0.060	0.063	0.063	0.030	0.030	0.053	0.054	0.971	0.938
Subject 10	0.073	0.072	0.077	0.076	0.037	0.037	0.045	0.045	0.940	0.926
MEAN (Standard Deviation)	**0.069 (0.010)**	**0.069 (0.011)**	**0.073 (0.011)**	**0.073 (0.012)**	**0.035 (0.004)**	**0.035 (0.005)**	**0.054 (0.006)**	**0.054 (0.005)**	**0.906 (0.111)**	**0.902 (0.104)**



(a) Exponential Simple Calculation



(b) Exponential Modified Calculation

Figure 4.6 - Effect of Moving Average Filter

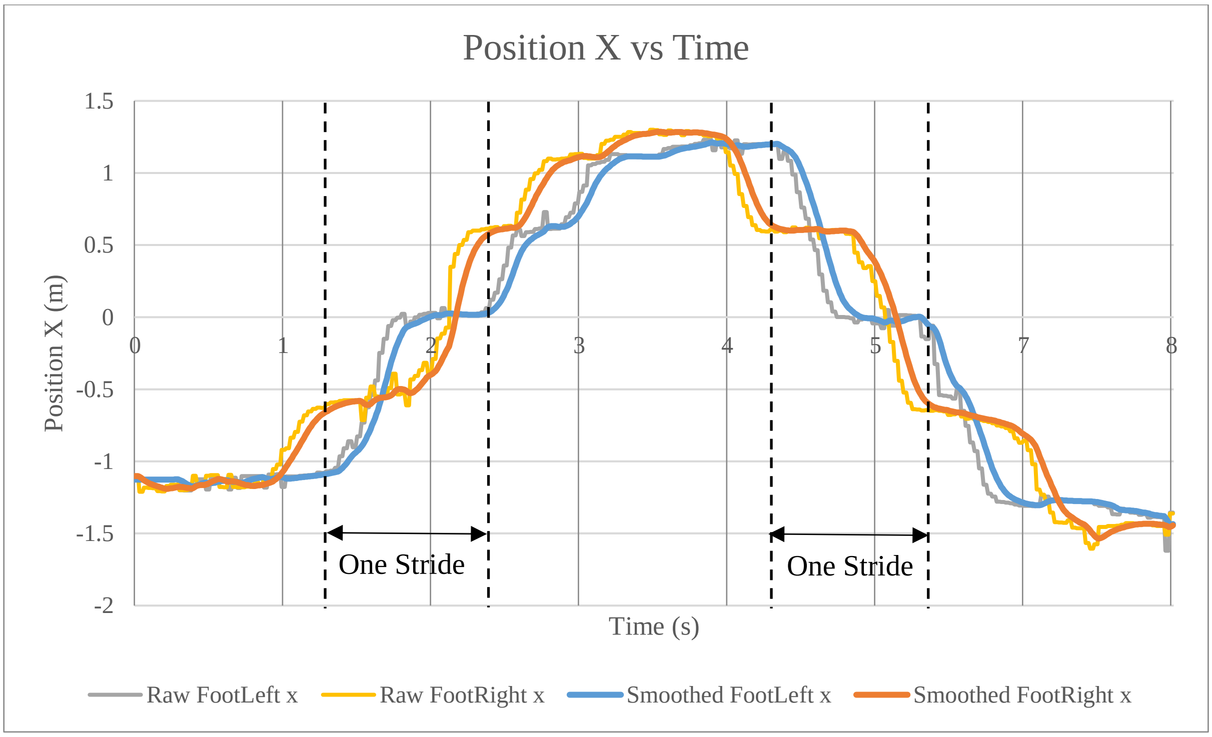


Figure 4.7 - Comparison between Raw Data and Smoothed Data using Exponential Modified Calculation

Discussion:

The Moving Average filter applies to each set of data and calculates a running moving average, where calculating the moving average at any one point considers the previously computed moving average at all preceding points. Effect of Moving Average using different calculations are presented in Appendix D.2. According to the RMSE calculated, 'Exponential Simple' has the lowest among all, followed by 'Exponential Modified' while 'Cumulative' has the highest prediction error. However, 'Exponential Modified' Moving Average yields a smoother trend line compared to 'Exponential Simple' (Figure 4.6) while still containing the pattern of original data, hence it is chosen for the system. The difference between the raw skeleton and smoothed data after filtered can be seen. The trend of data movement always remains the same as the original data but the deviation is less compared to the raw skeleton data.

Conclusion:

'Exponential Modified' Moving Average Filter is chosen for the system as it gives a smoother trend line with low RMSE.

4.2.3 EFFECT OF DISCRETISATION ON STRIDE IDENTIFICATION

Theoretical Background:

Binning or grouping data (sometimes called quantization) is useful for scenarios such as when a large amount of dataset has too many unique values which makes the segmentation of data difficult, discretisation can be applied to assign the approximately same number of samples fall into each bin, to create a smaller set of discrete ranges which make it easier for the grouping of data (Docs.microsoft.com., 2019). Quantiles binning mode is chosen in Azure Machine Learning Studio which uses Quantile normalization option to determine how values are normalized prior to sorting into quantiles which the values are normalized within the range of 0 to 100. Number of bins needs to be verified to specify how many bins or quantiles to create in order to efficiently and accurately segment the gait cycle. Changing point of data can be determined by using the discretised range of value. Red crosses shown in Figure 4.8 are the changing points of the right foot joint movement. It can be seen that three changing points are found in one complete stride where first point is the start of stance phase, followed by the end of stance phase which indicates the start of swing phase then finished by the end of swing phase. Owing to the function of Microsoft Azure, changing point needs to be identified by choosing the peak of the discretisation level and removing the duplicate rows, but only maximum (Max point) and minimum value (Min point) will be used to calculate the required stride length and cycle time as shown in Figure 4.10.

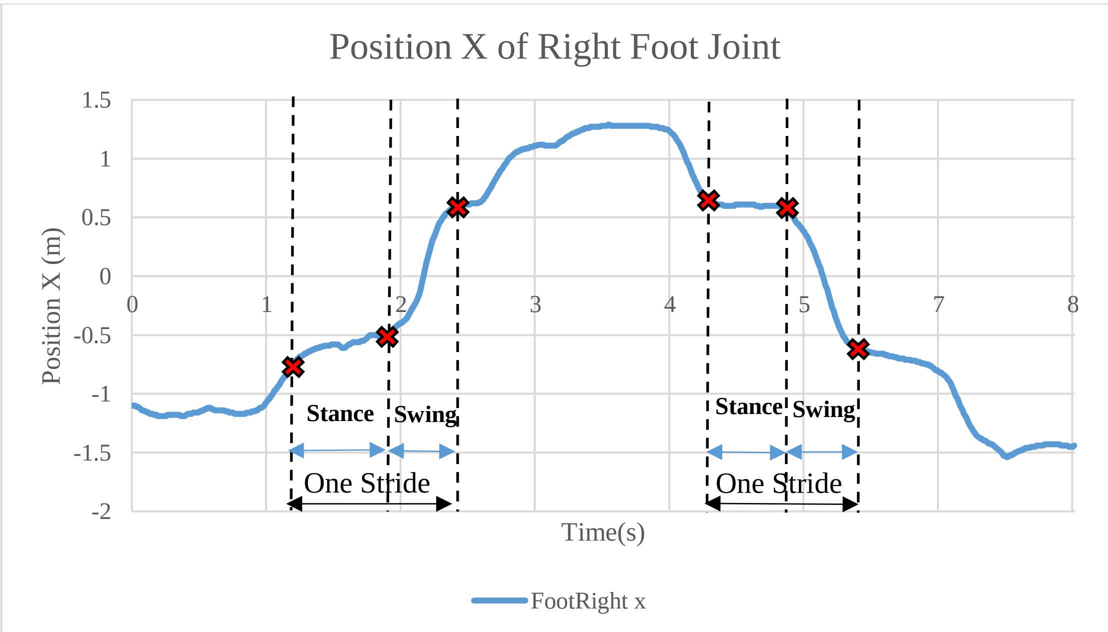


Figure 4.8 - Changing Point of a Complete Stride

Objective:

- To determine the most optimum bin numbers in enabling the ease of the calculation of gait parameter.

Hypothesis:

Discretisation is used to identify the optimal groupings of data values and create a set of specific discrete ranges for the segmentation of gait cycle.

Apparatus required:

- Kinect device
- Subject 1
- Manila card
- Measuring tape
- Stop watch

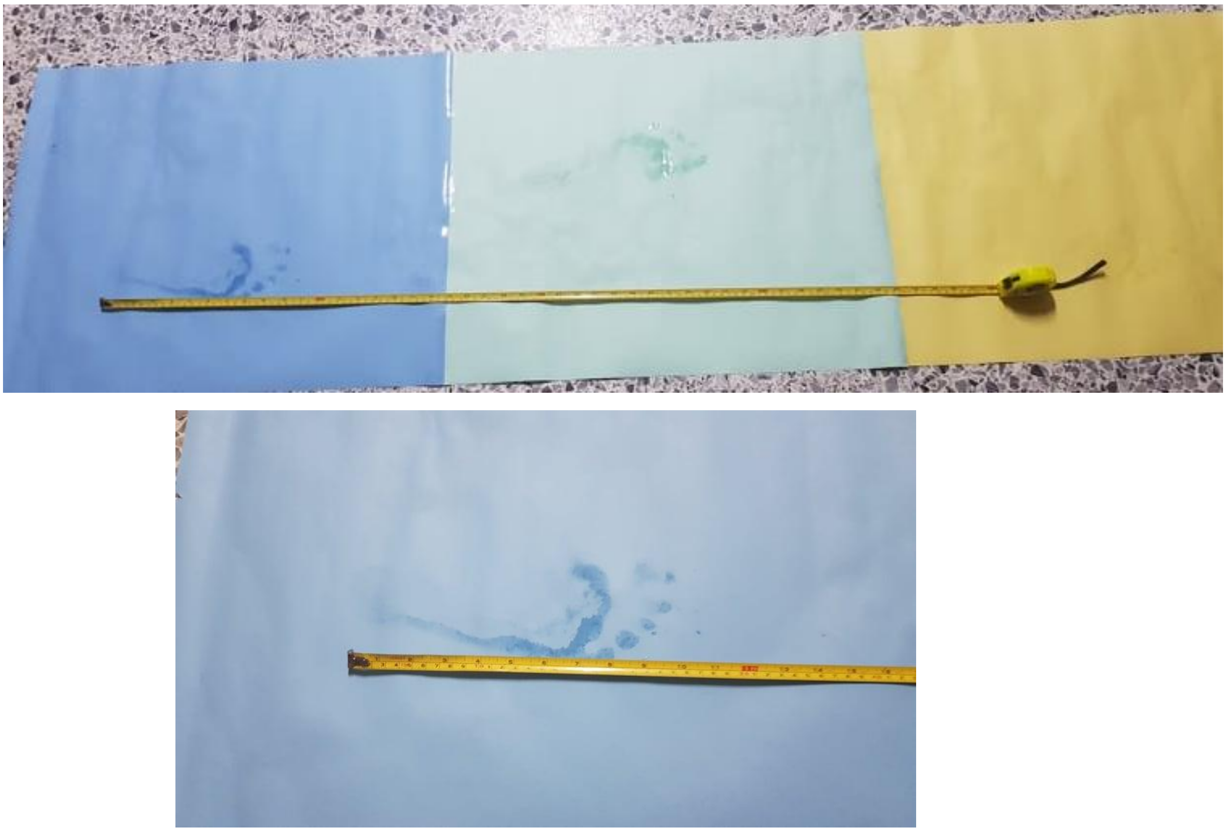


Figure 4.9 - Actual Measurement of Stride Length

Procedure:

1. Kinect is setup as mentioned in Section 3.4.
2. Subject will be required to walk forth and back at his/her normal pace in the designated walking path line made by manila card with right foot as starting foot.
3. The time taken for the subject to complete a stride is timed with a stop watch.
4. Actual measurement of stride length will be taken by measuring the distance between two successive placements of heel contact of the right foot.
5. The whole operation is recorded with frame rate of 30 samples/second.
6. The readings of right foot coordinates are taken with respect of time measured.
7. The dataset is fed into Azure Machine Learning Studio and moving average filter is applied.
8. The smoothed data will be fed into discretisation module to group the data into bins.
9. The number of bins is set to 3.
10. Partition and split module is applied to remove the duplicate rows and choose only first three peak points of the X position of right foot joint.
11. Max point and Min point are obtained to calculate stride length and cycle time.
12. Step 9 to 11 is repeated by changing the number of bins (5, 7, 10 and 12) for comparison.
13. The results from gait evaluation performed using discretisation are compared with the actual measurement.
14. RMSE is calculated with predicted value obtained using discretisation and actual value from the actual measurement of stride length and cycle time.

Results:

Table 4.5 - RMSE Calculated for Different Number of Bins

	Discretisation									
No. of Bins	**3**		**5**		**7**		**10**		**12**	
	Cycle Time (s)	**Stride Length (m)**	**Cycle Time (s)**	**Stride Length (m)**	**Cycle Time (s)**	**Stride Length (m)**	**Cycle Time (s)**	**Stride Length (m)**	**Cycle Time (s)**	**Stride Length (m)**
Reading 1	0.47	0.45	0.50	0.10	0.07	0.02	0.11	0.24	0.52	0.33
Reading 2	0.35	0.14	0.47	0.23	0.03	0.07	0.05	0.11	0.74	0.49
Reading 3	0.11	0.20	0.17	0.34	0.18	0.04	0.05	0.00	0.53	0.45
Reading 4	0.18	0.11	0.23	0.25	0.10	0.14	0.32	0.28	0.33	0.53
Reading 5	0.25	0.10	0.01	0.34	0.06	0.13	0.23	0.13	0.35	0.51
Reading 6	0.42	0.20	0.43	0.17	0.12	0.11	0.24	0.16	0.46	0.46
Reading 7	0.09	0.08	0.35	0.30	0.04	0.05	0.06	0.04	0.50	0.53
Reading 8	0.20	0.11	0.40	0.34	0.05	0.06	0.05	0.06	0.13	0.01
Reading 9	0.36	0.24	0.30	0.41	0.00	0.04	0.03	0.06	0.38	0.43
Reading 10	0.02	0.20	0.53	0.31	0.06	0.00	0.28	0.17	0.25	0.44
MEAN (Standard Deviation)	**0.24 (0.14)**	**0.18 (0.10)**	**0.34 (0.15)**	**0.28 (0.09)**	**0.07 (0..05)**	**0.07 (0.04)**	**0.14 (0.10)**	**0.12 (0.08)**	**0.42 (0.16)**	**0.42 (0.15)**

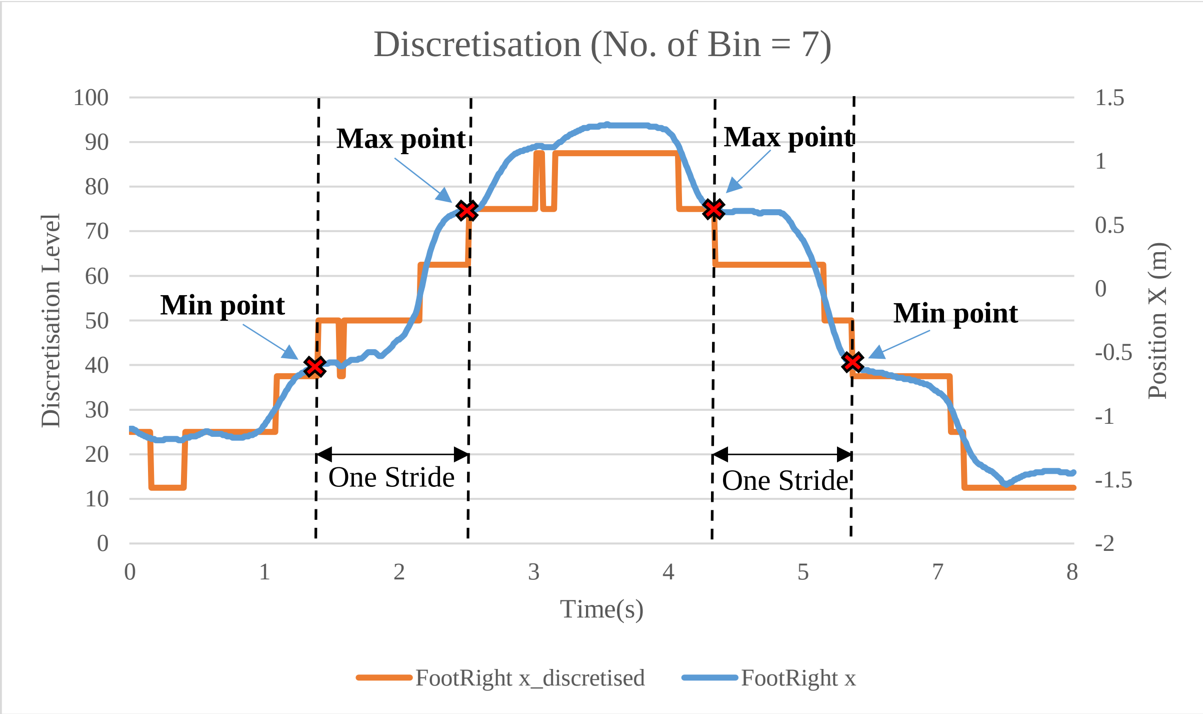


Figure 4.10 - Discretisation performed using 7 bins

Discussion:

During binning, each input element is mapped to a bin by comparing its value against the positions of bin edges. For example, if the actual value is 1.6 and the bin edges are 1, 2, 3, the input would be assigned to bin number 2. Discretisation error may occurs, for example, value 1.3 would be assigned to bin number 1 (the underflow bin) and value 2.6 would be assigned to bin number 3 (the overflow bin). Discretisation problem arises when the analogue value must be represented by the nearest digital value, resulting in a very slight error. For this case, number of bins is used to specify how many quantiles wanted and assign the normalization range. Smaller bins will introduce discretisation error whereby larger bins will create too many unique values which makes it harder for the grouping of data. Effect of discretisation using different numbers of bins are presented in Appendix D.3. Based on the result in Table 4.5, the gait parameters after segmented into its gait cycle are presented and the outcome results with the number of bins = 7 have the lowest RMSE and standard deviation among all as the stride length and cycle time produced showing a promising result which is found to be accurately match with the actual measurement of the fundamental spatio-temporal gait parameters. Spikes are present but will be neglected by the data processing algorithm mentioned in Section 3.3.4.

Conclusion:

Discretisation using 7 bins can be applied to segment the gait cycle and identify spatio-temporal gait parameters.

4.3 EXPERIMENT ON ACCURACY AND CONSISTENCY OF GAIT EVALUATION SYSTEM

Theoretical Background:

Experimental error defined as the difference between an experimental value and the actual value of a quantity, which indicates the accuracy of the measurement (Helmenstine, T., 2014). The accuracy is a measure of the degree of closeness of a measured or calculated value to its actual value.

Accuracy can be determined by calculating the error percentage and similarity:

Equation 4.2 - Error Percentage and Similarity

$$\%error = \frac{|Experimental\ Value - Actual\ Value|}{Actual\ Value} \times 100$$

$$\%Similarity = (100 - \%error)$$

Objective:

- To determine the accuracy and consistency of overall system in performing spatio-temporal gait evaluation.

Hypothesis:

The overall system designed for gait evaluation should have high accuracy and consistency.

Apparatus required:

- Kinect device
- 10 Subjects as listed in Table 4.1
- Manila card
- Measuring tape
- Stop watch

Procedure:

1. Kinect is setup as mentioned in Section 3.4.
2. Manila card is placed as the walking path line of the experiment.
3. Subject will be required to walk forth and back at his/her normal pace on the designated walk path line made by manila card with right foot as starting foot.
4. The time taken for the subject to complete a stride is timed with a stop watch.
5. Actual measurement of stride length will be taken by measuring the distance between two successive placements of heel contact of the right foot.
6. The whole operations is recorded with frame rate of 30 samples/second.
7. The results from gait evaluation performed with Kinect are compared with the actual measurement.

Results:

Table 4.6 – Spatio-temporal gait evaluation performed in 10 subjects.

	Spatio-Temporal Gait Evaluation							
	Spatial Parameter				Temporal Parameter			
Participants	**Stride Length (m)**	**Left Step Length (m)**	**Right Step Length (m)**	**Step Width (m)**	**Cycle Time (s)**	**Left Step Time (s)**	**Right Step Time (s)**	**Speed (m/s)**
Subject 1	1.09	0.56	0.54	0.12	1.19	0.55	0.64	0.92
Subject 2	1.28	0.60	0.68	0.10	1.21	0.67	0.64	1.06
Subject 3	1.23	0.65	0.58	0.10	1.09	0.57	0.52	1.13
Subject 4	1.12	0.54	0.58	0.16	0.97	0.54	0.42	1.15
Subject 5	0.84	0.34	0.50	0.13	1.10	0.50	0.60	0.76
Subject 6	1.05	0.49	0.56	0.17	1.16	0.51	0.65	0.90
Subject 7	0.89	0.46	0.44	0.08	1.15	0.59	0.56	0.77
Subject 8	1.01	0.46	0.55	0.10	1.24	0.66	0.58	0.81
Subject 9	1.11	0.54	0.57	0.15	1.21	0.56	0.64	0.92
Subject 10	1.18	0.60	0.57	0.16	1.24	0.61	0.63	0.95
MEAN (Standard Deviation)	**1.08 (0.13)**	**0.52 (0.09)**	**0.56 (0.06)**	**0.13 (0.03)**	**1.16 (0.08)**	**0.58 (0.05)**	**0.59 (0.07)**	**0.94 (0.13)**

Discussion:

Results from the spatio-temporal gait evaluation performed with Kinect are presented in Table 4.6. This table include the results of the analysis averaged to 10 participants as listed in Table 4.1. Small standard deviation is discovered in the spatio-temporal measurement. The results are also found to be correctly in line with the actual normal range for spatio- temporal gait parameters listed in Section 3.3.5.

Table 4.7 - Comparison of Actual Measurement and the Results of System

	Spatio-Temporal Gait Evaluation					
	Stride Length (m)			**Cycle Time (s)**		
	System	**Actual**	**Similarity (%)**	**System**	**Actual**	**Similarity (%)**
Subject 1	1.09	1.10	99.09	1.19	1.22	97.54
Subject 2	1.28	1.23	95.93	1.21	1.11	90.99
Subject 3	1.23	1.20	97.50	1.09	1.01	92.08
Subject 4	1.12	1.13	99.12	0.97	1.04	93.27
Subject 5	0.84	0.72	83.33	1.10	1.22	90.16
Subject 6	1.05	1.01	96.04	1.16	1.10	94.55
Subject 7	0.89	0.80	88.75	1.15	1.02	87.25
Subject 8	1.01	0.98	96.94	1.24	1.16	93.10
Subject 9	1.11	1.08	97.22	1.21	1.19	98.32
Subject 10	1.18	1.10	92.73	1.24	1.17	94.02
MEAN (Standard Deviation)	**1.08 (0.13)**	**1.04 (0.16)**	**94.67 (4.79)**	**1.16 (0.08)**	**1.12 (0.08)**	**93.13 (3.13)**

Discussion:

Comparison is made between results from the spatio-temporal gait evaluation performed with Kinect and the actual measurement. Small error of value are found between these measures. It is found that the mean error between system outcomes and actual measurement is about 7% (by averaging all errors). The worst assessment obtained is 83% similar, but the similarity attained in several instances is greater than 90%. These errors can be reasoned. Some of them are introduced when the gait data is captured with Kinect due to the inherent skeleton tracking errors, but the major part of the error presented in Kinect's spatio-temporal gait evaluation can be introduced in several phases of the methodology: for example, moving average filter and discretisation in the data processing module will results in small latency and introduce inaccuracies. Despite of these differences, results obtained show an overall high similarity of at least 93% .

Conclusion:

The overall gait evaluation system performed by Kinect with data processed in Azure Machine Learning Studio shows high accuracy and consistency.

4.4 EXPERIMENT ON PERFORMANCE OF CATEGORISATION OF GAIT ABNORMALITY

4.4.1 QUANTITATIVE MEASUREMENT, DEVIATION AND SEVERITY LEVEL

Theoretical Background:

Categorisation of gait abnormality is performed based on the result of the gait parameters. Gait parameter value, the deviated value (as compared to Tables 3.3 and 3.4) and the corresponding severity level will be shown in the GUI of gait evaluation system. The severity level is obtained by using the equation in Section 3.3.5. Subject will be labelled as 'Normal', 'Abnormal LOW', 'Abnormal MEDIUM' and 'Abnormal HIGH' based on the overall deviation as set in Section 3.3.5.

Objective:

- To determine the performance of system in categorising the abnormality of gait based on deviation percentage and severity level.

Hypothesis:

The overall system designed should have high performance in categorising the abnormality of gait with deviation percentage and the corresponding severity level.

Apparatus required:

- Kinect device
- 10 Subjects as listed in Table 4.1

Procedure:

1. Kinect is setup as mentioned in Section 3.4.
2. Subject will be required to walk forth and back at his/her normal pace in the designated walking path line with right foot as starting foot.
3. The whole operations is recorded with frame rate of 30 samples/second.
4. Deviation percentage and severity level are recorded to be analysed.
5. Step 2 to 4 is repeated by subject emulating abnormal gait with the reference to the videos to verify the validity of deviation percentage and severity level computed by the system.

Results:

Table 4.8 - Results of Quantitative Gait Evaluation System

	Gait Evaluation Info										Outcome Result
	Spatio-Temporal Parameter								Gait Feature		
Emulated Pattern	**Stride Length (m)**	**Left Step Length (m)**	**Right Step Length (m)**	**Step Width (m)**	**Cycle Time (s)**	**Left Step Time (s)**	**Right Step Time (s)**	**Speed (m/s)**	**Body Posture**	**Arm Swing**	**Gait Status**
	Normal										
-	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (5.66%)	NORMAL (0%)	LOW (10.78%)	√	√	**NORMAL (2.06%)**
-	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	LOW (20%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	√	X	**NORMAL (2.5%)**
-	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (3.20%)	NORMAL (9.68%)	NORMAL (1.61%)	NORMAL (0%)	√	X	**NORMAL (1.81%)**
-	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0.8%)	NORMAL (0%)	NORMAL (6.45%)	NORMAL (0%)	X	X	**NORMAL (0.91%)**
-	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	√	√	**NORMAL (0%)**
	Abnormal										
Limping; Dragging Feet	LOW (15.48%)	MEDIUM (32.56%)	NORMAL (0%)	NORMAL (0%)	MEDIUM (22.78%)	MEDIUM (43.04%)	NORMAL (2.53%)	MEDIUM (40.32%)	√	√	**ABNORMAL LOW (19.59%)**
Wide Step Width; No Arm Swing	MEDIUM (20.69%)	MEDIUM (20.93%)	LOW (18.60%)	HIGH (86.67%)	LOW (13.29%)	NORMAL (0%)	MEDIUM (27.85%)	MEDIUM (37.10%)	√	X	**ABNORMAL MEDIUM (28.27%)**
Narrow Step Width; Short Step Length; No Arm Swing; Body not upright	LOW (13.79%)	LOW (16.28%)	LOW (16.28%)	MEDIUM (40%)	HIGH (120.25%)	HIGH (108.86%)	HIGH (131.65%)	HIGH (66.13%)	X	X	**ABNORMAL HIGH (64.16%)**

Table 4.9 - Results of Quantitative Gait Evaluation System (Continued)

	Gait Evaluation Info										Outcome Result
	Spatio-Temporal Parameter								Gait Feature		
Emulated Pattern	**Stride Length (m)**	**Left Step Length (m)**	**Right Step Length (m)**	**Step Width (m)**	**Cycle Time (s)**	**Left Step Time (s)**	**Right Step Time (s)**	**Speed (m/s)**	**Body Posture**	**Arm Swing**	**Gait Status**
	Abnormal										
No Arm Swing; Circumduction of Right Leg	MEDIUM (26.44%)	MEDIUM (37.21%)	LOW (13.95%)	MEDIUM (26.67%)	HIGH (80.38%)	HIGH (79.75%)	HIGH (81.01%)	HIGH (62.90%)	√	X	**ABNORMAL HIGH (51.04%)**
Knees Stuck Together when Walking	NORMAL (9.20%)	NORMAL (0%)	LOW (13.95%)	HIGH (80%)	HIGH (66.46%)	HIGH (78.48%)	HIGH (54.43%)	MEDIUM (48.39%)	√	√	**ABNORMAL MEDIUM (43.86%)**
Lift Leg Higher than Normal; Dragging Feet	NORMAL (4.60%)	NORMAL (6.98%)	NORMAL (0%)	NORMAL (0%)	MEDIUM (22.16%)	HIGH (65.83%)	MEDIUM (21.52%)	MEDIUM (40.32%)	√	√	**ABNORMAL MEDIUM (20.18%)**
Lurch from Both Sides while Walking	LOW (19.54%)	LOW (11.63%)	NORMAL (4.65%)	NORMAL (0%)	LOW (14.56%)	NORMAL (6.33%)	MEDIUM (22.78%)	MEDIUM (37.10%)	X	√	**ABNORMAL LOW (14.57%)**
Swaying; Wide Step Width	NORMAL (0%)	NORMAL (0%)	NORMAL (4.65%)	HIGH (66.67%)	LOW (14.56%)	MEDIUM (27.85%)	NORMAL (1.27%)	LOW (16.13%)	X	√	**ABNORMAL LOW (16.39%)**

Note (s):

Body Posture : √ = Upright; X = Not Upright

Arm Swing : √ = Normal; X = Loss of Arm Swing

Severity Level:

- NORMAL (0% <= Deviation <=10%)
- ABNORMAL – LOW (10% < Deviation <=20%)
- ABNORMAL – MEDIUM (20% < Deviation <=50%)
- ABNORMAL – HIGH (Deviation > 50%)

Discussion:

Abnormality of the subject's gait is judged based on the ten features described. Quantitative measurement for eight spatio-temporal gait parameters are displayed whereas gait features, i.e. body posture and arm swing will only indicate the condition of the abnormality (either normal or abnormal). Deviation percentage is calculated to determine the severity level based on the equation in Section 3.3.5. Therefore, the severity level of gait parameters and the average deviation percentage are also determined. Based on the results in Tables 4.8 and 4.9, respective severity levels are correctly identified. Thus, the system is proved to be able to distinguish the normal gait and the abnormal gait.

Conclusion:

The overall system designed for the categorisation of gait abnormality based on deviation percentage and severity level shows satisfaction results as per the design objective.

4.4.2 GAIT DEVIATION PATTERN WITH ASSOCIATED SIGN

Theoretical Background:

Selection of associated signs is required to further classify the types of gait deviation pattern as in Sections 2.2.4 and 3.3.4. Gait deviation pattern could not be determined solely on spatio-temporal parameters. Hence, observational-based associated signs are added to aid physiotherapist in identifying the specific gait deviation pattern. This will assist him/her to create a rehabilitation plan for the patient.

Objective:

- To estimate the gait deviation pattern with the identification of associated signs for eight emulated patterns.

Hypothesis:

The overall system designed for gait evaluation should have high performance in categorising the abnormality of gait and further classifying the gait deviation pattern.

Apparatus required:

- Recorded gaits of 10 Subjects in experiment 4.4.1

Procedure:

1. Following with experiment 4.4.1, a physiotherapist is invited to identify the associated signs based on the recorded gaits.
2. Associated sign will be chosen from the GUI.
3. The system will classify the type of gait deviation pattern.

Table 4.10 - Categorisation of Abnormality of Gait and Estimation of Gait Deviation Pattern

	Gait Evaluation Info										Outcome Result		Outcome Result
	Spatio-Temporal Parameter								Gait Feature				
Emulated Pattern	**Stride Length (m)**	**Left Step Length (m)**	**Right Step Length (m)**	**Step Width (m)**	**Cycle Time (s)**	**Left Step Time (s)**	**Right Step Time (s)**	**Speed (m/s)**	**Body Posture**	**Arm Swing**	**Gait Status**	**Associated Sign Selected**	**Gait Deviation Pattern**
	Normal												
-	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (5.66%)	NORMAL (0%)	LOW (10.78%)	√	√	**NORMAL (2.06%)**	-	-
-	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	LOW (20%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	√	X	**NORMAL (2.5%)**	-	-
-	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (3.20%)	NORMAL (9.68%)	NORMAL (1.61%)	NORMAL (0%)	√	X	**NORMAL (1.81%)**	-	-
-	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0.8%)	NORMAL (0%)	NORMAL (6.45%)	NORMAL (0%)	X	X	**NORMAL (0.91%)**	-	-
-	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	NORMAL (0%)	√	√	**NORMAL (0%)**	-	-
	Abnormal												
Limping; Dragging Feet	LOW (15.48%)	MEDIUM (32.56%)	NORMAL (0%)	NORMAL (0%)	MEDIUM (22.78%)	MEDIUM (43.04%)	NORMAL (2.53%)	MEDIUM (40.32%)	√	√	**ABNORMAL LOW (19.59%)**	Reduced knee flexion	**Antalgic gait**
Wide Step Width; No Arm Swing	MEDIUM (20.69%)	MEDIUM (20.93%)	LOW (18.60%)	HIGH (86.67%)	LOW (13.29%)	NORMAL (0%)	MEDIUM (27.85%)	MEDIUM (37.10%)	√	X	**ABNORMAL MEDIUM (28.27%)**	Hard to turn body; Irregular, jerky or involuntary movements	**Cerebellar Ataxia gait**
Narrow Step Width; Short Step Length; No Arm Swing; Body not upright	LOW (13.79%)	LOW (16.28%)	LOW (16.28%)	MEDIUM (40%)	HIGH (120.25%)	HIGH (108.86%)	HIGH (131.65%)	HIGH (66.13%)	X	X	**ABNORMAL HIGH (64.16%)**	Hard to turn body; Shuffling gait pattern	**Parkinso-nian gait**

Table 4.11 - Categorisation of Abnormality of Gait and Estimation of Gait Deviation Pattern (Continued)

	Gait Evaluation Info										Outcome Result		Outcome Result
	Spatio-Temporal Parameter								Gait Feature				
Emulated Pattern	**Stride Length (m)**	**Left Step Length (m)**	**Right Step Length (m)**	**Step Width (m)**	**Cycle Time (s)**	**Left Step Time (s)**	**Right Step Time (s)**	**Speed (m/s)**	**Body Posture**	**Arm Swing**	**Gait Status**	**Associated Sign Selected**	**Gait Deviation Pattern**
	Abnormal												
No Arm Swing; Circum-duction of Right Leg	MEDIUM (26.44%)	MEDIUM (37.21%)	LOW (13.95%)	MEDIUM (26.67%)	HIGH (80.38%)	HIGH (79.75%)	HIGH (81.01%)	HIGH (62.90%)	√	X	**ABNORMAL HIGH (51.04%)**	Circumduc-tion gait pattern	**Hemiparetic gait**
Knees Stuck Together when Walking	NORMAL (9.20%)	NORMAL (0%)	LOW (13.95%)	HIGH (80%)	HIGH (66.46%)	HIGH (78.48%)	HIGH (54.43%)	MEDIUM (48.39%)	√	√	**ABNORMAL MEDIUM (43.86%)**	Scissors gait pattern	**Scissors gait**
Lift Leg Higher than Normal; Dragging Feet	NORMAL (4.60%)	NORMAL (6.98%)	NORMAL (0%)	NORMAL (0%)	MEDIUM (22.16%)	HIGH (65.83%)	MEDIUM (21.52%)	MEDIUM (40.32%)	√	√	**ABNORMAL MEDIUM (20.18%)**	Foot Drop; High Stepping	**Steppage gait**
Lurch from Both Sides while Walking	LOW (19.54%)	LOW (11.63%)	NORMAL (4.65%)	NORMAL (0%)	LOW (14.56%)	NORMAL (6.33%)	MEDIUM (22.78%)	MEDIUM (37.10%)	X	√	**ABNORMAL LOW (14.57%)**	Hip hiking	**Trendelen-burg gait**
Swaying; Wide Step Width	NORMAL (0%)	NORMAL (0%)	NORMAL (4.65%)	HIGH (66.67%)	LOW (14.56%)	MEDIUM (27.85%)	NORMAL (1.27%)	LOW (16.13%)	X	√	**ABNORMAL LOW (16.39%)**	Hard to balance	**Waddling gait**

Note (s):

Body Posture : √ = Upright; X = Not Upright

Arm Swing : √ = Normal; X = Loss of Arm Swing

Severity Level:

- NORMAL (0% <= Deviation <=10%)
- ABNORMAL – LOW (10% < Deviation <=20%)
- ABNORMAL – MEDIUM (20% < Deviation <=50%)
- ABNORMAL – HIGH (Deviation > 50%)

Discussion:

In Experiment 4.4.1, the abnormality of the subject's gait is categorised based on the ten features. In this experiment, a physiotherapist is invited to select the associated signs based on the recorded gaits. The results show that this system could make an estimation of the gait deviation pattern based on the problematic gait parameters and the selected associated signs. The identified gait deviation patterns with such associated signs are agreed by the physiotherapist. However, the system is designed to show 'Undefined gait' if the gait parameter deviation and associated sign are mismatched to the pre-defined values.

Conclusion:

The overall system designed for the categorisation of gait abnormality and estimation of gait deviation pattern demonstrates the correct result of gait deviation pattern based on the measured gait parameters and associated signs.

CHAPTER 5

CONCLUSION AND RECOMMENDATION FOR FUTURE WORK

5.1 CONCLUSION

To improve a patients' gait, physiotherapist must first determine what gait deviations are occurring and which is the problematic features. Gait evaluation is an important assessment which can reveal crucial information to pinpoint the cause of gait deviation. The aim and objectives of this project to obtain a quantitative measurement in terms of temporal and spatial parameters using a markerless motion capturing system, the Kinect system are achieved. Kinect sensor is setup to capture the skeletal joints of subject based on the X, Y, Z coordinates in 3D space. Besides, algorithms developed in Microsoft Azure Machine Learning Studio enable the ease in estimation of spatial and temporal gait parameters and the categorisation of gait. 10 healthy participants were approached to involve in the experiments. To test the validity of the system, some participants are asked to emulate the pattern of the abnormal gait. The results obtained show that the objective is accomplished favourably with a high similarity of 93%. Besides, with the opinion from a physiotherapist on the associated signs of gait obtained, a deviation pattern can be obtained and assist the expert to design a rehabilitation plan for the patient.

5.2 ADVANTAGE

- Gait evaluation system only requires a minimal amount of equipment, space and time.
- Provide quantitative spatio-temporal gait data.
- Environmental factor such as lighting condition does not affect the skeletal tracking efficiency of Kinect.

5.3 LIMITATION

- Unable to provide measures in real-time.
- Identification of gait deviation pattern is limited to only 8 types.
- Unable to perform skeletal tracking accurately when joint points are blocked owing to the projection of Kinect.

5.4 RECOMMENDATION FOR FUTURE WORK

Kinect sensor V2 could be used for future improvement as it offers a skeletal tracking with 26 joints position, which is more precise than the Kinect sensor V1 used in this project (Laxman Chavan, Y., 2011). Besides, according to the invited physiotherapist, Mr. Chew (Chew, K.H., 2019), a gait evaluation system with frontal tracking view would be better as side view tracking may causes inaccuracies owing to the limitation of Kinect sensor. A possible future improvement could be to perform the same study using Kinect but to define which variables and gait characteristics contribute to an abnormal gait in patients with gait abnormalities instead of healthy subjects simulating gait deviation patterns. Another choice for possible future improvement could be to develop a software that will automatically deliver all these steps in real time (when the subject is walking), accelerating the process. In this context, a feasible project could consist of creating a user-friendly software to provide users with real-time feedback on their walking performance, such as posture correction if necessary. Kinect could provide the user with a sort of "mirror" through this scheme, providing the needed real-time hints for maximum effectiveness.

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APPENDIX A : PROJECT COSTING

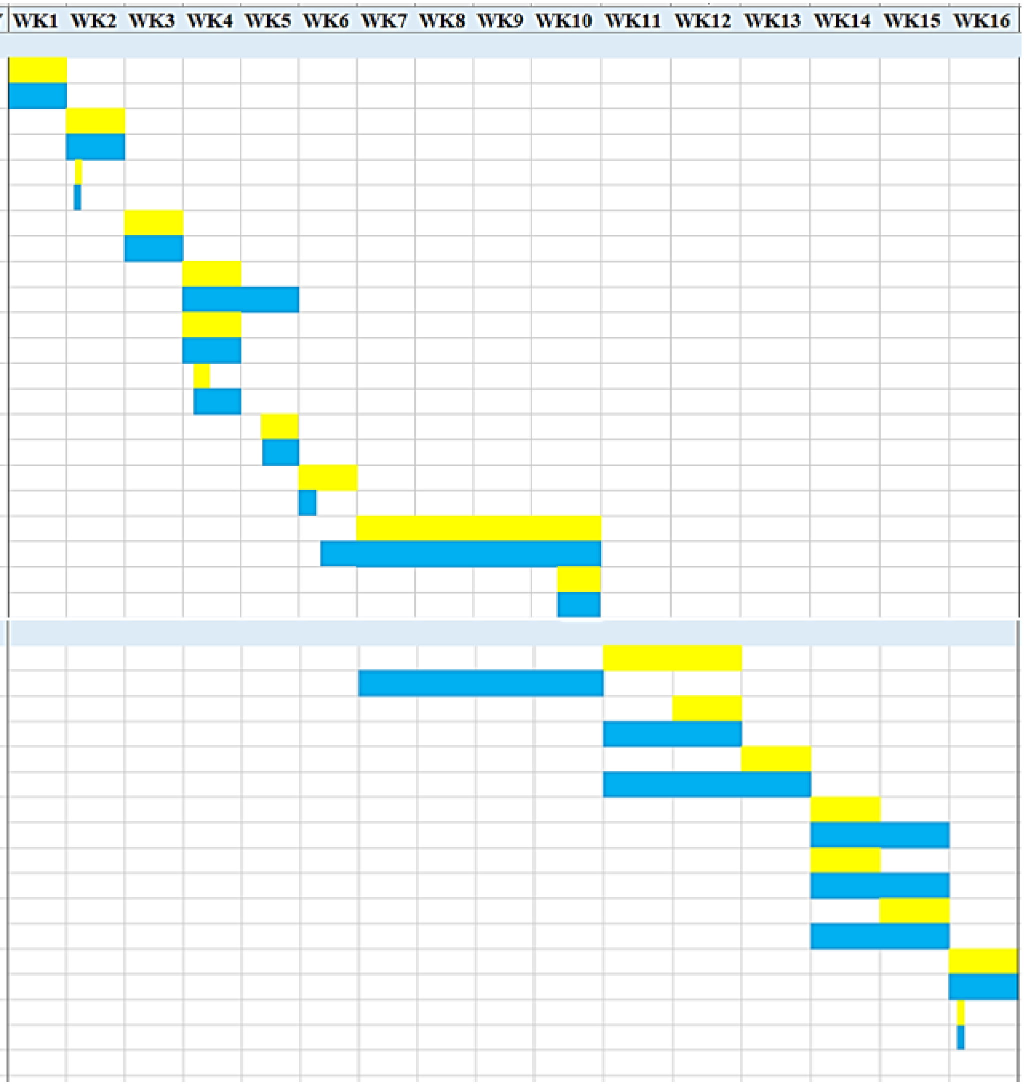
Items	Unit Cost (RM)	Actual Cost (RM)	Remarks
Kinect for Windows V1 Sensor	502.00	0	Loan
Personal Computer	2799.00	0	Self-owned
Kinect for Windows Developer Toolkit Browser v1.7.0	0	0	Freeware
Microsoft Visual Studio Express 2017	0	0	Freeware
Subscription for Microsoft Azure	$2.00 per compute hour	0	Free subscription provided : ‘Azure for student’
Total	**3301.00**	**0**	

Subscription is needed to provide access to Azure products. ‘Azure for Students’ gives $100 credit for 12 months and access to more than 25 free products, including compute, network, storage, and databases. The products provided in Azure are free according to their period of availability and service limitations as long as the Azure subscription has more than $0 available credit. Academic status is verified through KDU student’s email address in order to obtain the free subscription of ‘Azure for Student’.

APPENDIX B : GANNT CHART

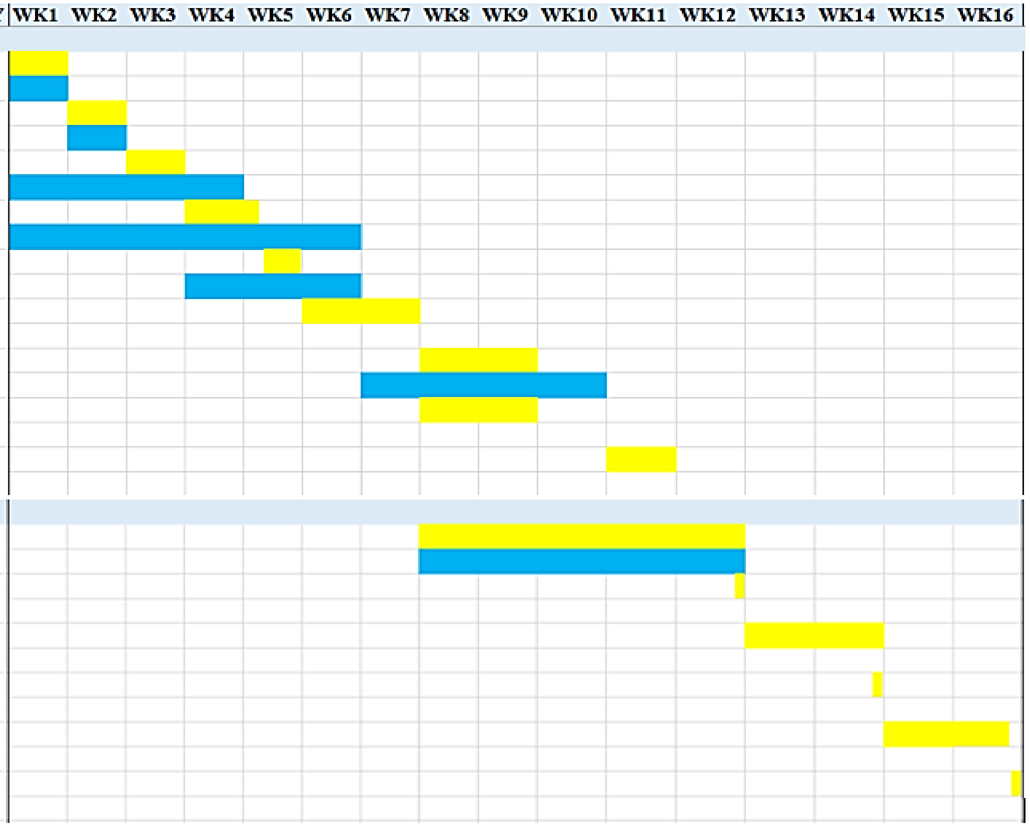
(a) Gantt Chart for Semester 1

WBS	TASK	START	END	DAY
1	**Project Planning**			
1.1	Project title research	Mon 1/21/19	Fri 1/25/19	5
1.2	Background research	Sat 1/26/19	Sun 2/03/19	9
1.3	Discussion with supervisor	Tue 1/29/19	Tue 1/29/19	1
1.4	Semester break (Chinese New Year)	Mon 2/04/19	Sun 2/10/19	7
1.5	Project conceptual design	Mon 2/11/19	Sun 2/17/19	7
1.6	Component survey	Mon 2/11/19	Sun 2/17/19	7
1.7	Ethics form documentation	Thu 2/14/19	Sun 2/17/19	4
1.8	Ehics form submission	Wed 2/20/19	Wed 2/20/19	1
1.9	Project costing analysis	Mon 2/25/19	Sun 3/03/19	7
1.10	Project Planning Document (PPD) documentation	Mon 3/04/19	Sun 3/31/19	28
1.11	PPD submission	Thu 4/04/19	Thu 4/04/19	1
2	**Project Implemantation**			
2.1	Microsoft Kinect Exploration	Mon 4/01/19	Sun 4/14/19	14
2.2	Kinect SDK learning	Mon 4/08/19	Sun 4/14/19	7
2.3	Software learning	Mon 4/15/19	Sun 4/21/19	7
2.4	Data acquisition method research	Mon 4/22/19	Sun 4/28/19	7
2.5	Body traking analysis	Mon 4/22/19	Sun 4/28/19	7
2.6	Skeletal joint data extraction analysis	Mon 4/29/19	Sat 5/04/19	6
2.7	Study Break	Mon 5/06/19	Sun 5/12/19	7
2.8	Project mid-term assessment	Tue 5/07/19	Tue 5/07/19	1
2.9	Examination Period	Mon 5/13/19	Sun 5/26/19	14



(b) Gantt Chart for Semester 2

WBS	TASK	START	END	DAY
3	**Project Implementation**			
3.1	Enhanced motion tracking system	Mon 5/27/19	Sun 6/02/19	7
3.2	Semester break (hari Raya Puasa)	Mon 6/03/19	Sun 6/09/19	7
3.3	Graphical user interface design	Mon 6/10/19	Sun 6/16/19	7
3.4	Gait features extraction	Mon 6/17/19	Mon 6/24/19	8
3.5	Gait classification	Tue 6/25/19	Sun 6/30/19	6
3.6	Feedaback solution	Mon 7/01/19	Sun 7/14/19	14
3.7	Project accuracy and consistency test	Mon 7/15/19	Sun 7/28/19	14
3.8	Troubleshooting and debugging	Mon 7/15/19	Sun 7/28/19	14
3.9	Accomplish new features	Mon 8/05/19	Sun 8/11/19	7
4	**Project Evaluation**			
4.1	Final project report documentation	Mon 7/15/19	Wed 8/14/19	31
4.2	Final project report and log book submission	Thu 8/15/19	Thu 8/15/19	1
4.3	Poster and presentation preparation	Fri 8/16/19	Thu 8/29/19	14
4.4	Internal poster presentation	Fri 8/30/19	Fri 8/30/19	1
4.5	Evaluate project and finalization	Mon 9/02/19	Tue 9/10/19	9
4.6	Final interview by UNN	Wed 9/11/19	Wed 9/11/19	1



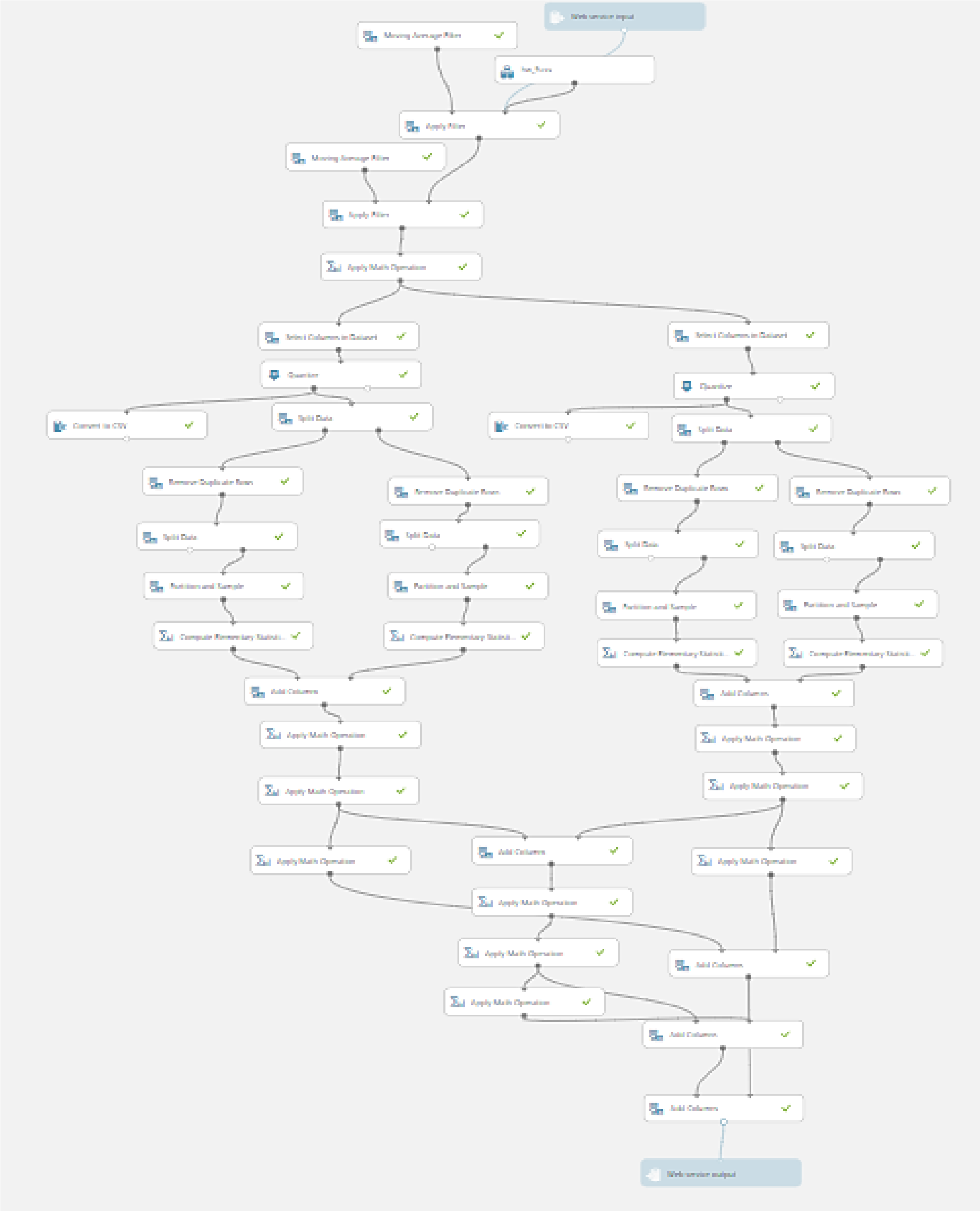
Note(s):

Planned time frame (yellow) | Actual (blue)

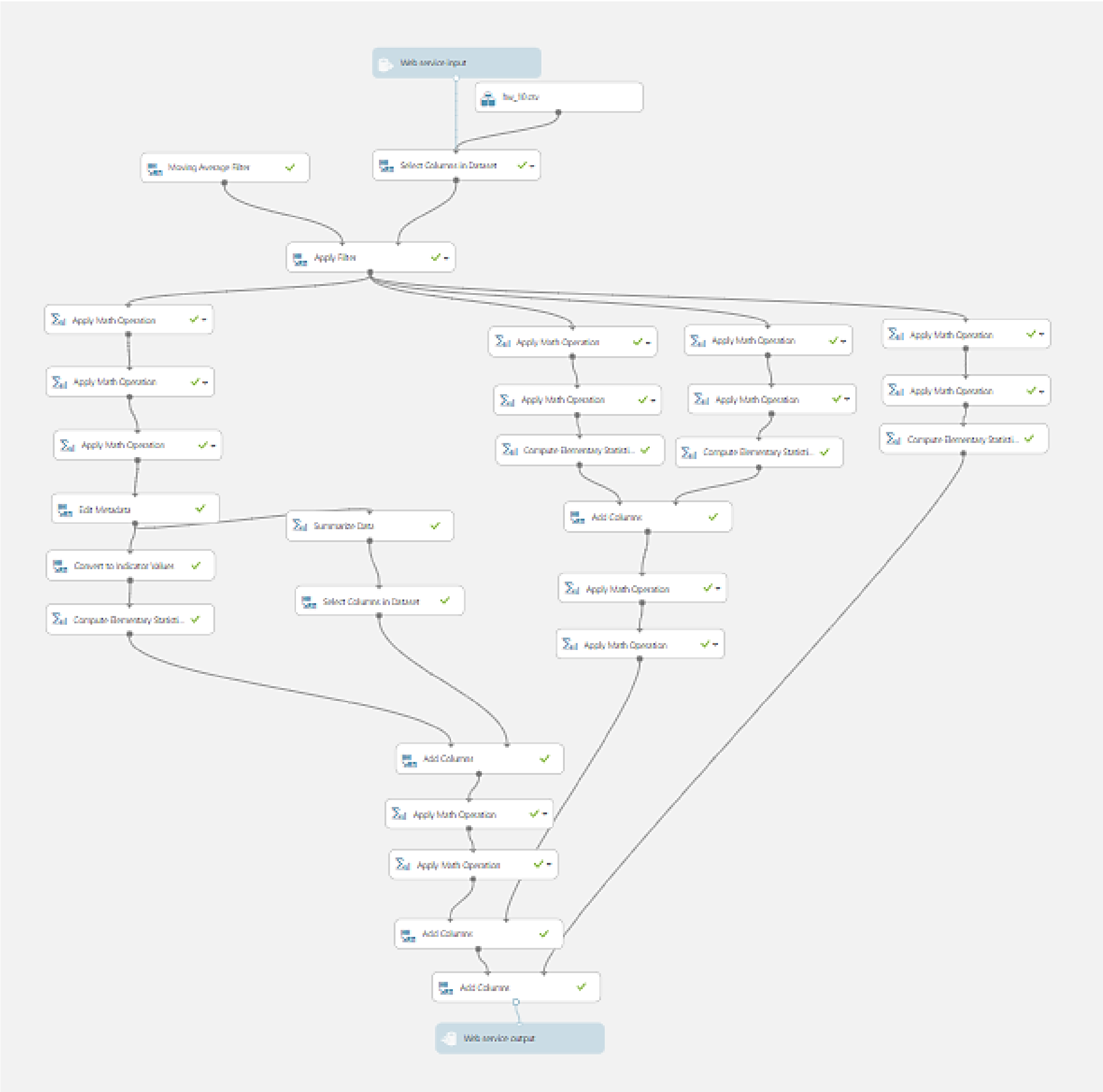
The project task has been split into two semester time frame which is Semester 1 (January 2019 – May 2019) and Semester 2 (May 2019 – September 2019). The tasks have been planned and are executed according to the Gantt Chart above. The main tasks were split into sub-tasks so that a detailed plan can be produce.

APPENDIX C : DATA PROCESSING ALGORITHM

(a) Snapshot of Published Experiment in Microsoft Azure Machine Learning Studio



(b) Snapshot of Published Experiment in Microsoft Azure Machine Learning Studio



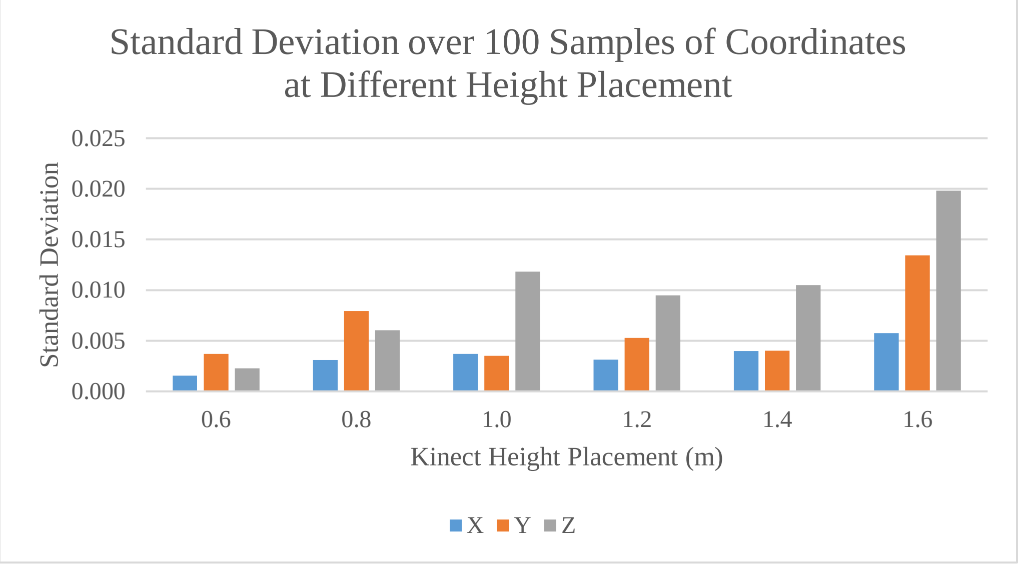
APPENDIX D : EXPERIMENTAL RESULTS

APPENDIX D.1 : SETUP AND PROCEDURE OF THE PROJECT

1. **Kinect Placement Height and Distance**

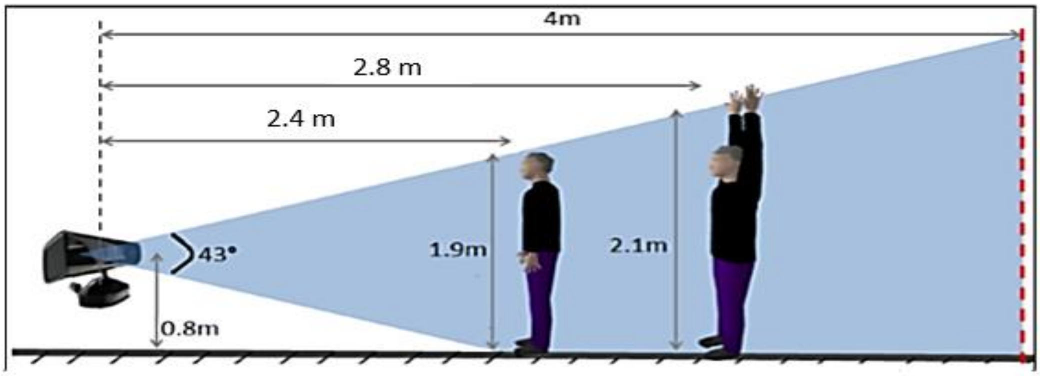
Objectives:

- To set a fix Kinect placement height and distance for skeletal tracking in gait evaluation system



The result shown above are the standard deviation for all X, Y, Z coordinates of right foot joint at different height placement capable of tracking full body of the subject. Kinect device shows high precision when it is placed at a flat and stable surface in between 0.6m to 0.8m off the floor. Therefore, the Kinect must be placed at a range of 0.6m to 0.8m off the floor when performing video capturing of the gait.

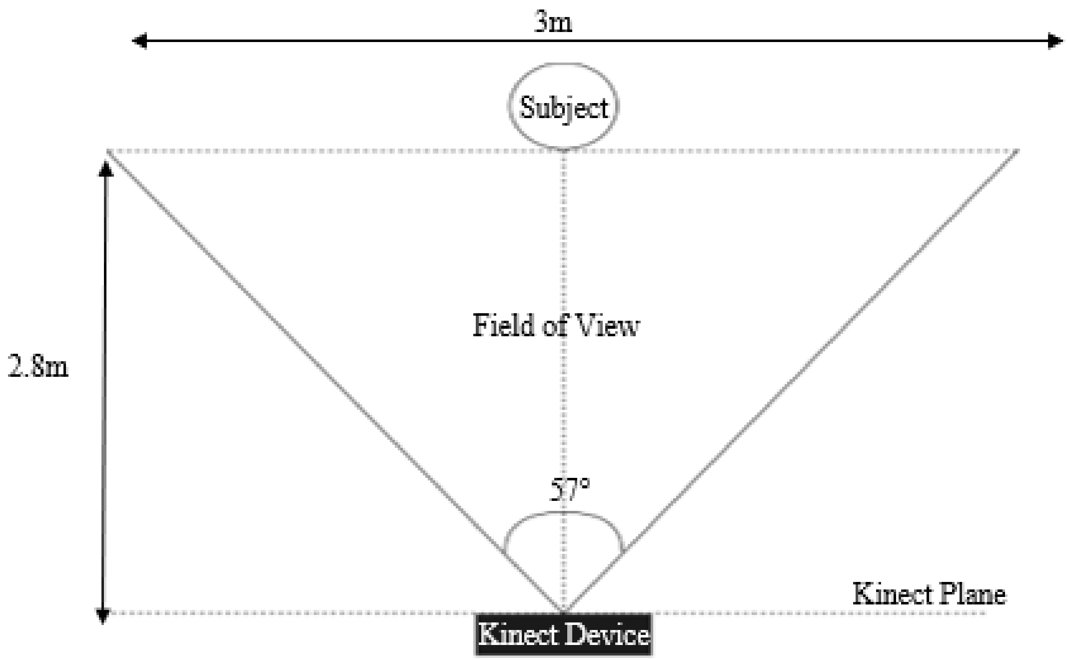
As the minimum tracking range calculated to track a full body is 2.8m as illustrated in figure below(User Guide for Single Depth Sensor Configuration, 2012; Lim (2018)). The tracking range set for gait evaluation system is between 2.8m to 3.5m away from Kinect IR sensor.



2. **Walking Path Line**

Objectives:

- To set a fix walking path line for the platform of gait evaluation system.

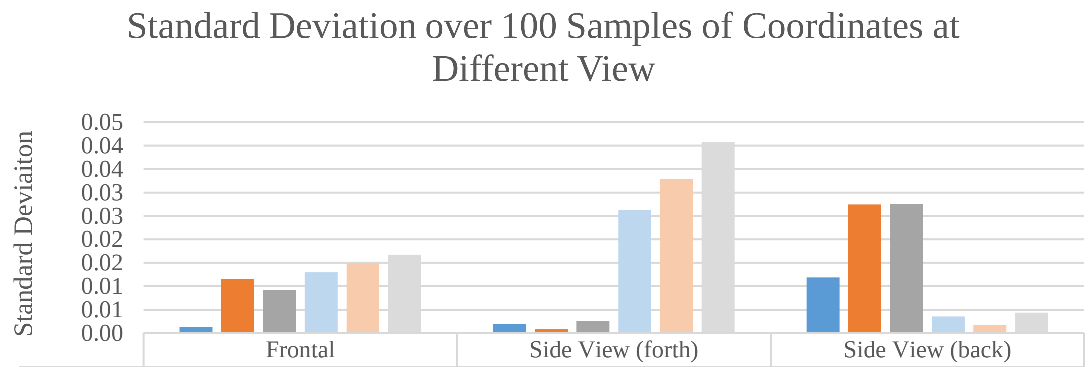


Since Kinect has an angle of 57° of horizontal field of view, assuming that Kinect is placed at 2.8 metres away from the subject, the calculated width of the captured area for Kinect would be approximately 3 metres as shown in figure shown. Skeleton figure will be clipped if the subject is too closed to the boundary or outside the field of vision of IR depth sensor which will results in distortion of joint coordinates. Owing to the limitations of Kinect sensor and the stride length for a normal gait person shouldn't be more than 1.50 metres which mentioned in Section 2.2.2, hence the walking path line for this project is fixed at 2.4 metres long.

3. Kinect Tracking View

Objectives:

- To determine the precision of joint position captured by Kinect sensor at different tracking view.



	Frontal	Side View (forth)	Side View (back)
X (Left)	0.001	0.002	0.012
Y (Left)	0.011	0.001	0.027
Z (Left)	0.009	0.003	0.028
X (Right)	0.013	0.026	0.004
Y (Right)	0.015	0.033	0.002
Z (Right)	0.017	0.041	0.004

From result shown above, the standard deviation of X, Y, Z coordinates shows variation at different angle where frontal view is when subject is facing directly at Kinect with 0° of angle while side view is when subject is standing at 90° to perpendicular of Kinect plane. The smallest deviation occurs when Kinect tracks the frontal view of subject. Standard deviation of coordinates increased when Kinect is tracking side view of subject as Kinect is unable to perform rendering pipeline accurately and the joint point detected is just an approximation of point which indicates inferred. However, the standard deviation for the description of each coordinates during side view still less than 2cm which is considered sufficiently accurate for gait evaluation.

(a) 100 Samples of Right Foot coordinate captured when Kinect is at different height placement.

Kinect Height (m)	Standard Deviation																										
	Reading 1						Reading 2						Reading 3						Mean								
	Left			Right			Left			Right			Left			Right			Left			Right			Average		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
0.6	0.0007	0.0022	0.0010	0.0002	0.0005	0.0005	0.0003	0.0006	0.0005	0.0066	0.0142	0.0106	0.0007	0.0018	0.0003	0.0007	0.0029	0.0008	0.0006	0.0015	0.0006	0.0025	0.0059	0.0040	0.0015	0.0037	0.0023
0.8	0.0136	0.0300	0.0304	0.0010	0.0062	0.0011	0.0005	0.0020	0.0007	0.0017	0.0042	0.0009	0.0007	0.0024	0.0010	0.0010	0.0028	0.0021	0.0050	0.0115	0.0107	0.0012	0.0044	0.0014	0.0031	0.0079	0.0060
1.0	0.0049	0.0045	0.0233	0.0032	0.0025	0.0049	0.0016	0.0010	0.0021	0.0045	0.0060	0.0132	0.0026	0.0009	0.0021	0.0055	0.0061	0.0252	0.0030	0.0021	0.0092	0.0044	0.0049	0.0145	0.0037	0.0035	0.0118
1.2	0.0014	0.0047	0.0119	0.0042	0.0006	0.0086	0.0010	0.0098	0.0116	0.0068	0.0120	0.0113	0.0014	0.0023	0.0023	0.0039	0.0023	0.0113	0.0013	0.0056	0.0086	0.0050	0.0050	0.0104	0.0031	0.0053	0.0095
1.4	0.0006	0.0018	0.0015	0.0010	0.0020	0.0122	0.0031	0.0021	0.0017	0.0056	0.0094	0.0115	0.0127	0.0049	0.0248	0.0009	0.0040	0.0111	0.0055	0.0029	0.0093	0.0025	0.0051	0.0116	0.0040	0.0040	0.0105
1.6	0.0016	0.0075	0.0025	0.0063	0.0256	0.0314	0.0070	0.0147	0.0225	0.0015	0.0053	0.0025	0.0003	0.0017	0.0015	0.0010	0.0023	0.0010	0.0091	0.0139	0.0323	0.0024	0.0129	0.0073	0.0057	0.0134	0.0198

(b) 100 Samples of Right Foot coordinate captured when Kinect is at different distance.

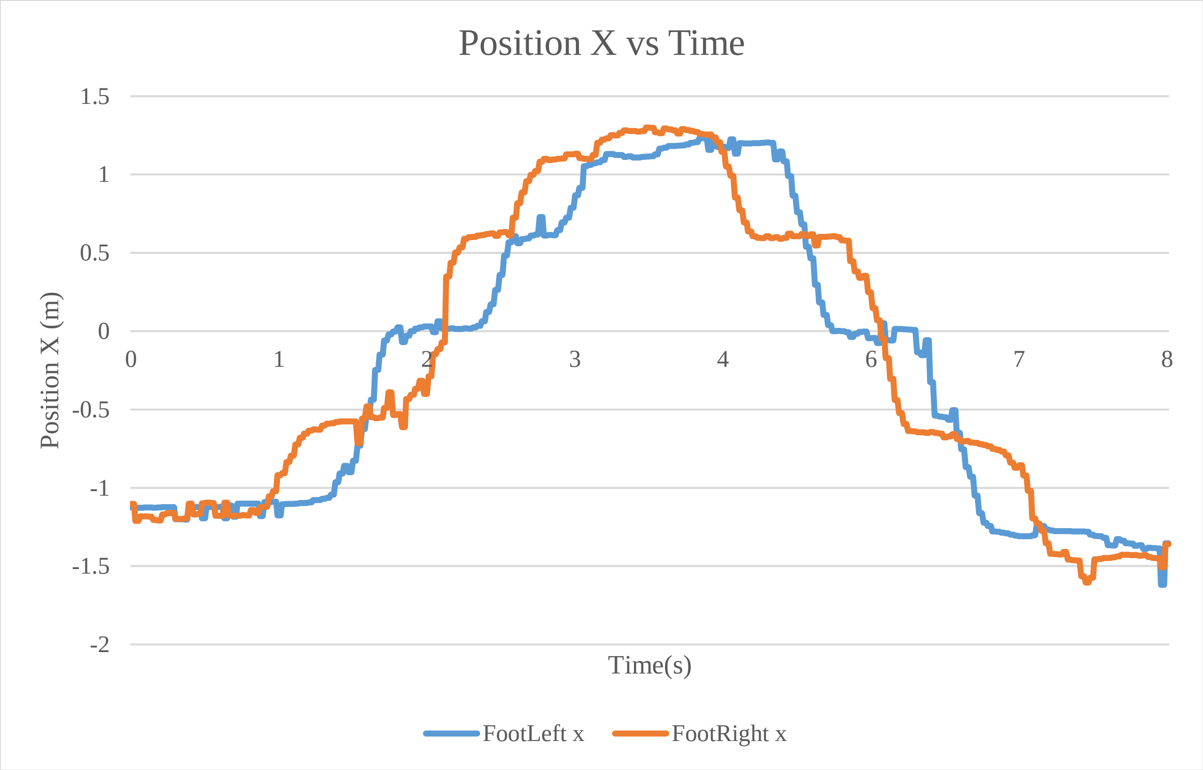
Actual Distance (m)	Measured Distance (m)						Mean		Tolerance		Error Percentage(%)		Average Error Percentage (%)
	Reading 1		Reading 2		Reading 3								
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	
0.5	0	0	0	0	0	0	–	–	–	–	–	–	–
1	0	0	0	0	0	0	–	–	–	–	–	–	–
1.5	1.47	1.48	1.46	1.48	1.48	1.50	1.47	1.49	0.03	0.01	1.95%	0.94%	1.44%
2	1.99	2.02	2.02	2.04	2.05	2.08	2.02	2.05	-0.52	0.55	-0.83%	-2.54%	-1.69%
2.5	2.55	2.58	2.54	2.57	2.57	2.56	2.56	2.57	-1.06	1.07	-2.23%	-2.96%	-2.60%
3	3.05	3.09	3.08	3.13	3.08	3.12	3.07	3.11	-1.57	1.61	-2.35%	-3.74%	-3.04%
3.5	3.62	3.68	3.61	3.66	3.62	3.67	3.62	3.67	-2.12	2.17	-3.33%	-4.91%	-4.12%
4	0	0	0	0	0	0	–	–	–	–	–	–	–
4.5	0	0	0	0	0	0	–	–	–	–	–	–	–
5	0	0	0	0	0	0	–	–	–	–	–	–	–

(c) 100 Samples of Right Foot coordinate captured when Kinect is at different tracking view.

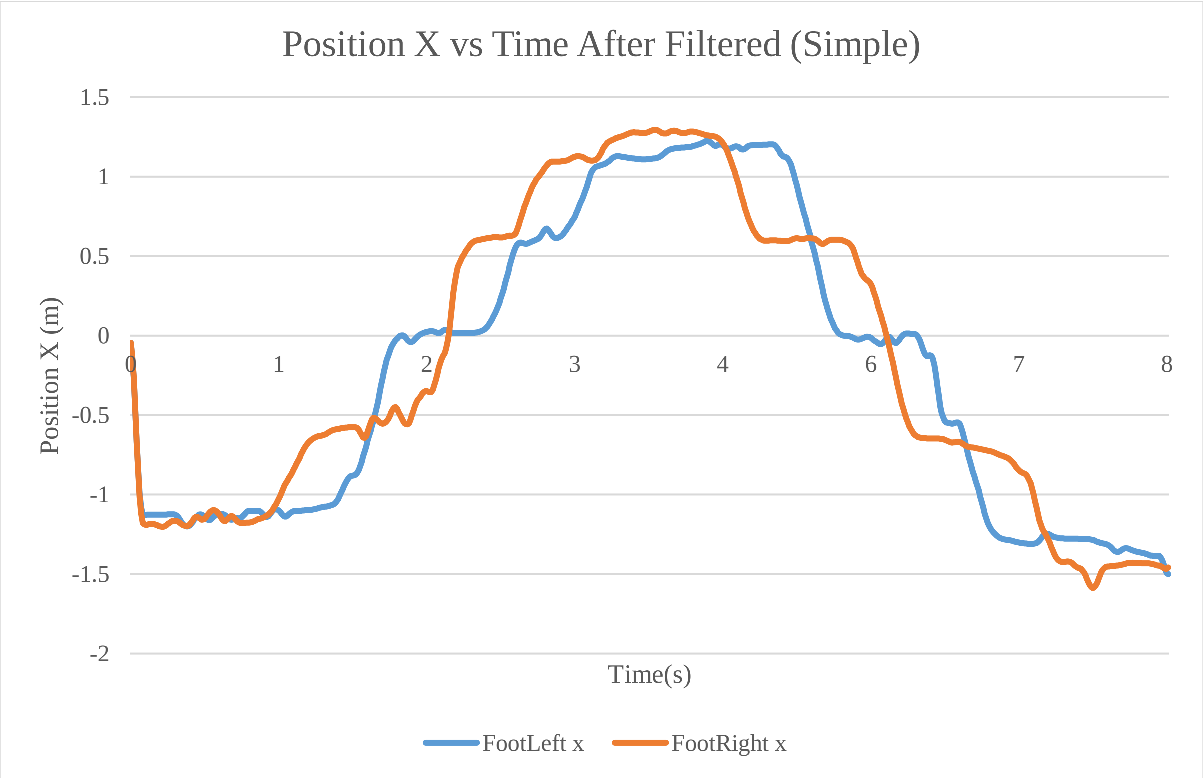
Kinect View	Standard Deviation																							
	Reading 1						**Reading 2**						**Reading 3**						**Mean**					
	Left			**Right**			**Left**			**Right**			**Left**			**Right**			**Left**			**Right**		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
Frontal	0.002	0.031	0.026	0.013	0.012	0.017	0.001	0.002	0.000	0.012	0.018	0.015	0.001	0.001	0.001	0.014	0.015	0.018	0.001	0.011	0.009	0.013	0.015	0.017
Side View (forth)	0.003	0.001	0.003	0.027	0.038	0.028	0.002	0.001	0.003	0.011	0.049	0.036	0.001	0.000	0.001	0.040	0.012	0.059	0.002	0.001	0.003	0.026	0.033	0.041
Side View (back)	0.006	0.019	0.014	0.004	0.001	0.006	0.014	0.017	0.032	0.001	0.002	0.002	0.015	0.046	0.036	0.005	0.002	0.005	0.012	0.027	0.028	0.004	0.002	0.004

APPENDIX D.2 : EXPERIMENT 4.2.2

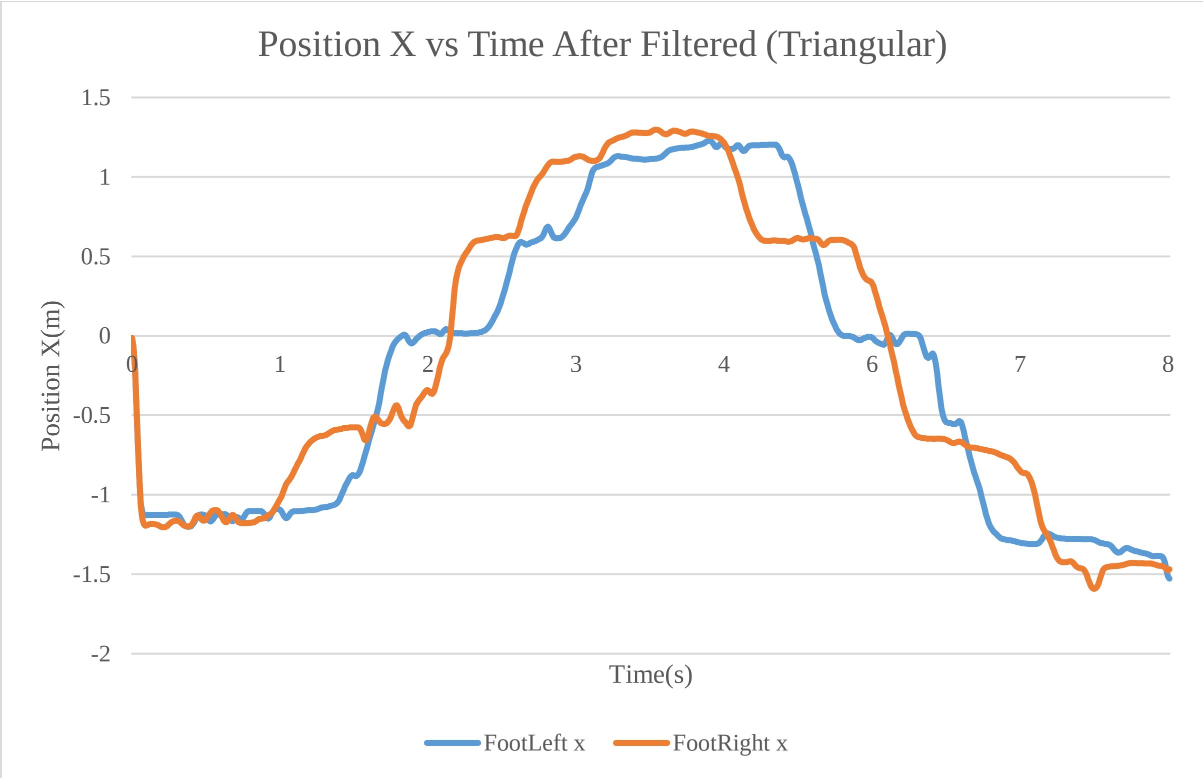
Raw Data before Moving Average Filtering



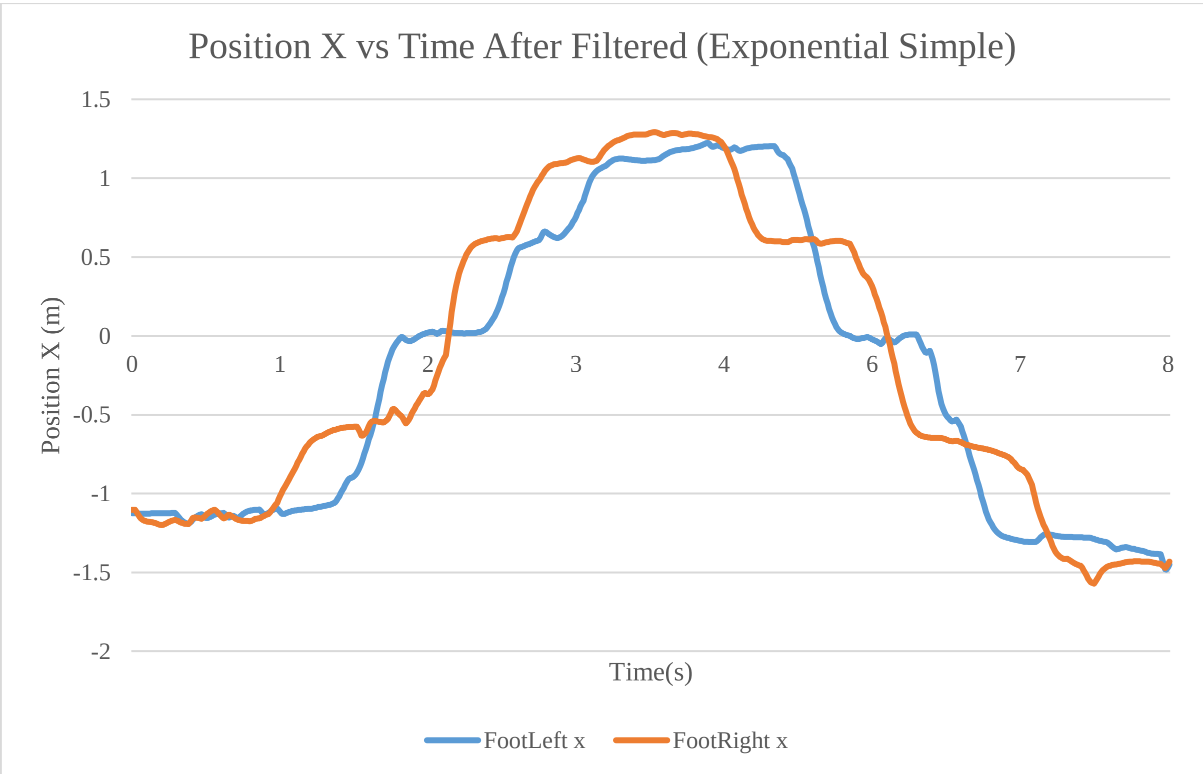
Smoothed Data by Different types of Moving Average Calculations



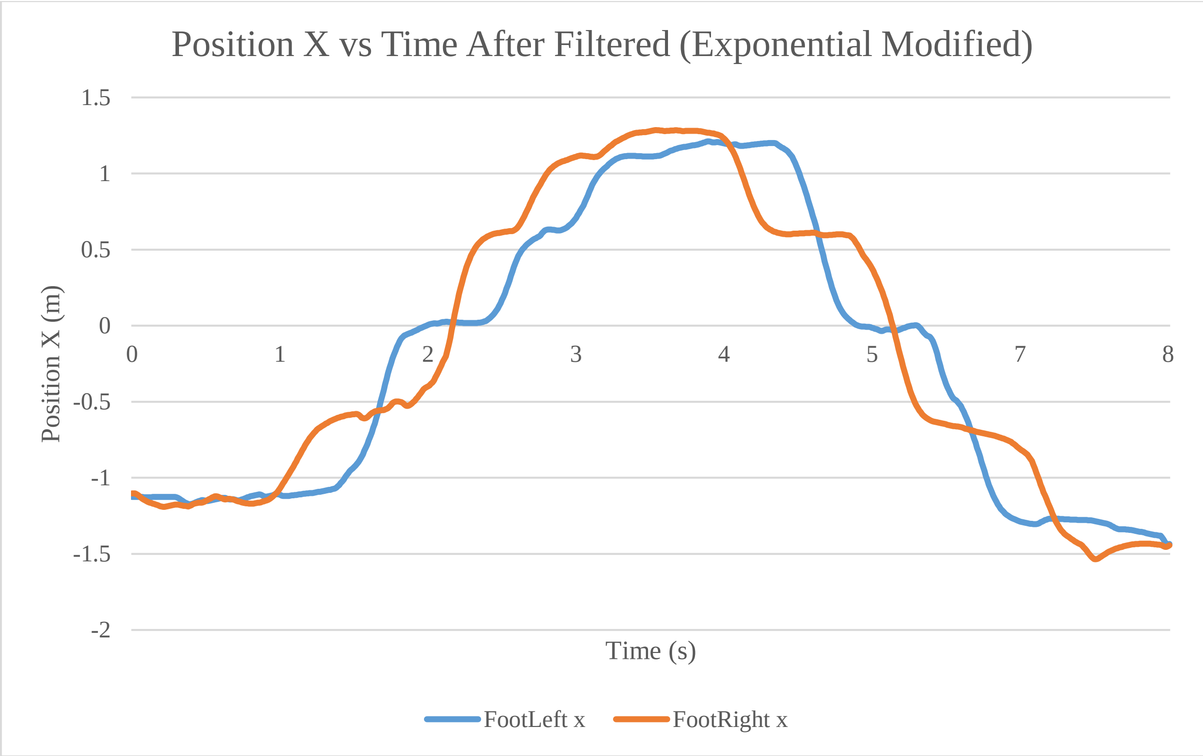
(a)


Position X vs Time After Filtered (Triangular)
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Position X(m)
0
1
2
3
4
6
7
8
Time(s)
FootLeft x
FootRight x

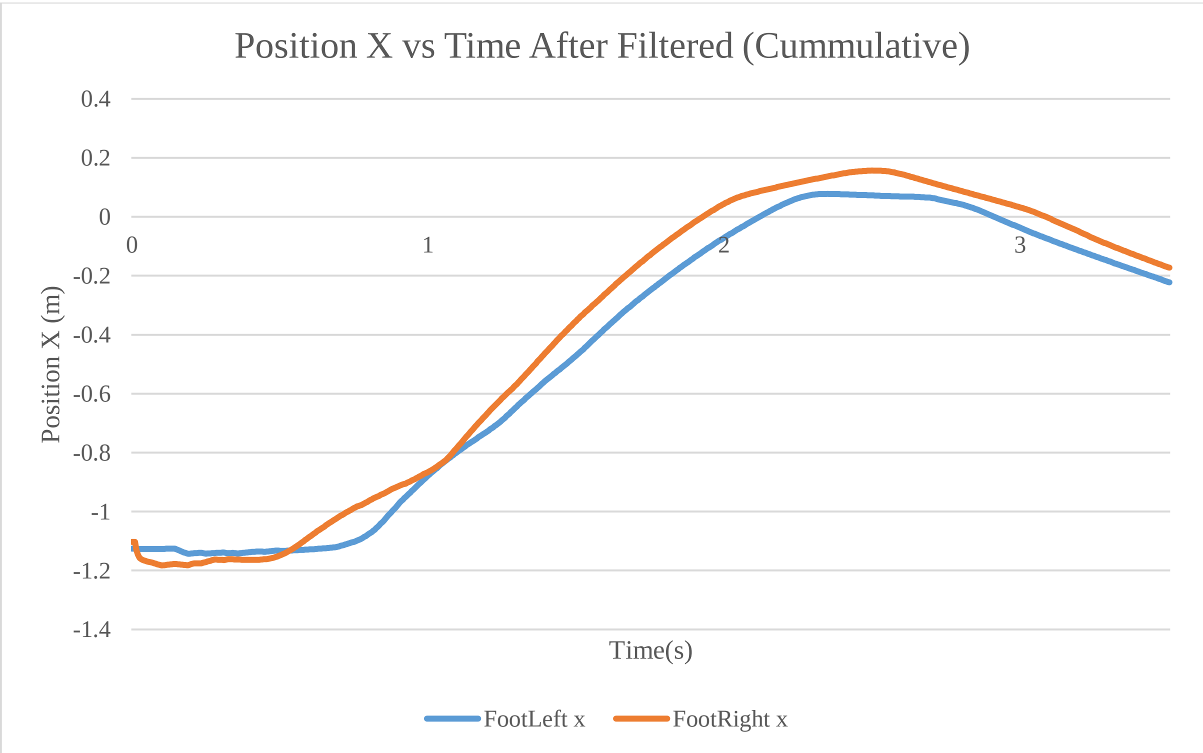
(b)


Position X vs Time After Filtered (Exponential Simple)
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Position X (m)
0
1
2
3
4
6
7
8
Time(s)
FootLeft x
FootRight x

(c)


Position X vs Time After Filtered (Exponential Modified)
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
7
8
Position X (m)
Time (s)
FootLeft x
FootRight x

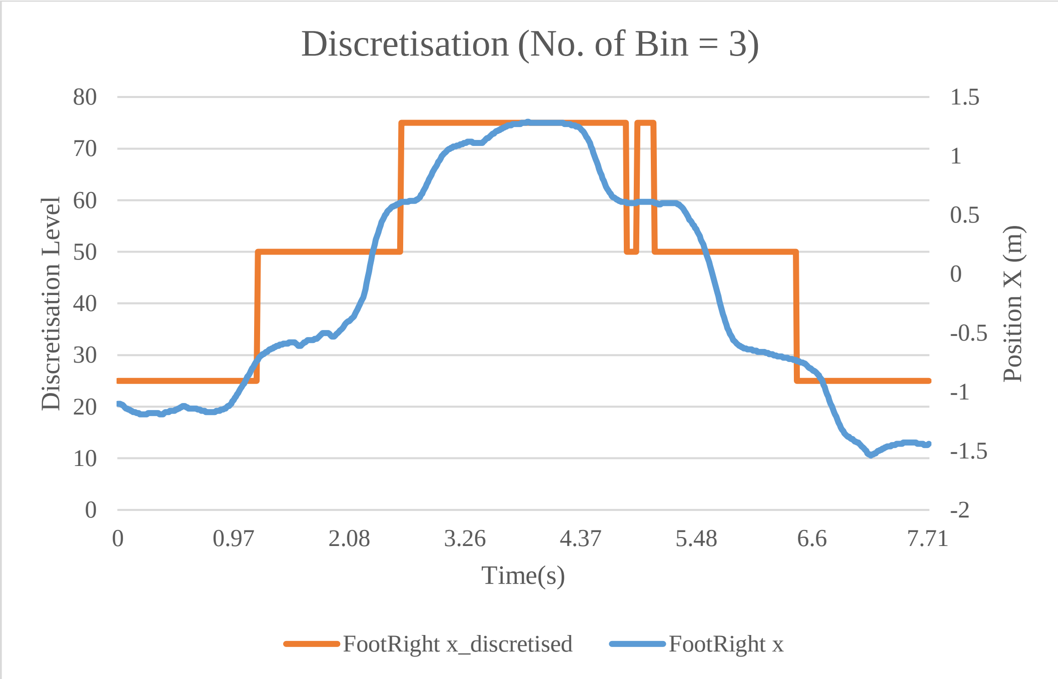
(d)


Position X vs Time After Filtered (Cummulative)
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
0
1
2
3
Position X (m)
Time(s)
FootLeft x
FootRight x

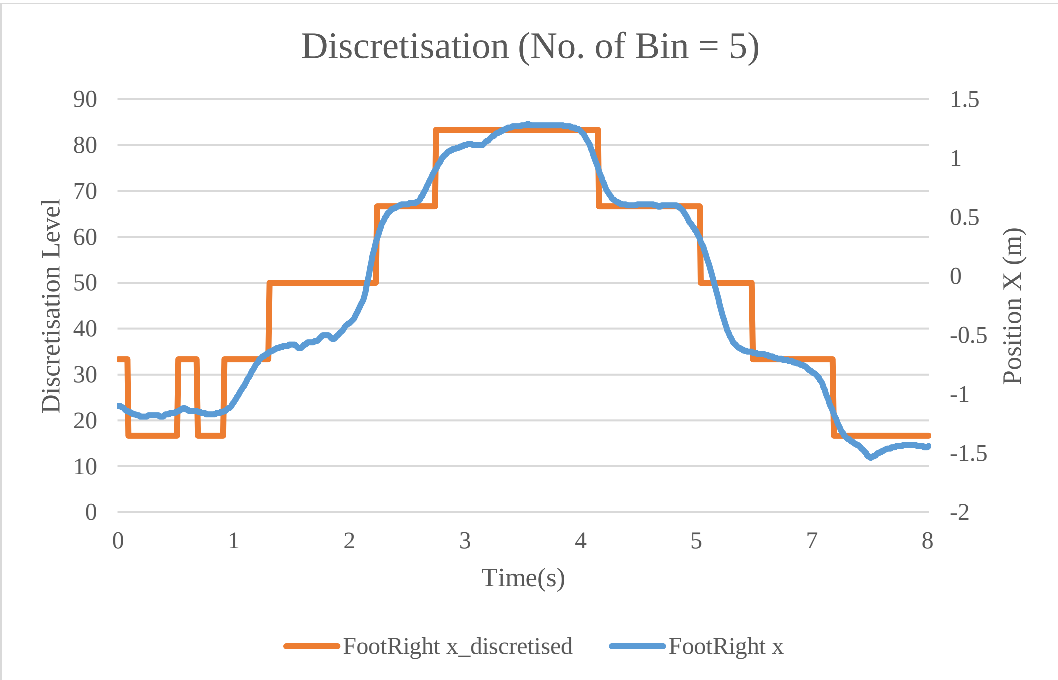
(e)

APPENDIX D.3 : EXPERIMENT 4.2.3

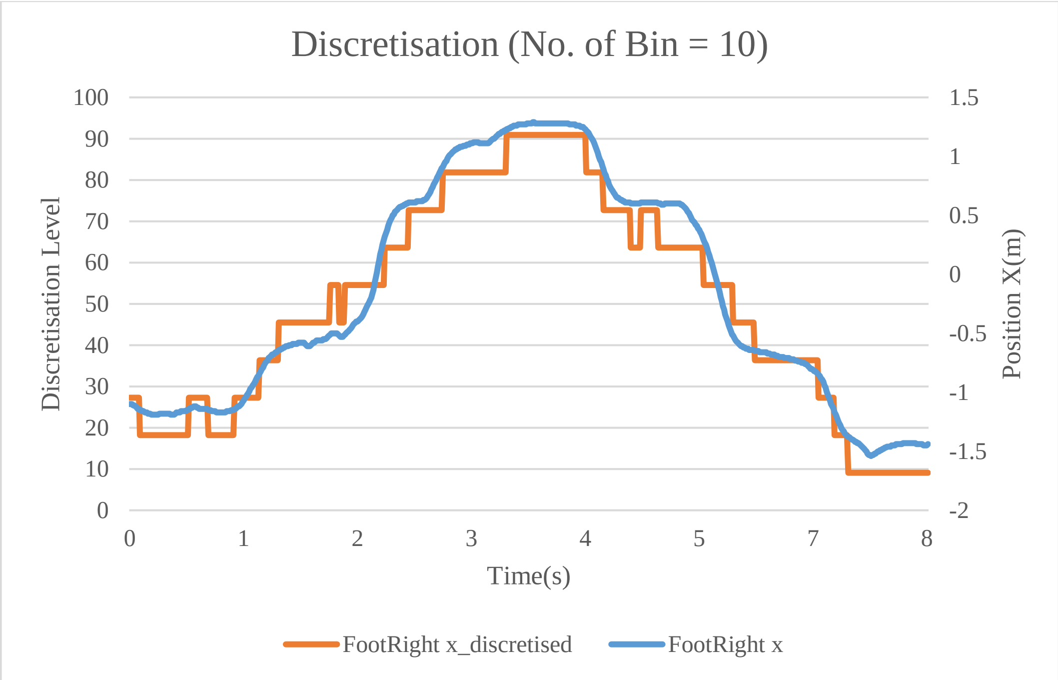
<u>Discretisation by Different Number of Bins</u>



(a)

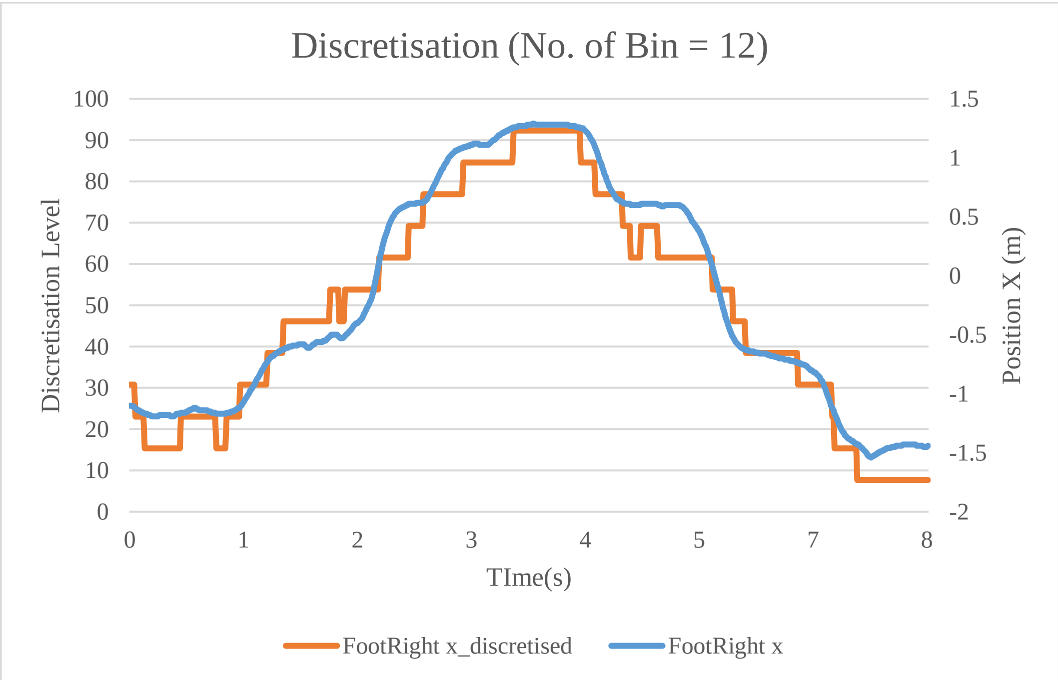


(b)



Discretisation (No. of Bin = 10)
100
90
80
70
60
50
40
30
20
10
0
Discretisation Level
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Position X(m)
0
1
2
3
4
5
7
8
Time(s)
FootRight x_discretised
FootRight x

(c)



Discretisation (No. of Bin = 12)
100
90
80
70
60
50
40
30
20
10
0
Discretisation Level
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Position X (m)
0
1
2
3
4
5
7
8
TIme(s)
FootRight x_discretised
FootRight x

(d)

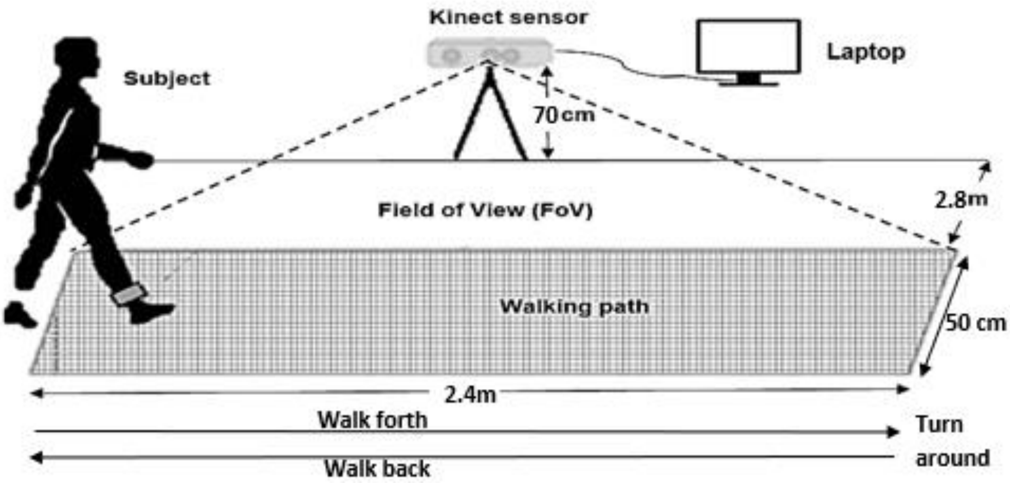
APPENDIX E : CONSENT FORM

INFORMATION SHEET

My name is Ooi Han Wei and I am a final year undergraduate student from the School of Engineering at KDU Penang University College, in collaboration with Northumbria University, UK. As part of my degree course, I am undertaking a research project for my Final Year Project. The title of my project is: **Quantitative Gait Evaluation System.**

In this project, it is aimed to aimed to present a gait evaluation system which provides quantitative information on gait quality of a user. The findings of the project will be useful / valuable for the therapist/physician in the clinic in both a time-effective and cost-effective way.

I am looking for volunteers to participate in the project. There are no criteria (e.g. gender, age, or health) for being included or excluded – everyone is welcome to take part. If you agree to participate in the study, you will be asked to walk forth and back in front of a Kinect camera sensor which setup as in the following figure for the video acquisition. The video shooting procedure should take no longer than 5 minutes. You will be free to withdraw from the study at any stage without providing a reason, and it will not affect your treatment (if applicable). This project will also mean that I will have to acquire your personal details (e.g. gender, age, height and weight).



All data will be anonymised, but you may be identifiable from video clips of your body movement. Your name will be replaced with a participant number or a pseudonym, and it will not be possible for you to be identified in any reporting of the data gathered. All data collected will be kept in a secured place (stored on a pc that is password protected) to which only the owner, I can access. These will be destroyed by the end of the examination process. Though, the results may be published in my Final Year Project Thesis or presented at a presentation or any publications.

If you would like to contact an independent person, who knows about this project but is not involved in it, you are welcome to contact my principal supervisor, Mr. Koay Fong Thai. His contact is +601x-xxxxxxx.

If you have read and understood this information sheet, any questions you had have been answered, and you would like to be a participant in the study, please now fill in the consent form given.

CONSENT FORM

KDU Penang University College requires that all persons who participate in research studies give their written consent to do so. Please read the following and sign it if you agree with what it says.

1. I freely and voluntarily consent to be a participant in the research project on the topic of **Quantitative Gait Evaluation System** to be conducted by **Ooi Han Wei,** who is an undergraduate student at KDU Penang University College.

2. I have been told that my responses will be anonymised. My name will not be linked with the research materials, and I will not be identified or identifiable in any report subsequently produced by the researcher.

3. I also made understand that if at any time during the session I feel unable or unwilling to continue, I am free to leave. That is, my participation in this study is completely voluntary, and I may withdraw from it without negative consequences. However, after data has been anonymised or after publication of results it will not be possible for my data to be removed as it would be untraceable at this point.

4. In addition, should I not wish to answer any particular question or questions, I am free to decline.

5. I have been given the opportunity to ask questions regarding the procedure and my questions have been answered to my satisfaction.

6. I have read and understand the above and consent to participate in this study. My signature is not a waiver of any legal rights. Furthermore, I understand that I will be able to keep a copy of the informed consent form for my records.

Participant's Signature (**Name:**) Date

I have explained and defined in detail the research procedure in which the respondent has consented to participate. Furthermore, I will retain one copy of the informed consent form for my records.