IDENTIFICATION OF GAIT DISPARITY USING GAIT ANALYSIS AND CYCLOGRAMS: APPLICATION FOR PROSTHETIC KNEE CONTROL

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DISSERTATION SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING SCIENCE

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2013

ABSTRACT

Choosing cyclograms over a function of time plots is very useful as a reference for designing a microprocessor-controlled prosthesis. This is because, the fact that locomotion is a tightly coordinated movement of several limb segments can be more naturally grasped as the coupled variables of two or more joints rather than from the study of individual joint kinematics or kinetics. Therefore, a new method developed by using the cyclic representation of locomotion and two-variable interaction, i.e. cyclograms, to determine the functional control parameter in terms of each gait sub-phases for prosthetic knee control design, is presented in this study. This study was divided into 3 phases. Phase 1 involved the gait data collection of normal subjects, transtibial amputees, transfemoral amputees and subjects wearing orthoses by using instrumented motion analysis system to characterize walking gait cyclograms. Phase 2 is where the cyclograms for the transtibial and transfemoral amputees were analyzed by using the neural network (NN) individually. The feedforward-backpropagation NN was used to predict each amputee's gait characteristics from 10 trials and the deviations were determined at each gait sub-phase for each of the amputees. The results obtained from Phase 2 were then transferred to Phase 3, where the values at the sub-phase of the cyclograms that has greatest deviation percentage were extracted and replaced with the normal values and analyzed it again using NN. This study concluded that, in order to define the control design for the prosthetic knee, one should control at each gait sub-phase: Loading response – knee power, Mid-stance – Knee power, Terminal-stance – knee moment and knee angle, Pre-swing – Knee angle and knee power, Initial-swing – knee angle, Mid-swing – independent (no control), and terminal-swing – knee power.

By controlling the knee parameter with respect to its affected joint kinetics and kinematics using artificial intelligence such as neural network, more natural gait can be achieved towards application in the prosthetic leg control design.

ABSTRAK

Pemilihan *cyclograms* berbanding plot satu parameter melawan masa adalah sangat berguna sebagai rujukan untuk merekabentuk prostesis yang dikawal oleh mikropemproses. Ini kerana, berjalan adalah sebuah gerakan yang ketat yang diselaraskan beberapa segmen anggota semula jadi akan lebih difahami dengan interaksi dua pembolehubah pada satu-satu sendi atau lebih sendi, bukannya daripada kajian kinematik individu atau bersama kinetik. Oleh itu, satu usaha untuk membangunkan kaedah dengan menggunakan perwakilan kitaran pergerakan dan interaksi dua pembolehubah, *cyclograms* iaitu, untuk menentukan parameter kawalan berfungsi dalam segi gaya berjalan setiap sub-fasa untuk rekabentuk kawalan lutut prostetik, dibentangkan dalam kajian ini. Kajian ini telah dibahagikan kepada 3 fasa. Fasa 1 melibatkan pengumpulan data daripada subjek sihat tubuh badan, amputi transtibial, amputi transfemoral dan pengguna ortosis dengan menggunakan alat gerakan analisis sistem. Fasa 2 di mana *cyclograms* untuk *transtibial* dan *transfemoral amputees* dianalisis dengan menggunakan rangkaian neural (NN) individu. NN suap depan-rambatan balik telah digunakan untuk meramal ciri-ciri gaya berjalan setiap *amputee* daripada 10 ujian dan perbezaan ditentukan pada setiap sub fasa bagi setiap satu *amputees*. Keputusan yang diperolehi daripada Fasa 2 kemudiannya dipindahkan ke Fasa 3,di mana nilai pada fasa cyclograms yang mempunyai sisihan peratusan terbesar telah diekstrak keluar dan digantikan dengan nilai-nilai biasa dan dianalisis sekali lagi menggunakan NN. Kajian ini menyimpulkan bahawa, dalam usaha untuk menentukan reka bentuk kawalan untuk lutut palsu, seseorang itu perlu mengawal pada setiap sub-fasa: *Loading response* - kuasa lutut, *Mid-stance* – kuasa lutut, *Terminal-stance* - lutut masa dan sudut lutut, *Pre-swing* - sudut lutut dan kuasa lutut, *Initial-swing* - sudut lutut,

Mid-swing - bebas (tiada kawalan), dan *terminal-swing* - kuasa lutut. Dengan mengawal parameter lutut terhadap parameter kinematik dan kinetic sendi menggunakan kepintaran buatan seperti rangkaian neural, gaya berjalan yang lebih semula jadi dapat diaplikasi ke dalam rekabentuk kawalan kaki prostetik.

ACKNOWLEDGEMENTS

I would like to express my grateful and sincere appreciation to my supervisor, **Dr Nur Azah Hamzaid** for her monitoring, encouraging advice, compliments and constructive critics. Throughout the completion of this dissertation, her guidance, knowledge and wisdom have been resourceful and engaging. A token of appreciation also goes to my second supervisor, **Assoc. Prof. Dr. Noor Azuan Abu Osman** for all his support, commentaries and advices.

A special thank goes to the subjects whom have greatly give their co-operation for the motion analysis session. The co-operation given has significant contribution to the completion of this study.

I deeply thank my parents and siblings for their love, continuous support and understanding over these years. Without their support and sacrifice, I would never been able to complete my dissertation.

Lastly, I would like to thank all the other lecturers, staffs of Biomedical Engineering Department and Motion Analysis Laboratory who have helped me a lot, dearest friends and colleagues who have accompanied me throughout the completion of the study and dissertation. Wish you all have great future.

Sincerely,

NOR ELLEEIANA BINTI MOHD SYAH

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

1.1. Background

As a human being, walking is regarded as the principle means of moving from one point to another point or in other word, locomotion itself (Adams, 1997). The human ability to ambulate securely in the upright position is thought as remarkable skill. Despite being considered as the natural tendency of human to move both his legs to be able to reach a point, this bipedal locomotion of human being has gained interest among the experts to study about human gait using scientific approach; the pattern of human locomotion is achieved by using the lower extremities. The mechanics of human gait involves many perspectives of knowledge, such as anatomy, kinesiology, physics, mechanics, neurophysiology and also mathematical computation (Bedotto, 2006). Even though volumes of investigation have been conducted to study the human gait, it has to be admitted by some experts that it is not an easy task to understand the mechanism lies behind the human bipedalism.

> *"Despite our fascination and years of scientific inquiry, we still do not know how we manage to get from point A to point B in an upright position. Controlling bipedal locomotion is not an easy task" (Craik & Oatis, 1995) pg. 47.*

Ironically, not every human is blessed of having both legs to self-ambulate naturally. The fact that human have been experienced the limb loss, acquired or due to trauma, unilateral or bilateral, especially lower extremity amputation indeed has great and significant effect to a person life involving their locomotive function. Severe cases of amputation begin during World War II (WWII), followed by Soviet Union's 1979-1989 war in Afghanistan, where the percentages of the amputees increase chronologically (Nechaev et al. 1995). From 1990's onwards, statistics have shown that the main cause which contributes to lower limb amputation amongst all age groups was dysvascularity; those aged under 16, trauma was considered as more common cause (Pechman 1991; Bowker & Michael 1992). Torres (1994) reported that of all lower extremity amputations, the population consists of 40% transfemoral amputees, 50% are transtibial, and remaining 10% are hip disarticulation. This worldwide amputation scenario invited the invention of different type of artificial limb namely prosthesis to replace the original function of the loss limb - the kick-start for advancement in the field of prosthetics and orthotics.

Prostheses have evolved from the earliest use of a simple peg leg or stick towards the introduction of the hinge to the knee to assist in the knee bending of the transfemoral amputees during the swing phase of walking. However, this hinge-type prosthesis did not provide adequate stability to the user, where stumbling is the major concern that has high possibility of occurrence to the user. After WWII, the prosthesis was improved by adding the hydraulic cylinders to the simple hinge joint, enabling the damping of knee rotation of the prosthesis; considered as modern knees, but mechanically passive. Since then, the mechanically passive knees have been progressively advancing until the introduction of highly adaptive, electrically-controlled prosthetic knee in 1970 onwards (Herr & Wilkenfeld, 2003). The motivation gained from such technology encouraged many researchers to develop prototype knees (Herr & Wilkenfeld, 2003; Zahedi, 1993; Popovic & Schwirtlich, 1988; Grimes, Flowers & Donath, 1977) which eventually led to the devices available in the market such as the Blatchford Endolite Intelligent Prothesis, the Otto Bock C-leg, and the Össur Rheo. These variable-damping prostheses offer several advantages over mechanically passive designs, such as knee stability and capability to adapt to different ambulatory speed (Michael, 1999; Marks & Michael, 2001), though, mechanically passive designs still gain the preference in terms of costs, cosmesis and comfort. Either way, both generations of prosthesis design had indeed took over the locomotive function of the loss lower limb and eventually adds an additional analysis element to the study of human gait (Bedotto, 2006).

(a) (b) (c)

Figure 1.1: Three most recent prosthetic knee offered in the market (a) Ossur Rheo Knee, (b) Otto Bock C-leg and (c) Endolite Adaptive knee

Regardless of the level of amputation, the use of the prosthesis has created a turning point in the human locomotion research. Researchers shifted their interest towards the comparisons between the normal human gait with those wearing prosthesis (Bae et. al., 2007; Bateni & Olney, 2002; Powers et. al, 1998) and somehow relate the deviation in the amputee's gait with the prosthesis features (Van der Linden et. al., 1999). To this point of view, kinematics and kinetics analysis have been conducted to describe the differences that occur in either type of locomotion by using quantitative explanation (Sutherland 2002; Sutherland, 2005). With the current advancement of 3D motion analysis system technology, the intention to conduct the dynamic analysis involved in human gait is no longer impossible and time-consuming (Zanchi et. al., 2000). The partaking of this dynamic analysis itself offers different perspective in the parameters variation in number of data that could be collected. Nowadays, the relevance of obtaining the variations of parameters quantitatively in human gait should be used to distinctively measure the required modification that should be improvised on the prosthetic leg in terms of its locomotive function on the user himself.

1.2. Problem Statement

To date, human walking behaviour is typically characterized by plotting single kinematics and kinetics curves as a function of time or percentage of gait cycle (Gage & Hicks, 1989; Kerrigan et al., 1998). There are vast amounts of these data available in the literature and has been put into application in the prosthetic design. These kinematics and kinetics curves became the "textbook" to design prosthesis control that mimicking the normal gait by analyzing the prosthesis performance as close as the normal single-variable curve. However, designing a prosthesis control based on the single-variable curve is arguable with regard to the prosthesis performance towards the user as the interactions of co-existing parameter across the lower limb joints during the gait cycle could not be harmonized.

There are a number of relevant dynamic effects (such as slope and geometric changes) can be identified when pairs of kinematics and kinetic variables are examined together and correlations among them are concurrently assessed (Crenna and Frigo, 2011). These combinations of kinematics and kinetics variables, omitting the time variables from the two signals, create different cyclic trajectories known as cyclograms. Figure 1.2 shows an example of how a cyclogram is created from two conventional single-variable gait curves. From the cyclic trajectories represented by the coupled variables, its changes could visualize us a clear indication of the dynamic modification that the gait is slowly undergoing. Besides, the interaction between two co-existing parameter across the joints could be concurrently assessed. This embarks an opportunity of applying the cyclograms concept to determine the control parameter for designing prosthetic leg control.

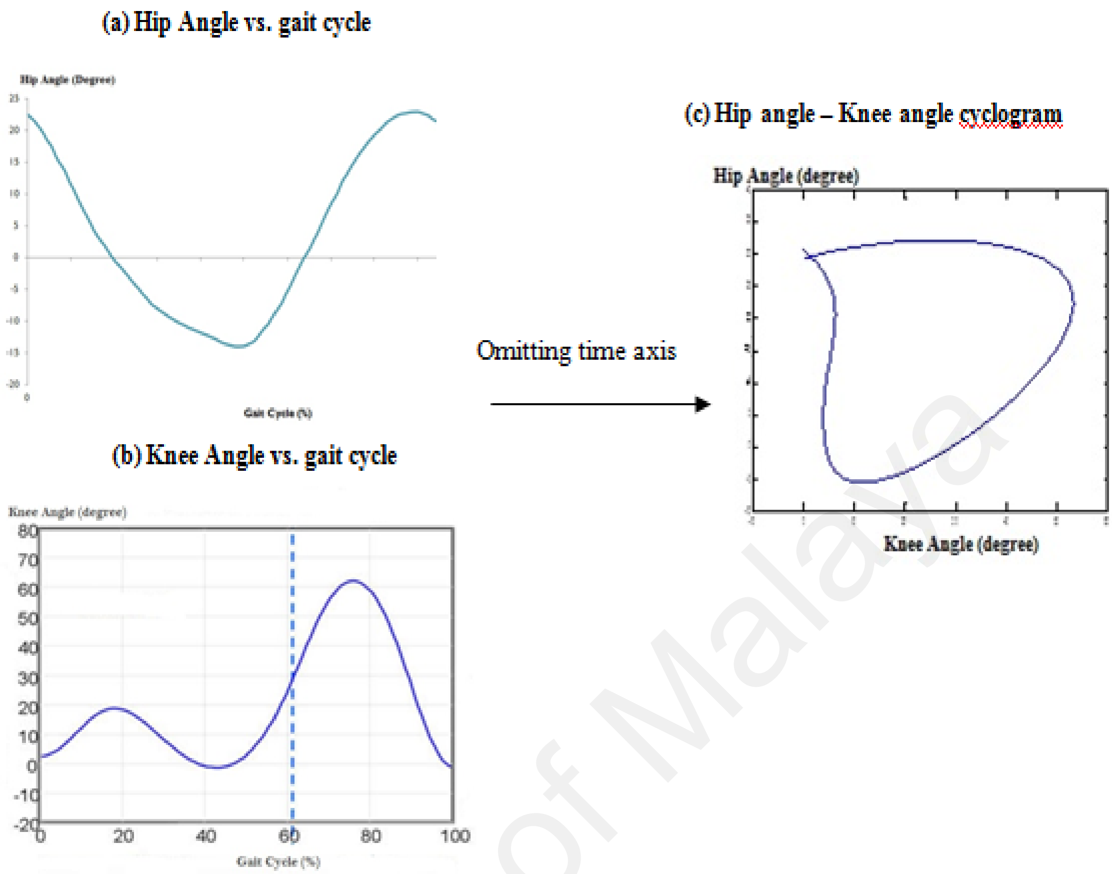


Figure 1.2: How a cyclogram is created from two conventional single-variable gait curves

The commercially available microprocessor-controlled prosthetics in the market nowadays offer different specific features in knee stability and capability of different ambulation function in each of the design. However, there is no certain proof that says these design could really adapt with the general amputees population. The design is always patient-oriented, thus, it defeat the function purpose for the other amputees. Traditionally, amputees are required to adapt with prosthetic leg fitted to them through training and rehabilitation. Thus, there exists a challenge to develop the prosthetic control foundation that could adapt to different amputees' conditions. According to

Pitkin (2010), designing a better prosthetic leg does not revolves around the integration to mimic closely-to-normal limb behaviour, but it must also be designed by taking the amputees pathological condition into account. Therefore, there is a need to outline the basis for the prosthetic control that requires only minimal modification to adjust with, might not all, but most of the amputees' conditions.

1.3. Objectives of Study

There are four objectives to be achieved in this study:

(a) To obtain the walking gait's kinematics and kinetics variables using motion analysis

(b) To construct the cyclograms for coupled variables within the joint and across the two joints of normal subjects

(c) To use each cyclogram's variables interaction to identify the gait disparity among amputees in term of sub-phases by means of neural network

(d) To use the cyclogram's variables manipulation to determine the relevant parameter that should be controlled at each gait sub-phases in prosthetic knee control.

1.4. Scope of Study

Choosing cyclograms over a function of time plots is very useful as a reference for designing a microprocessor-controlled prosthesis. This is because, the fact that locomotion is a tightly coordinated movement of several limb segments can be more naturally grasped as the coupled variables of two or more joints rather than from the study of individual joint kinematics or kinetics (Cavanagh & Grieve, 1973). Therefore, an attempt to develop a method by using the cyclic representation of locomotion and two-variable interaction, i.e. cyclograms, to determine the functional control parameter in terms of each gait sub-phases for prosthetic knee control design, is presented in this study. The approach is by analyzing the lower limb joints' coupled parameters holistically (of the joint itself and across two joints) using neural network. Then, the control parameter at each gait sub-phases is determined by analyzing the effect of manipulating one parameter towards another parameter of the coupled variables at the most deviated cyclogram for different amputee's profile.

1.5. Terminology Adjustment

The term cyclograms is usually used to refer the angle-angle relationship of the joints. For a coupled kinematics-kinetics variables, it is referred as a phase diagram. The phase diagram of a dynamic system resides in its phase space. There are two most popular definitions of the phase space. The first one described it as the space consisting of the generalized coordinate/generalized momentum variables and the generalized coordinate/generalized velocity variables (Bergé et. al, 1984; Hilborn,1994). The second definition, according to which the phase space is identical to the state space, is used in the biomechanics community.

> *"A state of a system is represented by a point in its phase space and the evolution of the system is given by a trajectory in the phase space, which called a phase diagram. A planar angle-angle diagram provides information about the posture of the leg and the coordination of two joints but is silent about the velocities involved. ... On the other hand, a planar phase diagram represents the complete dynamics of a single joint but provides no information about the coordination of two joints" (Goswami, 1998).*

In this study current context, phase space would contain the joint displacements (angle) and the joint velocities/momentum of the movement under study and therefore can be considered as a superset of cyclograms, which contain the joint displacements only. However, since neither the entire phase diagram nor the entire cyclogram of a multi-degree of freedom system is graphically visualizable (Goswami, 1998), therefore, in this study, the 2-D projections of these diagrams are unanimously called cyclograms to simplify the terminology used in the subsequent chapters.

1.6. How to Read the Cyclograms

In this study, the cyclograms plots for normal subject are combined together with its respective gait sub-phases. Figure 1.3 below shows an example of how the cyclograms are plotted in this study. The blue line represents the left side trajectory, while the red line represents the right side trajectory. Different markers to represent the gait sub-phase changes that the trajectory undergoing is plotted on the trajectory line. Abbreviations are used to simplify the gait sub-phases terminology: LR = Loading Response, MSt = Mid-Stance, TSt = Terminal-Stance, PSw = Pre-Swing, ISw = Initial-Swing, MSw = Mid-Swing, and TSw = Terminal-Swing. The plot's axes consisted the two variables of the cyclogram. As the two variables are co-existing parameters during the gait cycle, therefore, the axes do not serve to represent the dependent or independent parameter as the usual purpose of graph's axes. Instead, the cyclograms is assessed by its trajectory cyclicity and the travelling direction from loading response to terminal stance. The information that would be obtained from the axes is the distance between minimum and maximum values, representing the changes from plantarflexion (-) to dorsiflexion (+) for ankle joint and the changes from extension (-) to flexion (+) for knee and hip joints.

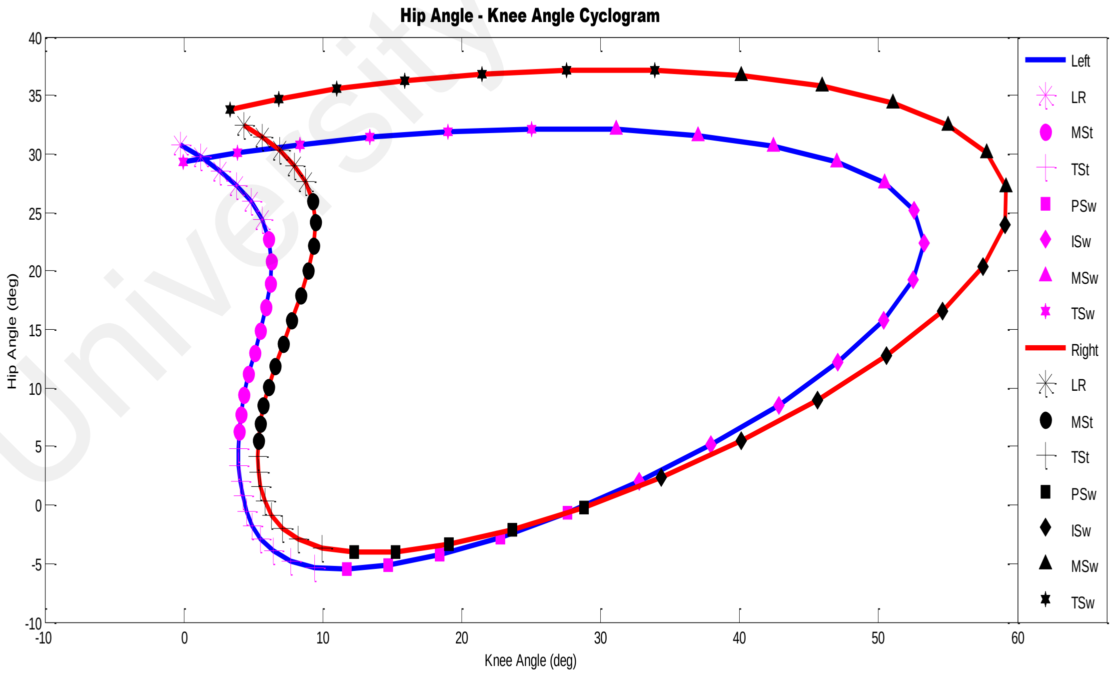


Figure 1.3: Example of how the cyclograms are plotted in this study's result

CHAPTER 2: LITERATURE REVIEW

2.1. Gait and Amputees

Gait can be broken down into a repetitive series of patterns, each representing distinct functional tasks. There are eight of these sub-phases of gait: 1) initial contact, 2) loading response, 3) mid stance, 4) terminal stance, 5) pre-swing, 6) initial swing, 7) mid-swing, and 8) terminal swing (Perry, 1992). Sub-phases (1) and (2) are involved in weight acceptance, which involves shock absorption, initial limb stability, and the preservation of progression. Sub-phases (3) and (4) make up the single limb support section of gait. During single-limb support, one limb entirely supports the weight of the body in both the sagittal and coronal planes. Limb advancement contains sub-phases (5)-(8), and involves the preparatory posturing of the support limb, as well as movement of the limb itself. Knowing the functional requirements of normal gait allows for greater insight into the changes incurred by pathological or injured gait.

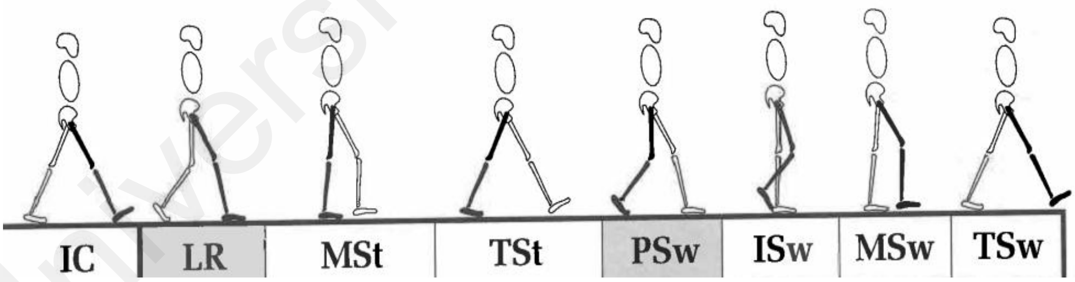


Figure 2.1: Illustration of gait sub-phases in a stride (Adapted from The Pathokinesiology Service and The Physical Therapy Department, 2001)

2.1.1. Transtibial amputees gait deviation

There have been many studies which have been aimed at quantifying the differences between transtibial amputee gait and able-bodied gait. In general, transtibial amputees have been shown to have decreased cadence, stride length, and a slower comfortable walking speed as compared to able-bodied individuals (Kovac et al., 2010; Isakov et al., 2000; Su et al., 2007). Transtibial amputees also generally take longer to initiate gait and reach a steady-state walking speed than able-bodied individuals (Tokuno et al., 2003). It has also been shown that transtibial amputees have wider step widths and shorter step lengths, which indicates decreased stability and less perceived security than able-bodied subjects (Su et al., 2007). However, amputee gait also differs from able-bodied gait where transtibial gait has asymmetry present between the prosthetic and sound limbs. It has been shown that step time, swing time, and step length were longer while stride length and stance time were shorter on the prosthetic limb as compared to the intact limb (Kovac et al., 2010; Isakov et al., 2000). Knee flexion in the prosthetic limb has also been reported as significantly higher than the intact limb at heel strike, which can be linked to the ideal positioning of the prosthetic socket (Isakov et al., 2000). In general, the amputated limb of transtibial amputees carries more weight than the sound limb, and a strong relationship was found between the weight-bearing on the amputated limb and the strength of the residual muscles (Nadollek et al., 2002). The relationship implied that the greater the strength of the residual limb, the greater the weight bearing capacity.

The leg muscles of transtibial amputees also behave differently than able-bodied individuals. In able-bodied individuals, the primary forward momentum required for walking is provided by the ankle plantarflexors (Winter, 2005). In transtibial amputees, the plantarflexors are missing, so it has been proposed that this forward propulsion is provided by hyperactivity of the hip extensors (Winter & Sienko, 1988; Isakov et al., 2000; Su et al., 2007). This increased muscle activity in the hip extensors is achieved by the hamstrings, which then generates an above-normal knee flexor moment, which must be cancelled out by co-contraction in the quadriceps (Winter & Sienko, 1988; Isakov et al., 2000; Soares et al., 2009). This co-contraction causes the net knee moment during stance to be near zero. During push-off, the hamstrings become less active, but the knee extensors remain active well into swing. These changes in muscle activation give an indication of how differently transtibial amputees walk as compared to able-bodied individuals, and it is apparent how vital the hip extensor muscles are to forward propulsion in this population.

2.1.2. Transfemoral amputees gait deviation

The differences between transfemoral amputee gait and able-bodied individuals are similar to those between transtibial amputees and able-bodied, but the differences have been magnified in the transfemoral amputees. In terms of time-distance parameters, transfemoral amputees have a slower gait speed, decreased cadence, increased cycle time, decreased stride length, and a decreased stance phase on the prosthetic side as compared to both transtibial and able-bodied individuals (Bae et al., 2007; Goujon-Pillet et al., 2008; Jaegers et al., 1995). Transfemoral amputees also show decreased hip flexion and extension, as well as increased hip abduction and adduction, and decreased knee flexion and extension on the intact side. In a difference from transtibial amputees, transfemoral amputees display a much larger range of motion of the pelvis and trunk. The angular range of motion of the pelvis in transfemoral amputees was significantly higher in the sagittal and frontal planes than that of able-bodied individuals, while the range of motion of the trunk was significantly higher in all three planes in the transfemoral amputees (Bae et al., 2007; Goujon-Pillet et al., 2008). The additional trunk movement significantly changes the upper body angular accelerations, which may in turn alter the individual's global torque production, which has a profound effect on joint loading (Goujon-Pillet et al., 2008).

Asymmetrical joint loading of the knee and hips has been shown to have serious consequences in amputee's intact joints. Therefore, it is important to have the control properties of the prosthesis to be effectively compensate both the motions and loading for intact joint(s) and replaced joint(s) simultaneously to avoid other complications on the joint, for example, osteoarthritis on the hip joint for transfemoral amputees.

2.2. Analytical Techniques in Gait Assessment: Neural Network

There are several techniques that have been used to mathematically represent the gait data and analyze it, such as fuzzy system methods, multivariate statistical analysis, fractal dynamics, artificial intelligence (including neural networks), and wavelet methods (Chau, 2001a; 2001b). Among all these methods, multivariate statistical methods presently are the most widely applied and understood in gait analysis

(Borghese et al., 1996; Kelly &Biden, 1989; Laassel et al., 1992; Lenhoff et al., 1999; Loslever et al., 1994; Sadeghi et al., 2000; Olney et al., 1998; Sutherland et al., 1992; Wilson et al., 1997; Wootten et al., 1990). Fuzzy and fractal analyses of gait data (Hausdorff et al., 1997c) are still in infant stage and remain largely untried. The potential of fuzzy and fractal analyses as well as that of wavelet methodology (Ismail & Asfour, 1999; Tamura et al., 1997) is unknown. Neural networks are the most widespread non-traditional methodologies currently emerge to be applied to the analysis of gait data (Barton & Lees, 1995, 1997; Chang et al., 2000; Hersh et al., 1997; Holzreiter & Kohle, 1993; Lafuente et al., 1997; Su & Wu, 2000; Wu & Su, 2000; Wu et al., 2000, 2001).

2.2.1. Structure of neural network

Artificial neural networks (NN) are simulations of the nerve system, and able to simulate the performance of a human brain. A NN is a group of highly interconnected neurons, arranged in layers. Figure 2.2 shows a multilayer neural network structure with input, output and hidden layer and respective weight/bias.

The operation of a NN can be divided into two phases. First, as a response to present inputs, the synaptic weights change, until the NN learns to associate the inputs with the expected outputs (Beale et al., 2009). This process is called 'learning'. The second mode of a NN is called 'testing', when it generates an output signal as a response to previously unknown inputs, i.e. it generalises. The effectiveness of generalisation can be expressed as the ratio

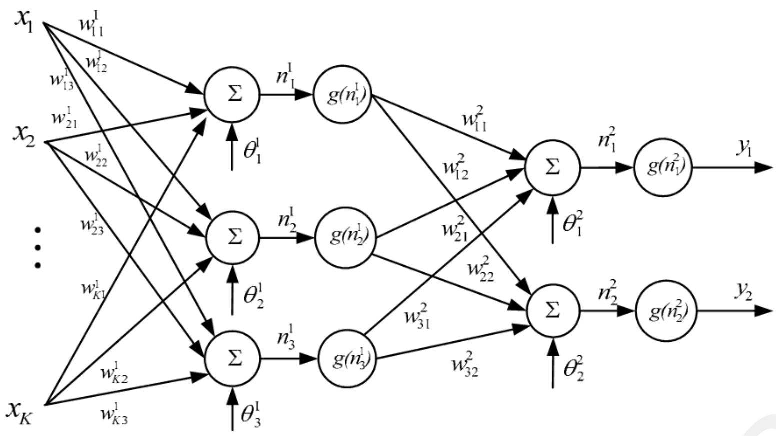


Figure 2.2: Example of multilayer neural network structure with one hidden layer

or regression of correctly recognised input patterns to all of the presented patterns in the test phase. The advantages of a NN is that it can receive large numbers of data simultaneously and because of its internal structure, the pieces of data do not have to be isolated from each other, preserving the inherent relationships amongst the data set (Barton & Lees, 1997). The attractive features of simultaneous data handling and the concept of contextuality make NNs potentially useful tools in the automated recognition of various gait patterns.

2.2.2. Neural network and gait analysis

Many studies have used neural networks to analyze normal versus pathologic gait and to differentiate different gait patterns for a particular medical disorder and pathological conditions (Barton & Lees, 1995, 1997; Holzreiter & Kohle,1993; Wu & Su, 2000; Wu et al., 2000, 2001). The result of the studies was able to obtain the desired differentiation for 70-90% of the patients studied. The medical disorders examined are such as classifying the gait pattern of dopa-responsive Parkinson's disease (Holzreiter & Kohle, 1993), recognizing the pattern associated with ankle arthrodesis (Wu & Su, 2000; Wu et al., 2000, 2001), the gait pattern obtained from children with cerebral palsy (CP) hemiplegia (Barton & Lees, 1997), and the preoperative gait patterns for children with CP that had successful rectus femoris transfer (Hersh et al., 1997). These techniques are considered preliminary despite the promising prospect. The number of subjects and variables selected in these studies were limited. The variables used differ in each study and depended on the question asked and the desired result (Simon, 2004). These studies give a bright view on how neural networks can be used to analyze a particular patient gait study (Chang et al., 2000). Besides that, these studies also suggested that neural network techniques may also be able to detect significant features of a pathological gait as an aid to diagnosis and treatment. Although there was no attempt has been made to use neural networks to analyze the prosthetic user's gait disparity, the promising aspect of the neural network could be look forward for the amputee population.

Table 2.1: Summary of studies using neural network for gait analysis

Author(s) (year)	Gait analysis study using neural network
Holzreiter & Kohle (1993)	• identifying the gait pattern of dopa-responsive Parkinson's disease
Hersh et al.(1997)	• the preoperative patterns associated with successful rectus femoris transfer in children with CP
Barton & Lees (1997)	• the patterns found in children with cerebral palsy (CP) hemiplegia
Wu & Su(2000); Wu et al.(2000 & 2001)	• the pattern associated with ankle arthrodesis

2.3. Cyclograms and Phase Diagrams

From the literature search, Grieve was the first to propose the use of cyclograms (also known as angle-angle diagrams) in his studies (Grieve, 1968; Grieve 1969). Grieve stated that by using a cyclic plot such as a cyclogram, a cyclic process such as walking can be better understood and proposed the gait events such as heel-strike and toe-off to be included in the cyclogram to make them more informative. From the observation of gait deviation's characteristics on cyclograms, Grieve implied that the gait characteristics deviation cannot be effectively represented by a mean deviation. This is due to the characteristics of the deviation are not random and both the direction and magnitude of the deviation should be considered in gait analysis. Apart from that, Grieve also recognized the shock absorption phase during heel-strike and the 'whiplash effect' of the leg at faster gaits by studying the representative cyclograms features. Traditionally, the planar knee-hip cyclogram have received the most attention in gait study (Kutilek & Farkasova, 2011).

2.3.1. Studies on Cyclograms

Although the concept of cyclograms is known to the biomechanics community, the study related to it is not frequently found in contemporary literature. The first six different cyclograms corresponding to six different walking speeds for each of hip – knee, hip – ankle, and knee – ankle combinations were presented by Lamoreux (1971). Cyclograms from standing broad jump, stair climbing, race walking as well as normal walking at different speeds was presented by Cavanagh and Grieve (1973). This study shows that the demonstration of cyclograms, in synergy with other kinematic representations of multi-joint movements, can become a powerful analytical tool. Use of cyclograms as a means of tracking the progress of patients undergoing total hip joint reconstruction was explored by Milner et al. (1973).The result demonstrated that the cyclograms of abnormal gaits are geometrically very different and are easy to visually identify from those obtained for normal gaits. The same work also reported the evolution of the geometric form of the cyclogram as a function of walking speed (Goswami, 1998).

Charteris et al. (1979) compared the gait patterns of human and dogs by representing the gait using cyclograms. The study highlighted the use of cyclic traces of joint variables and proposed that a coordinated motion of a leg should be regarded as an interaction between two or more limbs rather than a phenomenon of isolated joint movements over time (Charteris et al., 1979). Thus, the study has recognized cyclogrgams as an extremely stable mechanism to study the gait behaviour. The subsequent work of Charteris (1982) presented the evolution of cyclograms as a function of the walking speed. There were three different levels of speed corresponding to 0.5 – slow, 0.9 – medium, and 1.3 st/s – fast. The cyclograms presented in this study were added with auxillary information such as the important gait cycle events. The cyclograms in this study gives directive measure as to how the rehabilitation of the paralysed patient should take place. The study also made a constructive suggestion on how the cyclograms can be practically applied and interprets by the clinicians who are not a gait analysis expert (Charteris, 1982).

In 1990, Cavanagh used the cyclograms to perform the systematic analyses to study the effect of inclined surfaces during running. Although the study was not about the walking gait, however, the cyclograms from this study were used to demonstrate the gradual change in the running as a function of slope and running speed. The same work of studying the effect of slope in walking was then performed by Goswami (1998). The study reported the geometrical change on the cyclograms is very sensitive to the gradual changes of surface inclination, downward or upward with different slope (±11^{o} from flat surface) as shown in Figure 2.3.

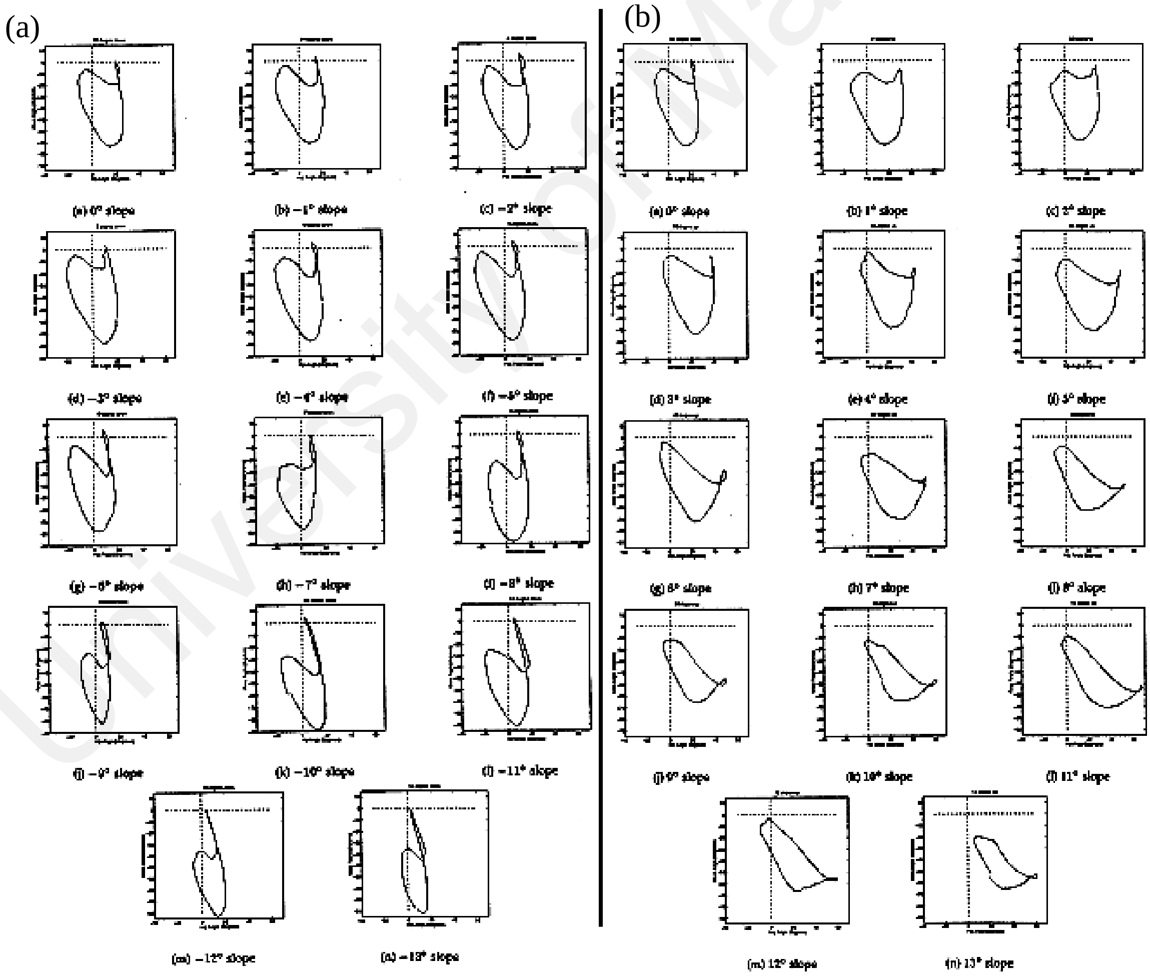


Figure 2.3: Geometrical evolution of the hip angle-knee angle cyclograms as a function of inclination slope (Adapted from Goswami 1998)

Table 2.2: Summary of cyclograms studies and respective finding(s)

Author(s) (year)	Study	Emphasized finding(s)
Cavanagh and Grieve (1973)	Cyclograms from standing broad jump, stair climbing, race walking as well as normal walking at different speeds	• The demonstration of cyclograms, **in synergy with other kinematic representations of multi-joint movements**, can become a powerful analytical tool.
Milner et al. (1973)	Use of cyclograms as a means of tracking the progress of patients undergoing total hip joint reconstruction	• The cyclograms of abnormal gaits are **geometrically very different and are easy to visually identify** from those obtained for normal gaits. • The **geometric shape of the cyclograms changes** as a function of walking speed
Charteris et al. (1979)	Compared the gait patterns of human and dogs by means of cyclograms	• The use of cyclic traces of joint variables by pointing out that **a coordinated motion of a leg is to be perceived as an interaction between two or more limbs** rather than a phenomenon of isolated joint movements over time • **Cyclogram pattern** is noted to be an **extremely stable mechanism to identify gait behaviour**
Charteris (1982)	Cyclograms geometric evolution as a function of 3 different speeds, made the comparison with paralysed patient.	• The cyclograms in this study gives **directive measure as to how the rehabilitation of the paralysed patient** should take place • Cyclograms can be practically applied by the clinicians to measure the patient's rehabilitation progress
Cavanagh (1990)	Used the cyclograms to perform the systematic analyses to study the effect of inclined surfaces during running	• the cyclograms from this study were used to **demonstrate the gradual change in the running as a function of slope and running speed**
Goswami (1998)	studying the effect of slope in walking by examining the cyclograms	• cyclograms is very **sensitive to the gradual changes of surface inclination**

2.3.2. Studies on Phase Diagrams

Although in the literature cyclograms have received more exposure in the biomechanics community, phase diagrams have started to be noticed as well (Hurmuzlu & Basdogan, 1994; Hurmuzlu et al., 1994; Hurmuzlu et al., 1996). Ankle moment-angle relationship received the most attention in the literature (Wang et al., 2012; Crenna & Frigo, 2011; Hansen, et al., 2004; Frigo et al., 1996; Davis & DeLuca, 1996). The slope of the moment–angle curve can be interpreted as the ‘‘dynamic stiffness’’ of the ankle joint (Davis & DeLuca, 1996) and can reveal the overall system behavior during the stance phase of walking. Hansen et al. (2004) used the sagittal ankle moment versus ankle angle diagram to examine the quasi-stiffness of the ankle when walking at different walking speeds. Their finding revealed that the slopes of the moment versus ankle angle curves (quasi-stiffness) during loading appeared to change as the speed was increased and the relationship between the moment and angle during loading became increasingly non-linear (Figure 2.4). This suggested that the concurrent response between kinematics and kinetics variables during walking could be observed clearly using the phase diagram and provides distinctive measure of the gait kinematics-kinetics changes.

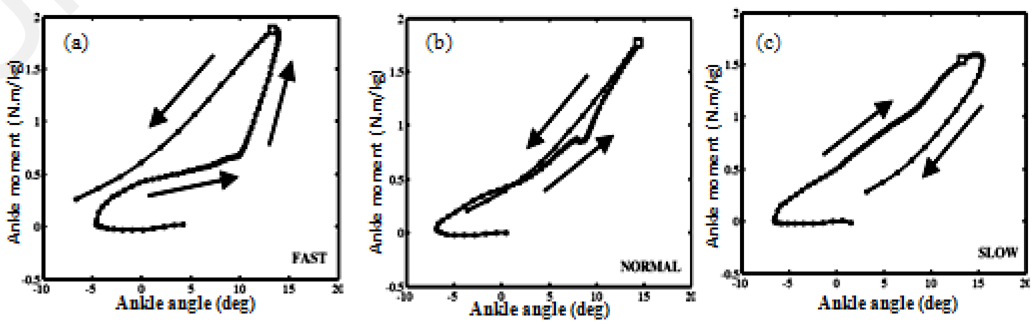


Figure 2.4: Ankle moment - ankle angle plots for normal subjects walking at three different speed (a) fast (1.9 m/s), (b) normal (1.5 m/s), and (c) slow (1.2 m/s) (adapted from Hansen et al., 2004)

2.4. Combination of Neural Network and Cyclograms in Walking Gait

The combination of neural network and cyclograms in a single study is rarely found in the literature, and none has been introduced for identifying gait disparity of the amputees. To date, neural network has been used to perform automated diagnose of gait patterns represented by cyclograms (Barton & Lees, 1997). Once trained, the network can identify with a 83.3% success rate the three different conditions — normal gait, a gait with unequal leg length and a gait with unequal leg weight. The work of Kutilek and Farkasova (2011) described the method for predicting the motion of lower extremities using neural network and suggested that the predicted data may be useful for evaluation of human walking in physiotherapy practice based on angle-angle diagram. This method carved an opportunity to be applied in a clinical practice for study of disorders or characteristics in motion function of human body, and also to be used in new design of lower limb prosthesis (Kutilek & Farkasova, 2011).

CHAPTER 3: METHODOLOGY

3.1. Introduction

This study was divided into 3 phases. Phase 1 involved the gait data collection of normal subjects, transtibial amputees, transfemoral amputees and subjects wearing orthoses by using instrumented motion analysis system. Medical Ethics approval was obtained preceding the data collection. The data obtained from the motion trials was then being analyzed and a total of 36 cyclograms of the gait variables on sagittal plane were obtained. Each of the relationship was plotted for normal subject to interpret gait changes with respect to the concurrent relationship of two variables and as the reference for the subsequent phases. Phase 2 is where the cyclograms for the transtibial and transfemoral amputees were analyzed by using the neural network (NN) individually. The feedforward-backpropagation NN was used to predict each amputee’s gait characteristics from 10 trials and the deviations were determined at each gait sub-phase for each of the amputees. The NN was first validated by comparing between the predicted output curve of single variable from the NN and the conventional trials averaging methods. The results obtained from Phase 2 were then transferred to Phase 3, where the values at the sub-phase of the cyclograms that has greatest deviation percentage were extracted and replaced with the normal values and analyzed it again using NN, i.e. each parameter of a single cyclogram was manipulated to determine the effect of the changes towards the other parameter. This way, the manipulated parameter(s) that contributed to the most close-to-normal (least errors) features of cyclograms regarded as the key parameter(s) that should be controlled at that particular sub-phase. Figure 3.1 below shows the flow chart of how the phases were connected to each other.

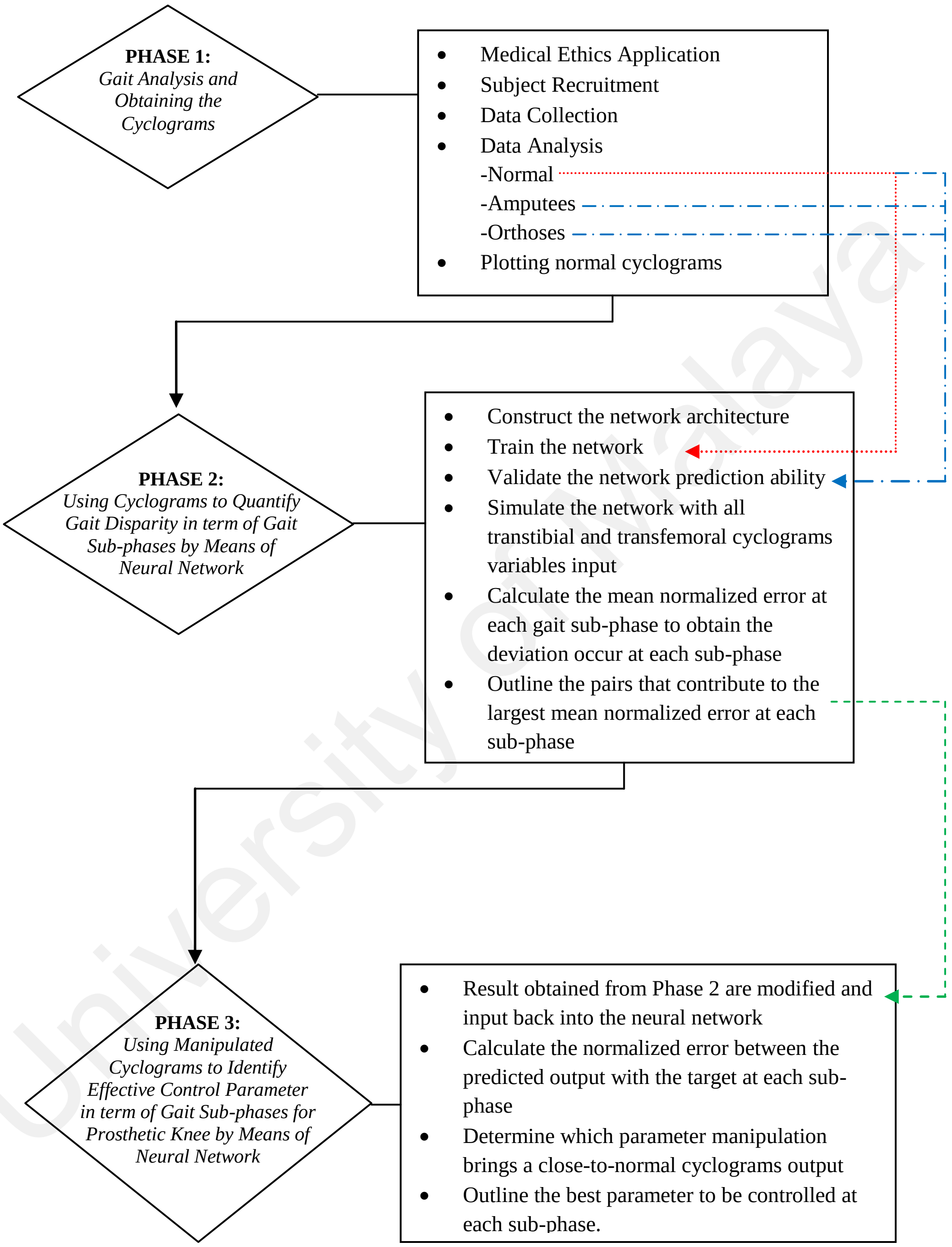


Figure 3.1: Research methodology workflow

3.2. Phase 1: Gait Analysis and Obtaining the Cyclograms

3.2.1. Ethics Application

The transtibial subjects, transfemoral subjects and orthoses subjects were recruited from the Rehabilitation Department of University of Malaya Medical Center (UMMC). Therefore, before proceeding with the gait trials, trials ethics approval has to be obtained prior to the data collection. This is because, to comply with UMMC Medical Ethics requirements, the present of Certified Prosthetist/Orthotist (CPO) or Medical Assistant during conducting the trials with amputees and proper trials procedures has to be evaluated. The ethics was approved on March 2012. The official document of approval can be referred in **Appendix A.**

3.2.2. Subjects participant and requirements

There were 3 types of subjects involved in this study, (1) Normal healthy subject (N = 20; Mass = 65.43±17.96 kg; Height = 161.4±10.25 cm; Age = 24±2.53 yrs) with no pathological conditions, no history of lower limb surgery, no physiological disease (e.g: asthma, heart disease), and right limb dominant, served as the reference to identify the gait disparity of the amputee subjects based on the cyclograms; (2) The target subjects for this study were transtibial amputees (N = 10; Mass = 77.15±21.45 kg; Height = 168.45±9.95 cm; Age = 45.70±9.90 yrs) and transfemoral amputees (N = 5; Mass = 70.60±19.07 kg; Height = 167.2±7.58 cm; Age = 34±7.56 yrs), and (3) Different pathological profiles of subjects who wear orthoses (N =10; Mass = 67.40±17.31 kg; 165.20±10.81 cm; 35.40±12.90 yrs) , where all their anatomical joints were still intact. Figure 3.2 below shows a few of the amputees and orthoses subjects involved in this gait analysis.

Figure 3.2: Some of the subjects involved in the gait analysis ranging from different profile of orthoses subjects, transtibial and transfemoral amputees

The criteria for all of the subjects were that they could walk without assistance or any upper extremity aids; for the amputees, the requirement must be unilateral amputee who has been wearing the prosthesis for more than 6 months; extra requirement for orthoses users was to must be able to walk with the absent of their orthoses. All of the subjects must have the ability to follow the instruction given properly and perform accordingly. Table 3.1 shows the profiles data for each of the transtibial, transfemoral and orthoses subjects and their respective pathological condition. All the subjects have given their written consent to participate in this study.

Table 3.1: Profile data for transfemoral, transtibial and orthoses subjects

Subject Code	Reason of Amputation / Wearing Orthoses	Type of Prosthesis knee, locking and foot/ Orthoses	Affected Side
TF1	Osteosarcoma	Mechanical knee joint, Auto-lock system	R
TF2	Diabetes, infection	Quadrilateral socket, single axis knee joint, SACH foot	R
TF3	Trauma	Mechanical knee-joint, single-axis foot	R
TF4	Doctor carelessness during surgery	Hydraulic knee joint, auto-lock system Flex-foot	R
TF5	Trauma	Mechanical knee-joint, flex-foot	R
TT1	Trauma	Pin lock, Flex-foot	R
TT2	Trauma	Shuttle lock, SACH foot	R
TT3	Trauma	Pin lock, SACH foot	L
TT4	Trauma	Shuttle lock, Flex-foot	R
TT5	Trauma	Pin lock, flex-foot	L
TT6	Trauma	Shuttle lock, flex-foot	L
TT7	Diabetes	Shuttle lock, Flex-foot	R
TT8	Trauma	Pin lock, SACH foot	L
TT9	Trauma	Shuttle lock, Flex-foot	R
TT10	Gangrene on 1st toe, Diabetes	Pin lock, Flex-foot	R
OT1	Congenital flexible pes planus	Custom-made shoe with arch insole	B
OT2	Limb length discrepancy (1.2cm)	Custom-made insole	L
OT3	Diabetes, 1st metatarsal ray amputation	Diabetic shoe	L
OT4	Inflammation at medial collateral ligament	Knee brace	R
OT5	Diabetes, callus at 5th metatarsal	Diabetic shoe with insole	B
OT6	Flexible Pes Planus	Arch insole	B
OT7	Diabetes, 2nd metatarsal ray amputation	Custom-made insole	R
OT8	Flexible pes Planus	Custom-made insole	B
OT9	Hallux valgus, present of bunion on 1st metatarsal	Hinged AFO	L
OT10	Charcot foot	Rigid AFO	R

Abbreviation: R – Right; L – Left; B – Both; TT – Transtibial; TF- Transfemoral; OT – Orthotic; AFO – Ankle-foot Orthoses

3.2.3. Data Collection

The experimental procedures of this study were conducted in a motion analysis lab which has 4m straight walkway. The lab is equipped with an optical three-dimensional motion capture system, a 6- infrared camera Vicon Nexus 1.5 (Vicon, United Kingdom) mounted strategically around the room, working at 50Hz and integrated with two force plates (Kistler Instruments, Switzerland) working at 200Hz, located midway to obtain synchronized kinematic and kinetic data within a capture volume of approximate 4m X 4m X 2m. As the subjects walked into the camera capture volume, the system's cameras would automatically activated by using the infrared gate, capturing the kinematic properties of the subject's gait.

Before the trials begin, the subjects' bilateral leg length (from greater trochanter to lateral malleolus), ankle width and knee width were measured and inserted into the system software for automated calculation of mass, COM and moment of inertia. Ground reaction force was obtained from the force plates for kinetic automated calculation by the Vicon software to obtained joint power and moment. The knee width of residual limb was considered as similar with the sound limb for transfemoral subjects. The ankle width for both transfemoral and transtibial subject residual limb also considered similar as to the sound limb measurement. Subjects were taped with 16 reflective markers of 14mm diameter bilaterally, each on their second metatarsal, lateral malleolus, calcaneus, fibula bone (laterally), lateral condyle, femur bone (laterally), anterior superior iliac spine and posterior superior iliac spine.

Figure 3.3 shows the marker placement reference for lower limb according to Helen Hayes marker placement on the human skeletal system.

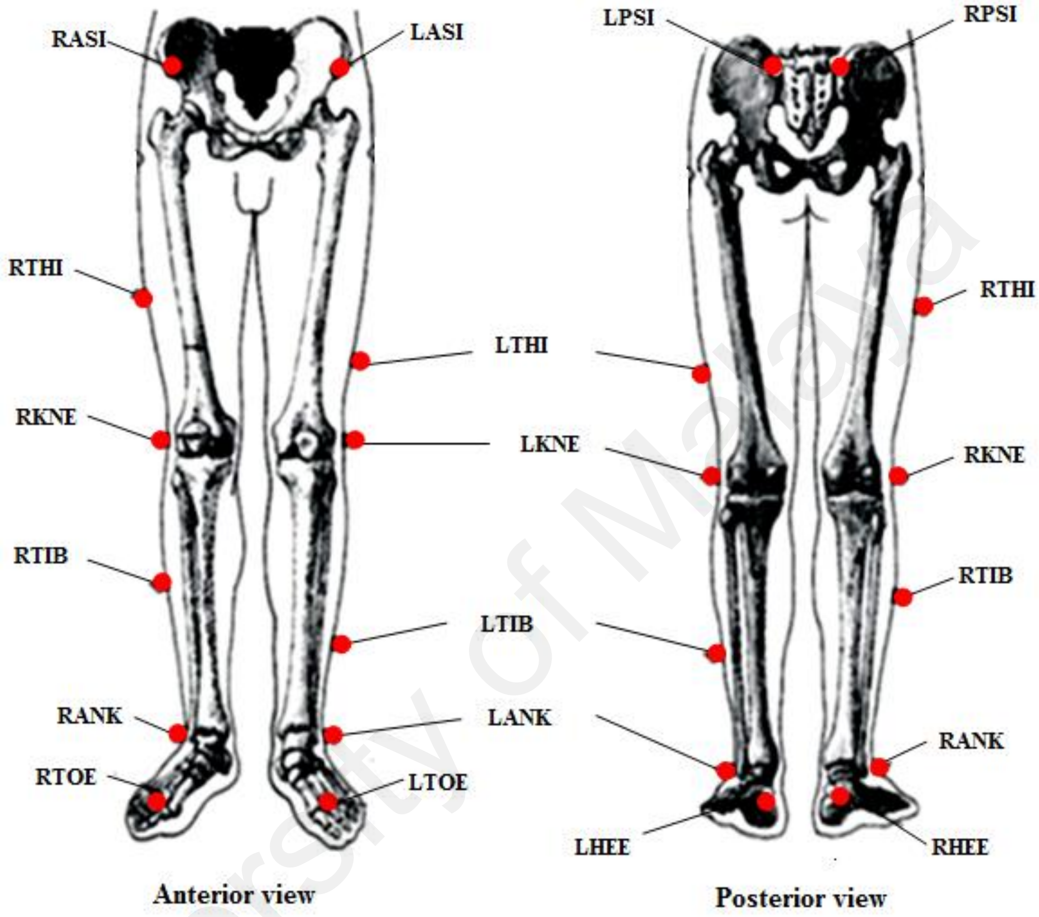


Figure 3.3: Marker placement (red dot) on the lower limb for both anterior and posterior view (Courtesy of Vicon)

After preparing the subject, the MX cameras were first calibrated in order to set the capture volume and axis zero point. Then, subject calibration took place where the subject was asked to stand in static position in order to capture and label the markers. The technical details on how to handle the software during calibration and data collection can be referred in study design and procedure in **Appendix B**. After the system and subject calibration was done, the procedure proceeds with the data collection. Subjects were asked to walk at their comfortable speed along the walkway and each trial considered as successful when each of the foot stepped on the force plate respectively. The trial was discarded from analysis if the subject's foot did not make a full contact with the force plates. Therefore, at least 20 trials were recorded for each subject and all the subjects were asked to rest in between the trial to prevent fatigue effect to the data collection. Figure 3.4 below shows the summary of the procedure took place in preparing for data collection.

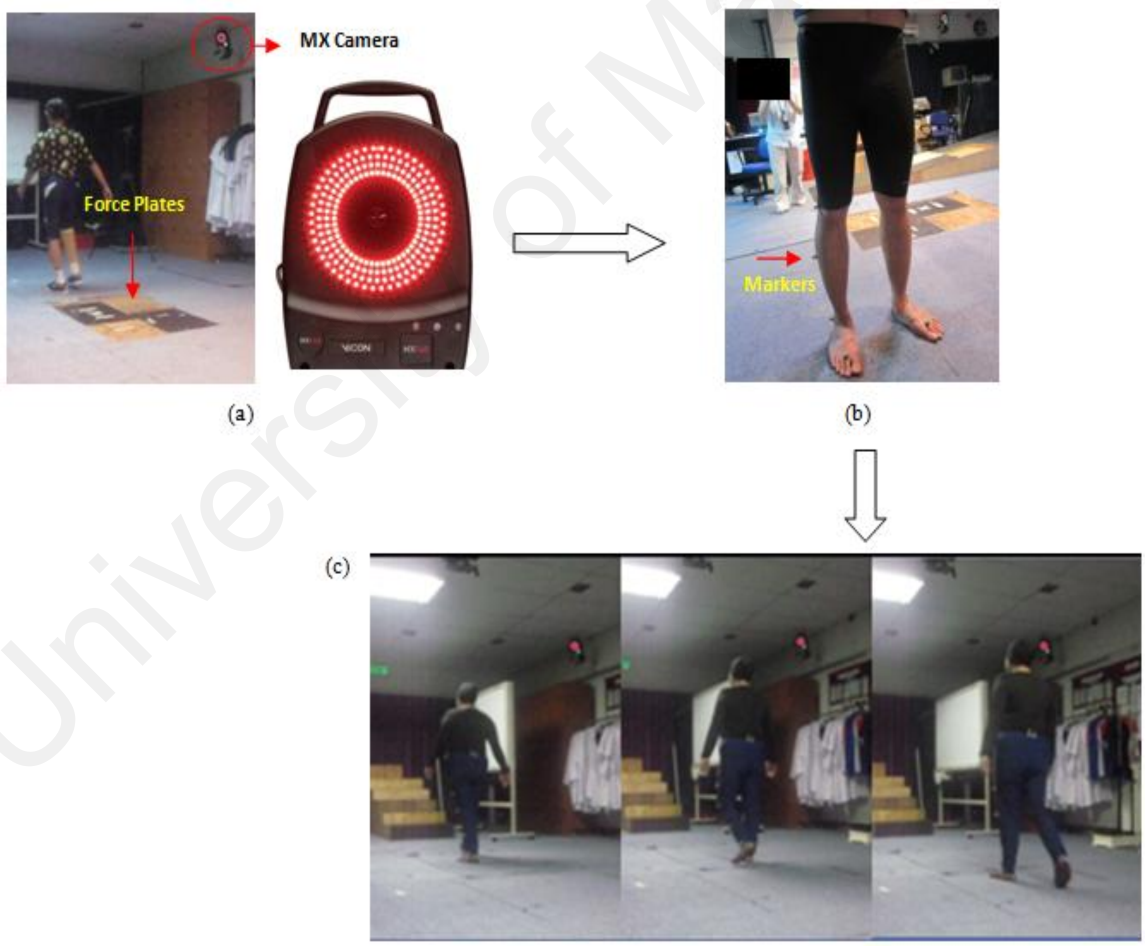


Figure 3.4: Data collection procedure's summary (a) Motion analysis equipments, (b) Markers placement on the subject's lower limbs, and (c) Subject walking at their comfortable speed during data collection

3.2.4. Data Analysis

Gait data was analyzed with a conventional model Vicon Plug-In-Gait and filtered using second-order Butterworth filter. The ankle, knee and hip joint kinematics, moments and gait events as well as relevant markers' trajectories, GRF and COP data were imported into Matlab (MathWorks, Inc., Natick, USA) for extraction and further analysis. Linear interpolation was applied to the original data points to obtain data points for joint kinematics and kinetics data at every 2% of stride duration. The joint moment was computed by inverse dynamics, using subjects' measurements and anthropometric properties (Robertson, 2004) and normalized to body weight.

The ankle dorsi-plantar flexion angles, knee and hip flexion-extension angles were the kinematic data that required in this study, while for kinetic analysis, all the three joints sagittal moment and power were extracted. A total of 36 relationship obtained by pairing the variables of the joint itself and across the two joints pair. The relationship are: angle-angle across the two joints pair (3 pairs), moment-moment across the two joints pair (3pairs), power-power across the two joints pair (3 pairs), angle-moment within the joint and across the two joints pair (9 pairs), angle-power within the joint and across the two joints pair (9 pairs), and moment-power within the joint and across the two joints pair (9 pairs). Most of this relationship has not been found in the literature except for angle-angle relationship across the two joints pair and moment-angle of the ankle joint.

The cyclograms relationships for the normal subjects were obtained by averaging the parameters of 20 subjects due to the consistency of the gait sub-phase duration among the normal subjects. However, this does not applied to the transtibial, transfemoral and orthoses subjects because of their irregularities of gait sub-phase duration in each trial. Thus, the relationships were obtained from each of the trial, for 10 trials for these subjects. These amputee subjects' cyclograms together with respective gait sub-phases from the trials being input into the neural network in Phase 2 to predict the output of subject-based movement profiles and identify the gait deviation at each of the gait sub-phase.

3.3. Phase 2: Using Cyclograms to Quantify Gait Disparity in term of Gait Sub-phases by Means of Neural Network

3.3.1. Introduction on how the cyclograms were applied to quantify gait disparity

At this phase, the neural network architecture was constructed by using the neural network toolbox in Matlab and the predicted outputs and errors obtained were used to quantify the disparity occurrence at each of the gait sub-phase. Figure 3.5 illustrates the example on how the cyclograms was utilized to determine the gait disparity occurrence at each gait sub-phase for each of the subject. The orange-coloured area represents the error between predicted output from NN and the normal cyclogram, i.e., the gait disparity. This error was generated by the neural network from automated calculation by the NN structure during simulation.

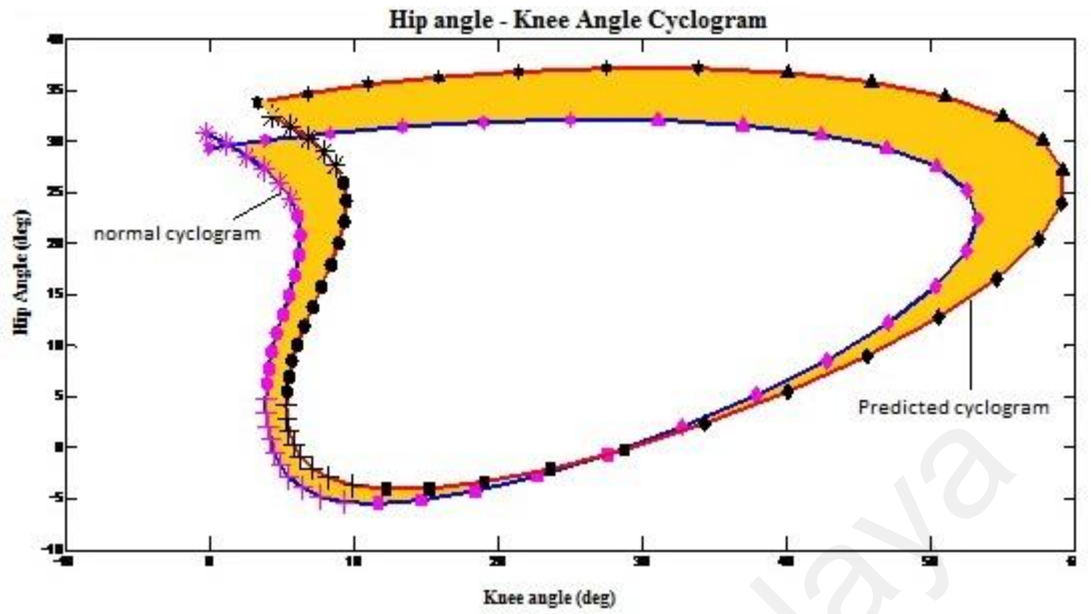


Figure 3.5: Example on how the cyclograms being applied to obtain the gait disparity in amputees. The shaded area indicates disparity from normal. Note some areas or gait phases are more deviated than others (This figure is for illustration purpose only, and does not related to the real geometric shape for amputees)

3.3.2. Network architecture

The type of feedforward network with backpropagation algorithm was chosen for this study. This network was chosen as it uses supervised learning rule during the training. The supervised learning rule provide an example for the network learning, and the network learn by comparing the predicted output with the desired output, and backpropagate the error to update the weight/bias (Beale et al., 2009). The network consisted of 3 layers, which respectively represent input layer, hidden layer and output layer. The input layer and output layer consist of 30 and 3 neurons, respectively, corresponding to the number of input data (30) and output data (3). The hidden layer was defined with 7 neurons to serve as the processing function to predict the output of cyclograms from 10 trials of each transfemoral and transtibial subjects. The relationship between the input data and the output data was linear, and the purpose of this phase was not to classify the different gait pattern, but to predict the interaction outcome of the two variables from given 10 trials of different data values. Thus, the default sigmoid transfer function of the network was replaced with the linear transfer function in the hidden layer. Figure 3.6 below shows the network architecture used in this study.

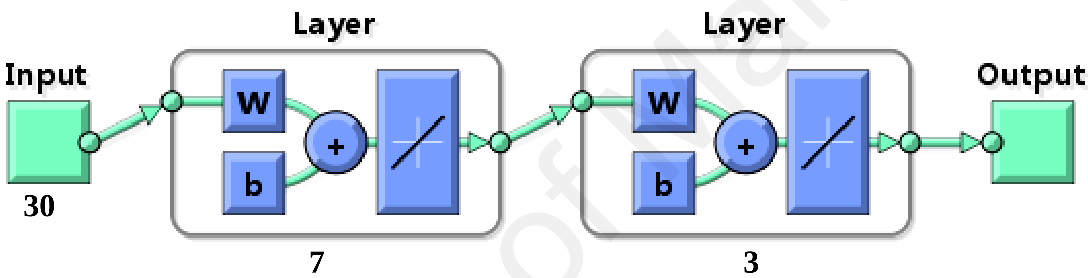


Figure 3.6: The network architecture with 3 layers

3.3.3. Input and output data arrangement for training, network validation and testing

The input data were arranged in 30 x 50 matrices, corresponding to 30 elements and 50 samples. By default, the NN read the data by rows, thus the first 10 rows were the first cyclogram's variable, the next 10 rows were the second cyclogram's variable, and the last 10 rows were the gait sub-phases which annotated as 1 until 7 corresponding to loading response to terminal-swing. The 50 columns of the data represent the samples of the variables series at an interval of 2% gait cycle and its respective gait sub-phase duration. The output data was 3 x 50 matrices correspond to first cyclogram's variable, second cyclogram's variable and the gait sub-phases. The input and target data arrangement is illustratesd as in Figure 3.7 below. The annotation of E1 to E30 and E1 to E3 represents the number of elements for input and target data respectively. While the annotation of S1 to S50 represents the samples of the data. For the network training, the input data that used was from 10 normal subjects; for the simulation, the input data was from 10 trials involving all the 36 cyclograms values of each transfemoral and transtibial subjects.

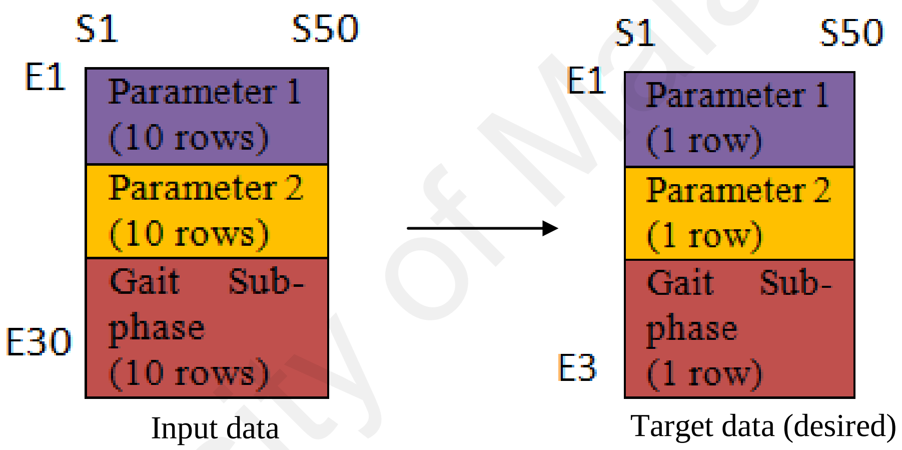


Figure 3.7: Illustration of the arrangment of input data and target data for network training

The network was first trained with the normal data of 100 trials from 10 subjects as network input and average normal data of 200 trials from 20 subjects as the network target. The purpose of network training was to let the NN learn the outcome of different paired variables interactions of normal subject as the reference. Total of 36 NN of the same architecture were created in Matlab Neural Network toolbox and are trained with 36 paired variables (cyclograms) respectively. During the training, default random division algorithm was used for the NN to divide the data randomly for training (60%), validation (20%), and testing (20%). When the neural network was trained, it starts up with randomized weights and progresses to the global solution as the input data was repeatedly presented. Therefore, the neural network would learn the desired output and predicted as close as to desired output when presented with unknown input during validation. The network weight was reinitialized if all the following criteria for the network performance were not met, only network that fulfilled the criteria as below are kept for simulation:

1. Final mean square error < 0.9 at the final iteration
2. The test set error and validation set error has similar characteristics (green line and red line in Figure 3.8 (a))
3. The regression for all set > 0.9 (regression line with grey colour in Figure 3.8 (b))

(a)

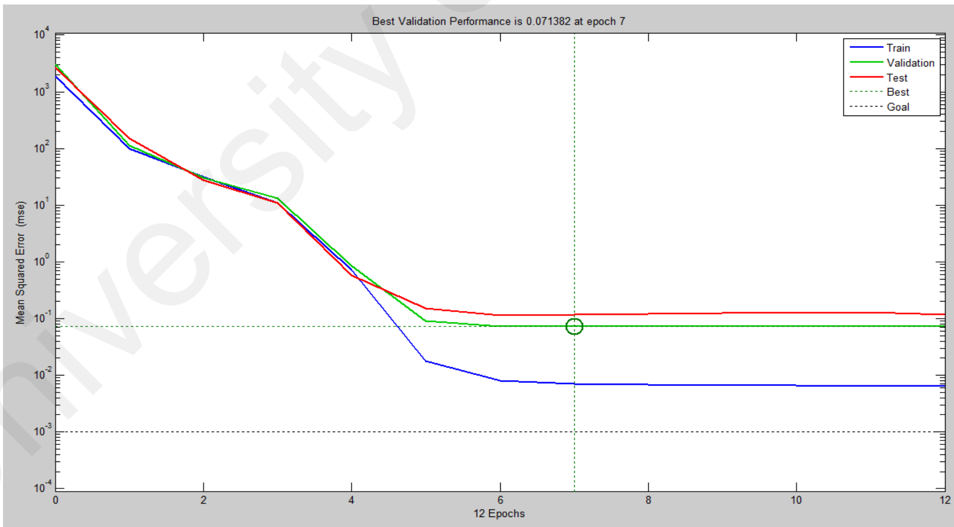
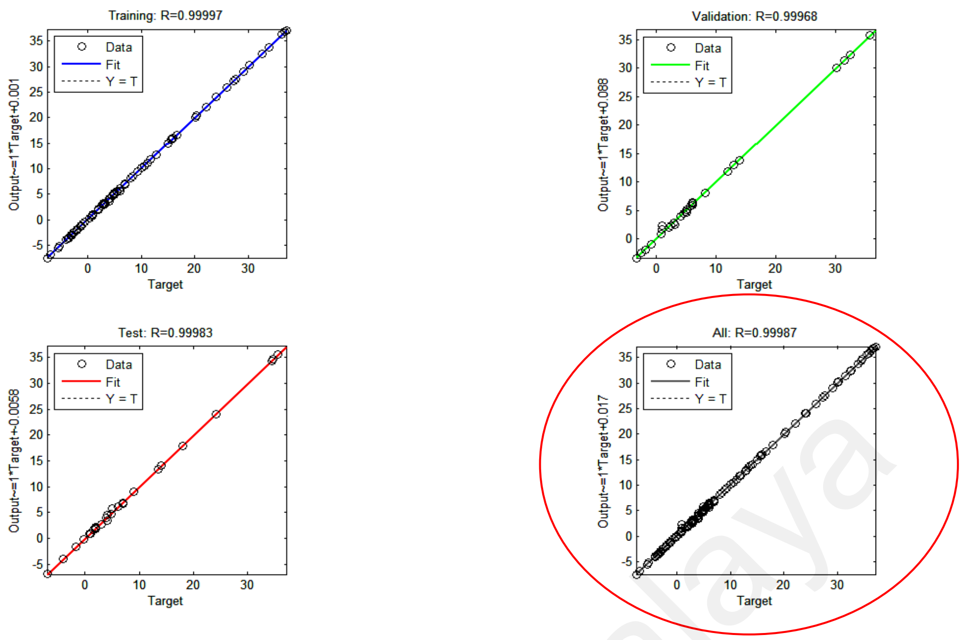


Figure 3.8: (a) Network performance curve in terms of mean squared error (mse) versus epochs, (b) Regression of predicted output versus target output for training, validation, testing and combination of all three

(b)



‘Figure 3.8 continued’

3.3.4. Validation of network prediction ability

Before simulating the network with the amputee subjects, the network was first tested and validated with 5 normal subjects and 25 different cases of amputees and orthoses subjects pathological conditions. The predicted cyclogram’s pair from the simulation was broken down into two variables curve as a function of gait cycle percentage. These two curves were then being compared with the curves that use the conventional trials averaging method. The errors between the two curves were calculated for each of the subject. Figure 3.9 shows the illustration example of how the network prediction ability was done.

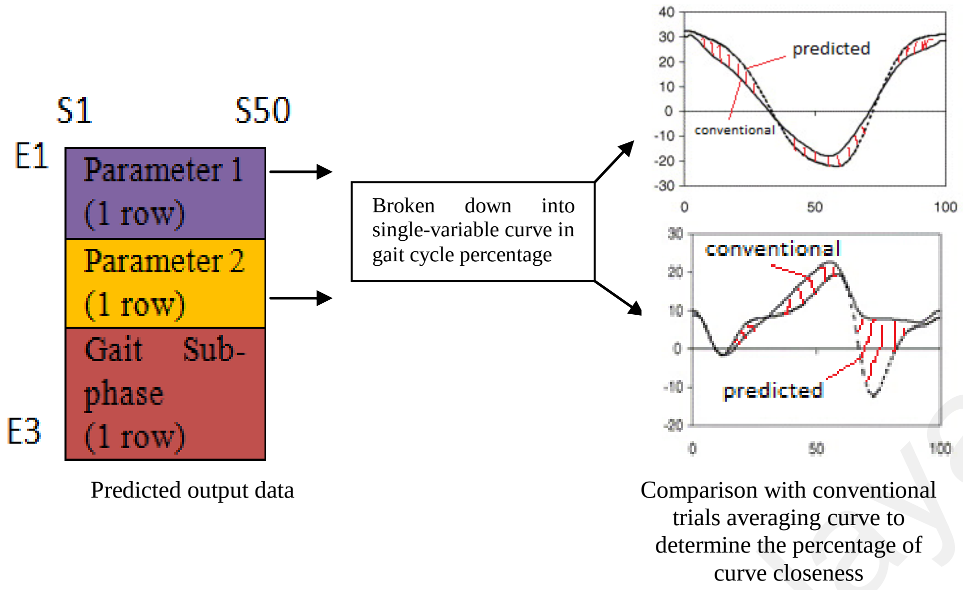


Figure 3.9: Workflow to validate the network prediction ability; the errors between the two curves were calculated at each point for each case of the subjects

This procedure was done to prove that the predicted output from the network has similar curve properties with the curve from using conventional trials averaging methods. The network prediction ability was presented in terms of percentage of the closeness of the network predicted output curve as compared to the conventional trials averaging curve. The percentage of closeness was calculated as Equation (3.1) below:

$$C = (1 - e_{p-c}) \times 100 \qquad \text{Equation (3.1)}$$

where, C = curves closeness

e_{p-c} = errors between predicted curve points and conventional curve points.

The percentage range for each type of validation subject is as presented in Table 3.2 below:

Table 3.2: Percentage range of closeness between network predicted output curve and conventional trials averaging curve

Subjects	No. of subjects	Percentage range (close-to-conventional-curve), C
Normal	5	91%- 99%
Orthosis	10	75%- 87%
Transtibial	10	73% - 81%
Transfemoral	5	68% - 79%

The validation percentage presented above indicates that the network, as it was trained with the normal subjects' data, it is as expected to have prediction ability of more than 90% with randomly-selected normal subjects. As for orthoses, transtibial and transfemoral subjects, the percentage range indicates that the NN used has the ability to segregate the deviated data as a whole series of gait cycle and interaction between two variables. The validation for these "pathological" subjects was expected to be less than 90%, and this error was the quantifying measure that was used in this study.

3.3.5. Network simulation and identification of gait disparity at each gait sub-phase

After the training and prediction ability validation, the network was used to predict the output of the transtibial and transfemoral cyclograms pattern when presented with the variables pair from 10 trials. The simulation was done for all 36 cyclograms pairs for each of the amputee subject. The target output as used in network training was supplied to the network in order to measure the error between the predicted output with the desired output. The errors were then normalized with the normal values from the target output. The mean normalized errors for each sub-phase were calculated in order to determine the pair that contributes to the largest error at particular sub-phase as compared to the normal cyclograms. The process was repeated for each of the transtibial and transfemoral subjects. The mean normalized error of each sub-phase was calculated as Equation (3.2) below:

$$\bar{E} = \frac{\sum(\frac{e_{phase}}{M})}{n}$$

Equation (3.2)

where, $\bar{E}$ = mean normalized error,

e_{phase} = error between predicted output and target at each point of particular sub-phase

M = normal variable value at each point of a particular sub-phase

n = number of points at the particular sub-phase

3.4. Phase 3: Using Manipulated Cyclograms to Identify Effective Control Parameter in term of Gait Sub-phases for Prosthetic Knee by Means of Neural Network

At this phase, the results obtained from the previous phase were used to assess the effect of manipulating one variable towards the other variable of the cyclograms. At each of the gait sub-phase for each amputee, the cyclograms relationship that has the largest deviation was then being input back into the neural network. A modification of the variable values at the particular sub-phase where the highest mean normalized error occurred was done by inserting the normal value at one of the paired variables as illustrated in Figure 3.10. The network was simulated with the modified input data and the target output data was again being supplied. The error between the predicted output and the desired output was calculated again at each of the sub-phase. This process was repeated again with the other variable of the pair. The results obtained were compared to determine which parameter manipulation gives predicted output that closer-to-normal cyclograms. This way, the relevant parameter to be controlled at each of the gait sub-phase was outlined.

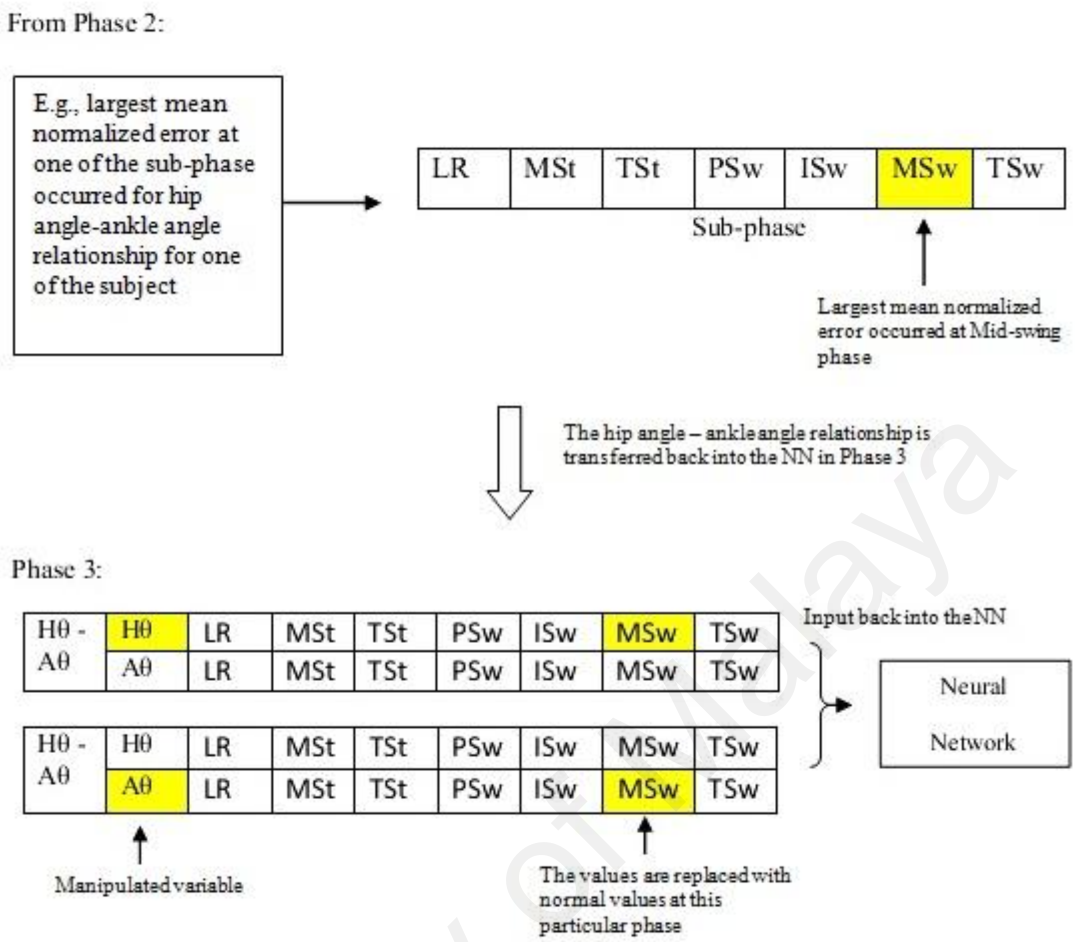


Figure 3.10: The workflow of transferring the result from Phase 2 into Phase 3

CHAPTER 4: RESULTS

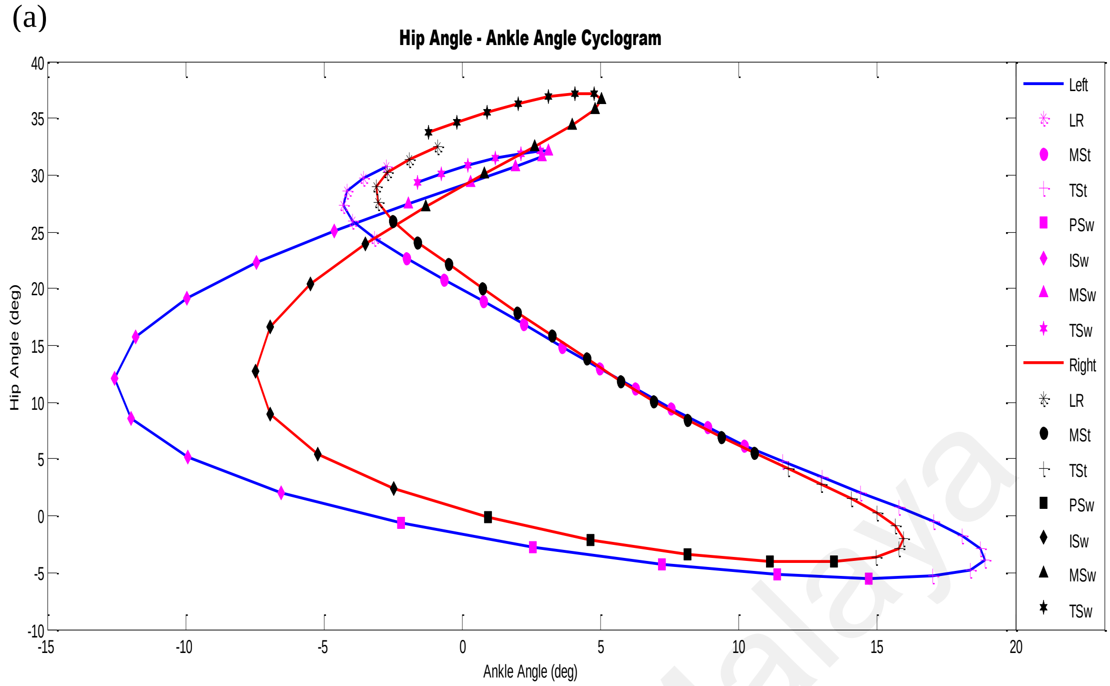
4.1. Phase 1: Cyclograms of Normal Subjects

From the analysis of kinematics and kinetics properties of the gait trials, a total of 36 pairs of the cyclograms, each on left and right side were plotted. Generally, the pattern of one side was shifted from the other side. The gait sub-phase duration for each side was almost identical to one another.

4.1.1. Angle-angle cyclograms

The result from Figure 4.1 (a) - (c) shows that the range of motion of ankle angle ranged from 10^{o} (plantarflexion) to 20^{o} (dorsiflexion) on the right side and from 15^{o} (plantarflexion) to 20^{o} (dorsiflexion) on the left side, the hip ranged of motion is from 5^{o} (extension) to 40^{o} (flexion) on the right side and from 10^{o} (extension) to 35^{o} (flexion) on the left side, and as for the knee, it is from 0^{o} (extension) to 60^{o} (flexion) on the right side and 5^{o} (extension) to 55^{o} (flexion) on the left side. The cyclograms reveal that although the value for each plantarflexion/dorsiflexion and flexion/extension on each joint shifted from each other of left and right side, however the angle displacement when the joints changes from extension to flexion, were found to be similar on both left and right side except for ankle angle which has a difference of 5^{o}. This marked the angle displacement from extension to flexion for hip was 45^{o}, while as for the knee was 60^{o}. The travelling direction from loading response sub-phase to terminal-swing sub-phase of the cyclograms was also similar on both sides.

(a)



(b)

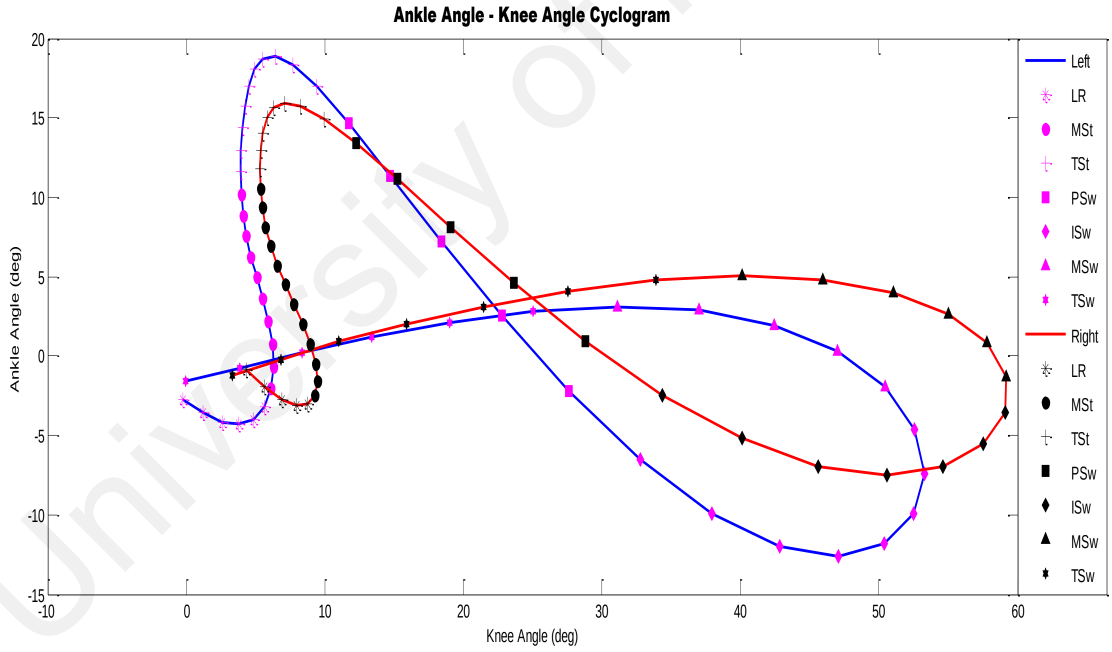
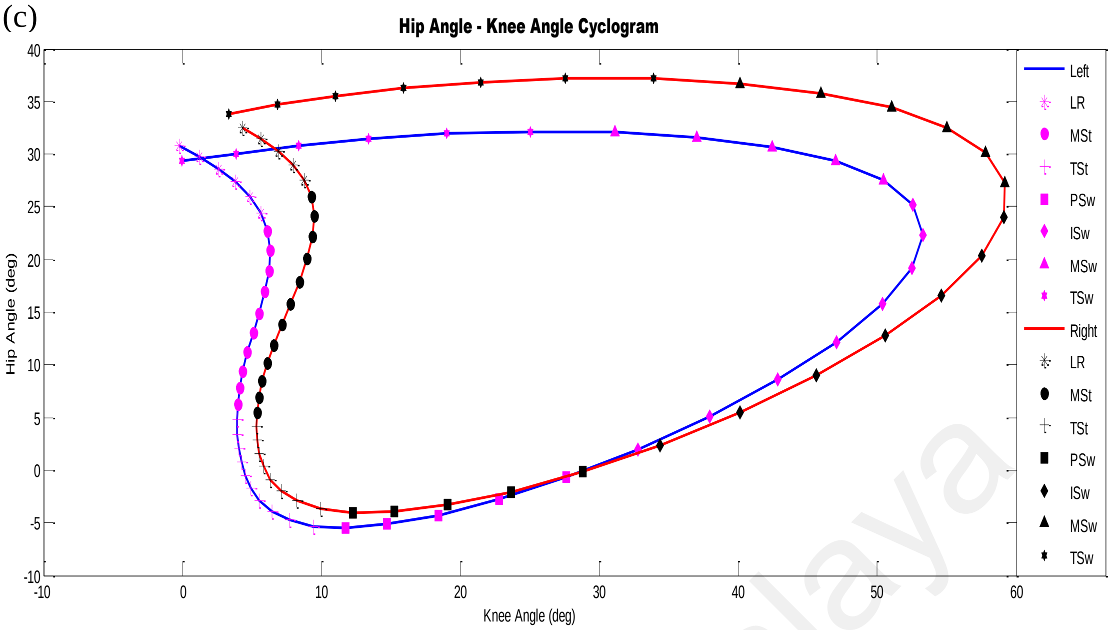


Figure 4.1: Angle and angle relationship across the two joints pair for both left and right leg with gait sub-phases (a) Hip Angle – Ankle Angle cyclogram, (b) Ankle Angle – Knee Angle cyclogram, (c) Hip Angle – Knee Angle cyclogram

(c)



'Figure 4.1, continued'

4.1.2. Moment-Moment cyclograms

From Figure 4.2 (a) – (c), the result shows that the ankle moment ranged from 0Nm/kg (plantarflexion) to 2.0Nm/kg (dorsiflexion) on the right side and from 0Nm/kg (plantarflexion) to 2.3Nm/kg (dorsiflexion) on the left side, the hip moment ranged from 1.5Nm/kg (extension) to 0.5Nm/kg (flexion) on the right side and from 0.5Nm/kg (extension) to 1.5Nm/kg (flexion) on the left side, while for the knee was from 0.4Nm/kg (extension) to 0.6Nm/kg (flexion) and from 0.8Nm/kg (extension) to 0.2Nm/kg (flexion). Similarly with the angle displacement, the moment displacement of the joint was similar on both sides despite the different values of extension/flexion moment except for ankle moment that has a difference of 0.3Nm/kg on the dorsiflexion on the right side. The moment displacement from extension moment to flexion moment for both sides' at knee joint was 1Nm/kg and the hip moment was measured to be 2Nm/kg on both sides. Despite the similar moment displacement on the both side, the pairs of moment across the two joints on each side are travelling on opposite direction from another, starting from the loading response sub-phase. The knee moment on the right side exhibits change of direction starting from Mid-stance to Pre-swing when paired with either ankle moment or hip moment.

(a)

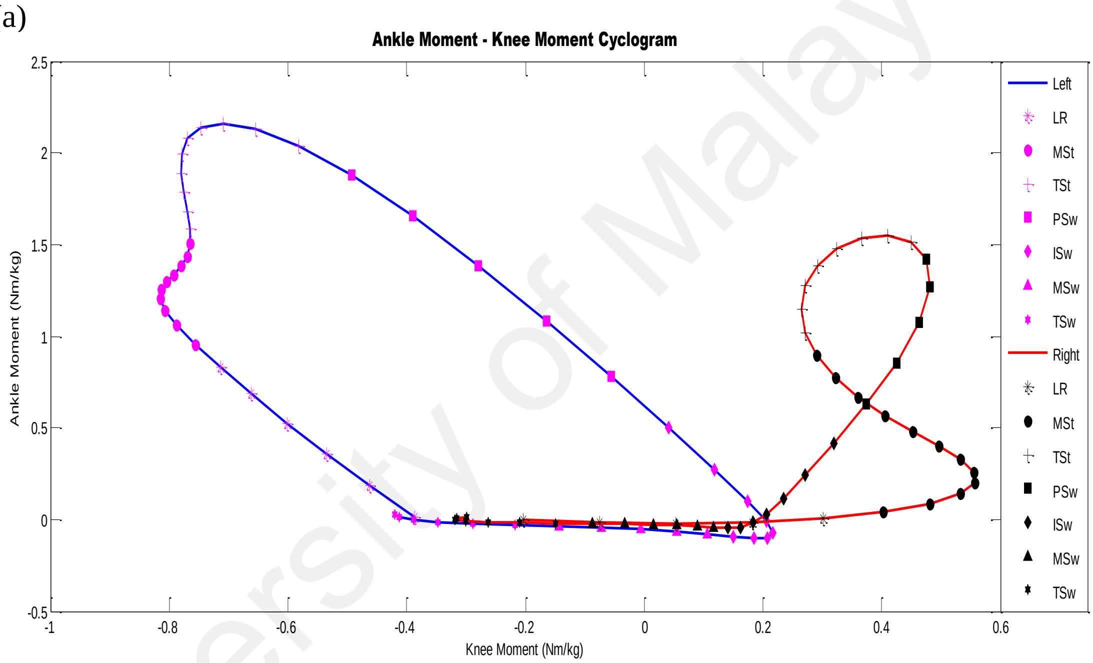
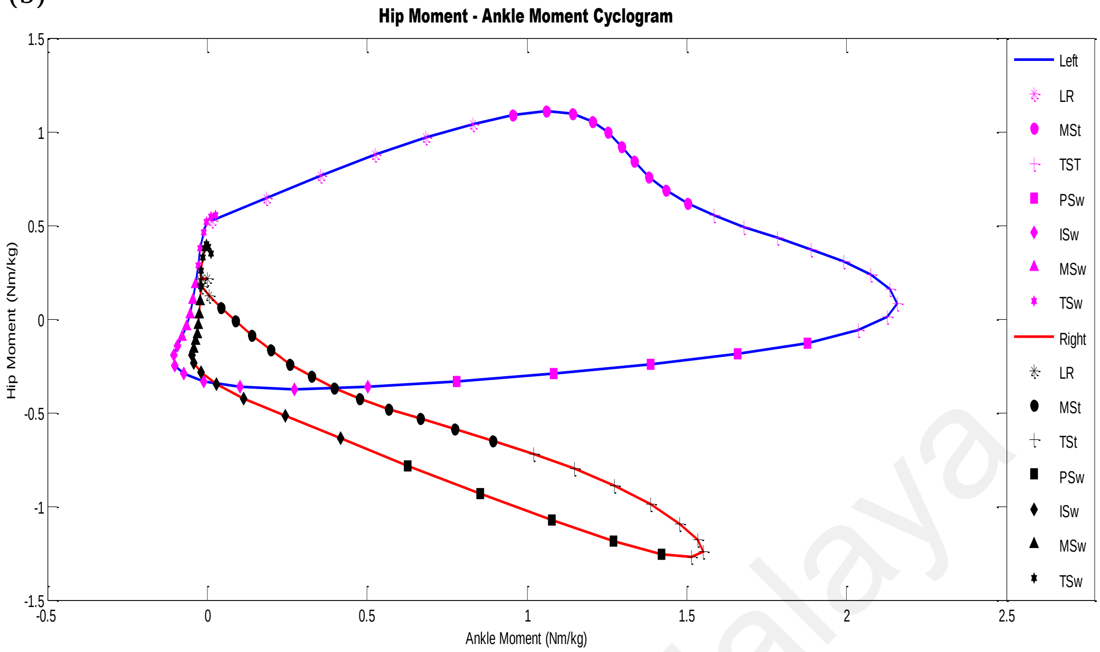


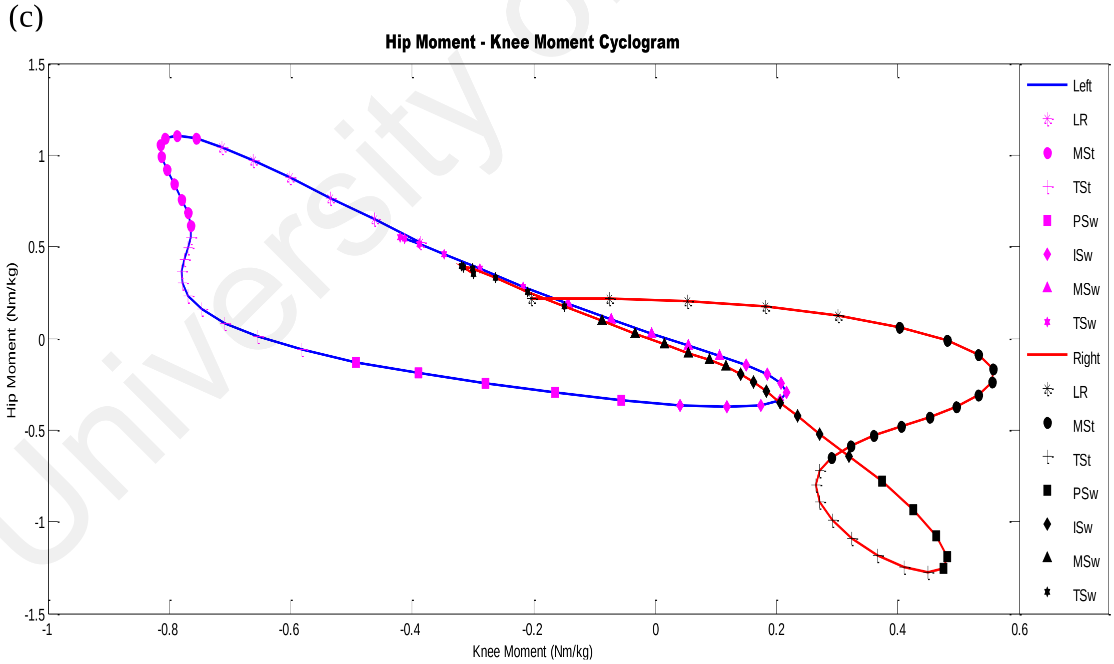
Figure 4.2: Moment and moment relationship across the two joints pair for both left and right leg with gait sub-phases (a) Ankle Moment – Knee Moment cyclogram, (b) Hip Moment – Ankle Moment cyclogram, (c) Hip Moment – Knee Moment cyclogram

(b)



'Figure 4.2, continued'

(c)

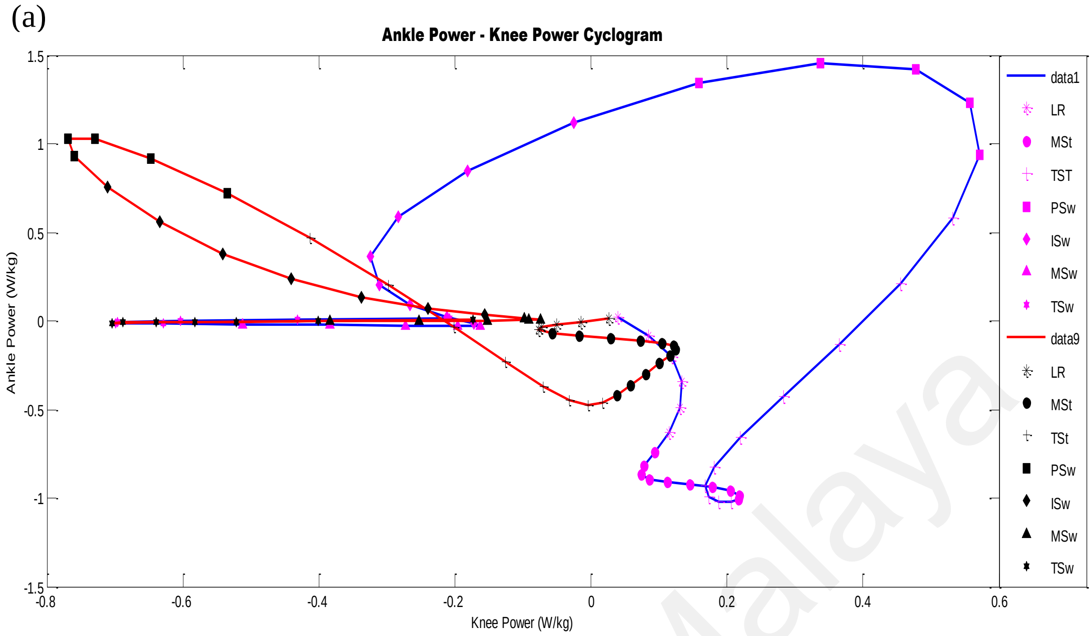


'Figure 4.2, continued'

4.1.3. Power-power cyclograms

From Figure 4.3 (a) – (c), the cyclograms shows that the ankle joint power was ranged from 0.5W/kg (absorption) to 1W/kg (generation) on the right side and from 1W/kg (absorption) to 1.5W/kg (generation) on the left side. As for the hip joint, the power was ranged from 0.4W/kg (absorption) to 0.7W/kg (generation) on the right side and from 0.1W/kg (absorption) to 1W/kg on the left side. Meanwhile for the knee joint, the power was from 0.8W/kg (absorption) to 0.2W/kg (generation) on the right side and from 0.7W/kg (absorption) to 0.6W/kg (generation) on the left side. The amount of power generated on the ankle joint and hip joint on both sides were more than the power being absorbed, while reversely, the amount of power generated on the knee joint was less than the power being absorbed for both sides. All three joints on the left side exhibit larger power generation as compared to the right side. All three pairs of moment and moment between two joints display opposite direction of travelling starting from the loading response.

(a)



(b)

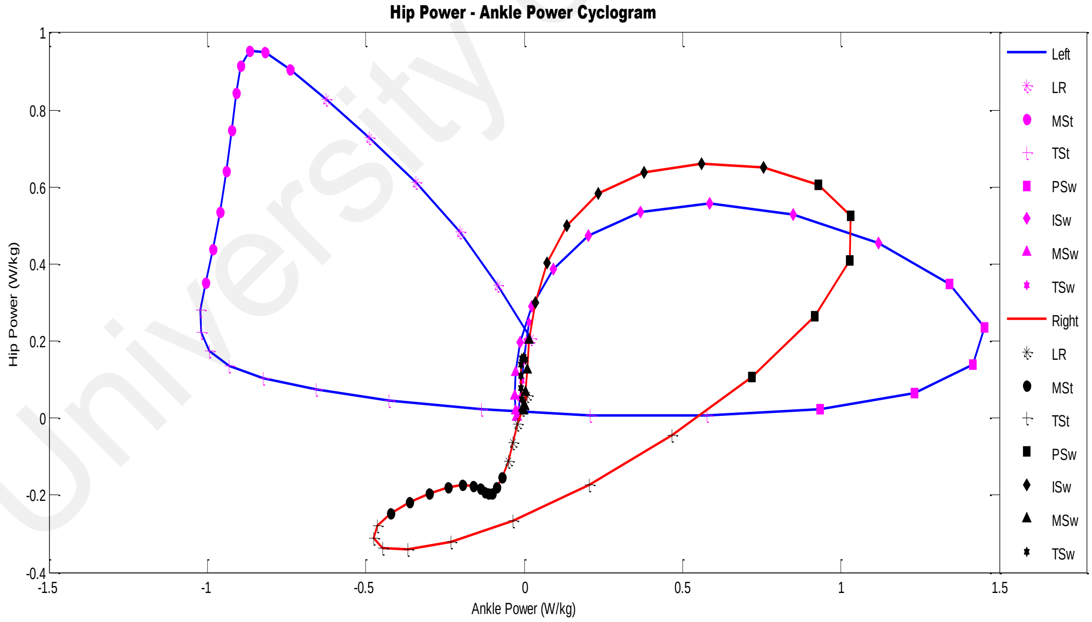
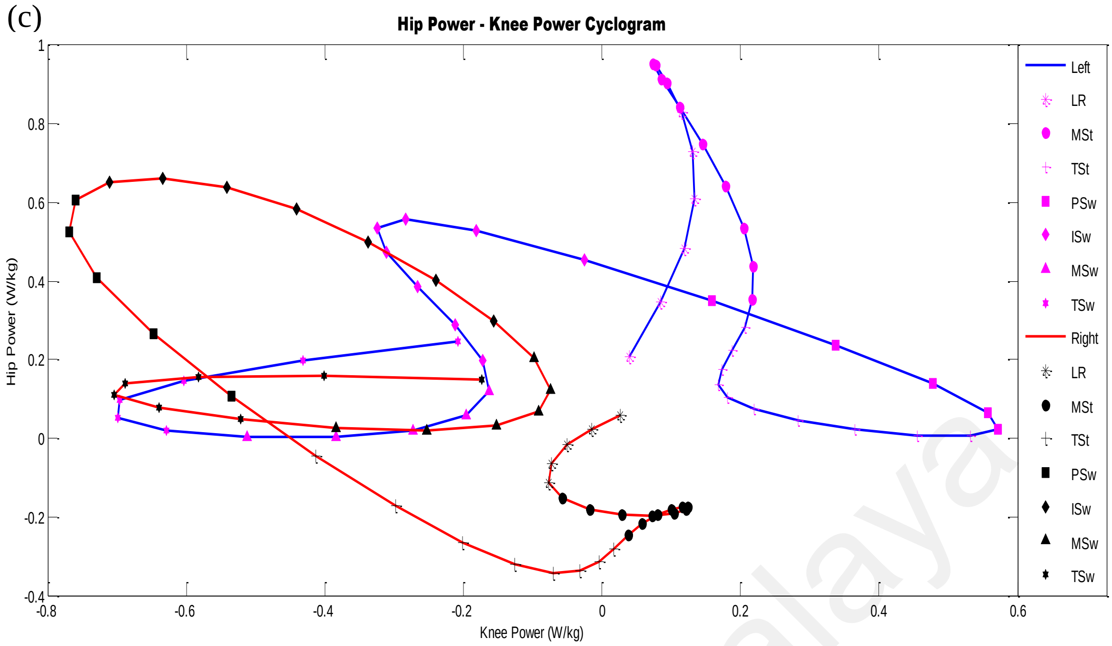


Figure 4.3: Power and power relationship across the two joints pair for both left and right leg with gait sub-phases (a) Ankle Power – Knee Power cyclogram, (b) Hip Power– Ankle Power cyclogram, (c) Hip Power – Knee Power cyclogram

(c)

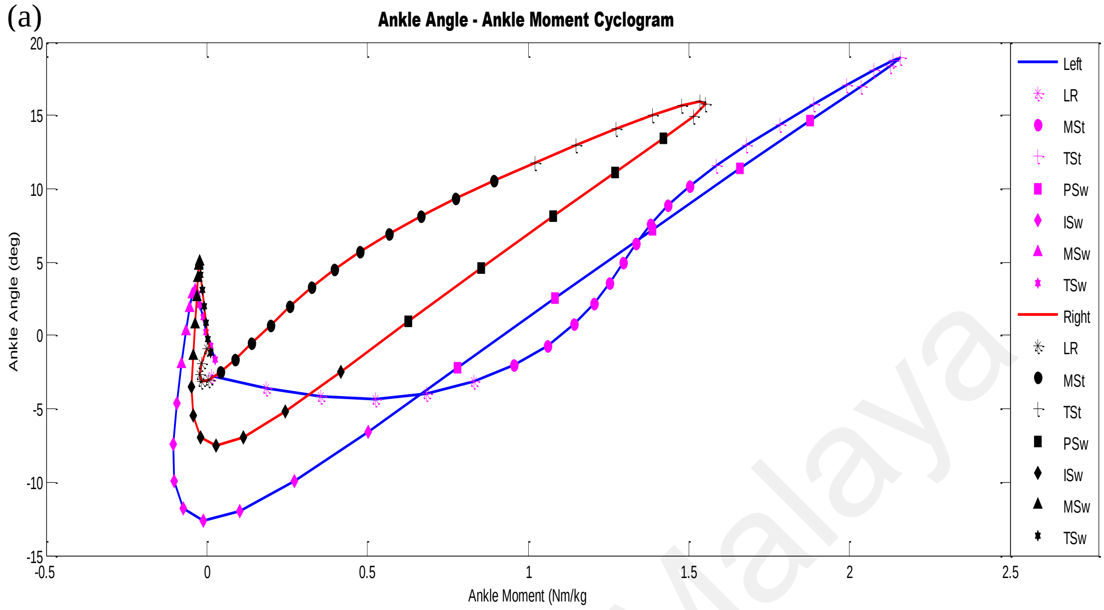


'Figure 4.3, continued'

4.1.4. Angle-moment Cyclograms

The angle and moment cyclograms for each of the joint itself, i.e. within the joint, are displayed as in Figure 4.4 (a) – (c). The result shows that the moments of plantarflexion/extension and dorsiflexion/flexion move along with angle of plantarflexion/extension and dorsiflexion/flexion respectively. The travelling direction from loading response for angle and moment relationship within the joint is similar for both sides except for knee joint. The change of travelling direction was occurred on the left side starting from the mid-stance until end of mid-stance at the left side for the ankle joint. The change in travelling direction was also observed on the left side at the knee joint starting from pre-swing phase until end of mid-swing phase. Meanwhile, the change of direction was observed on the right side for the hip joint starting from pre-swing until end of initial-swing.

(a)



(b)

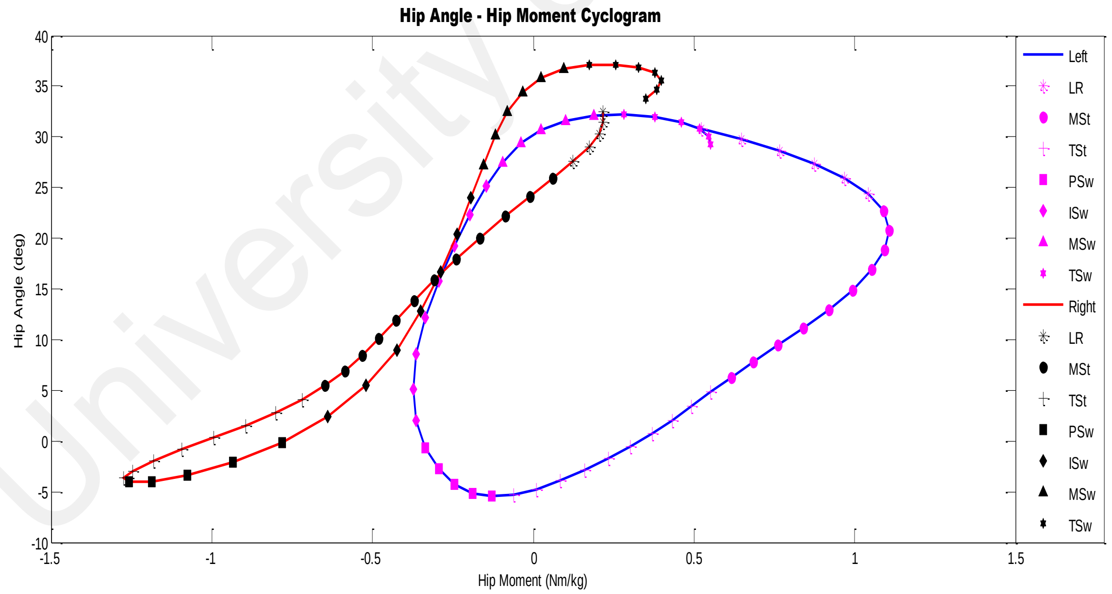
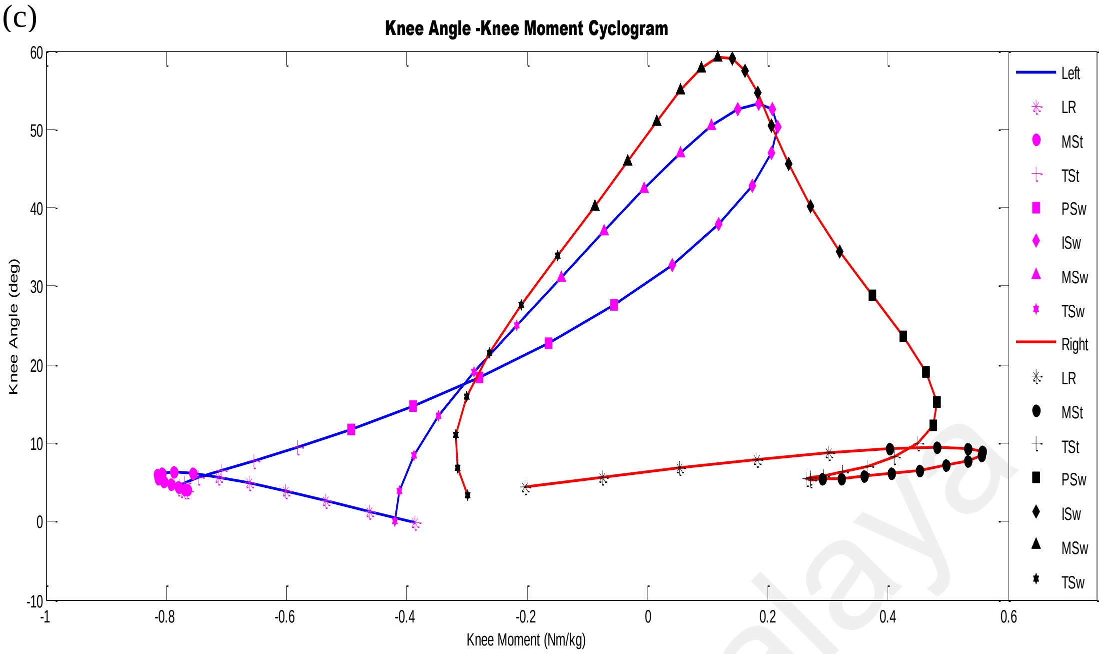


Figure 4.4: Angle and moment relationship within the lower limb joint for both left and right leg with gait sub-phases (a) Ankle Angle – Ankle Moment cyclogram, (b) Knee Angle – Knee Moment cyclogram, (c) Hip Angle – Hip Moment cyclogram

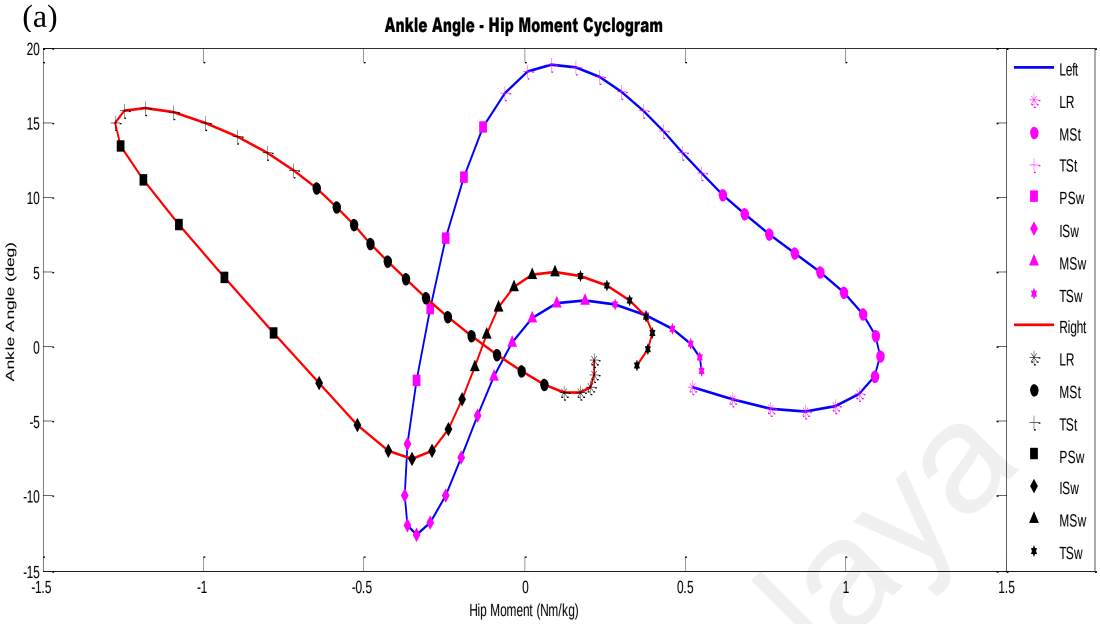
(c)



'Figure 4.4, continued'

The angle and moment cyclograms across the two joints pair are showed in Figure 4.5 (a) – (f). The results showed that the moment of plantarflexion/extension and dorsiflexion/flexion does not necessarily moves along with respective angle of plantarflexion/extension and dorsiflexion/flexion for both sides. At a certain phase, the moment of one joint moves with the opposite pairs of angle of the other joint. All the cyclograms travels in the opposite direction for each side except for hip angle – ankle moment relationship and knee angle – ankle moment relationship. The other pairs that move in opposite direction from each side exhibited an obvious change in travelling direction on the right side at a certain phase.

(a)



(b)

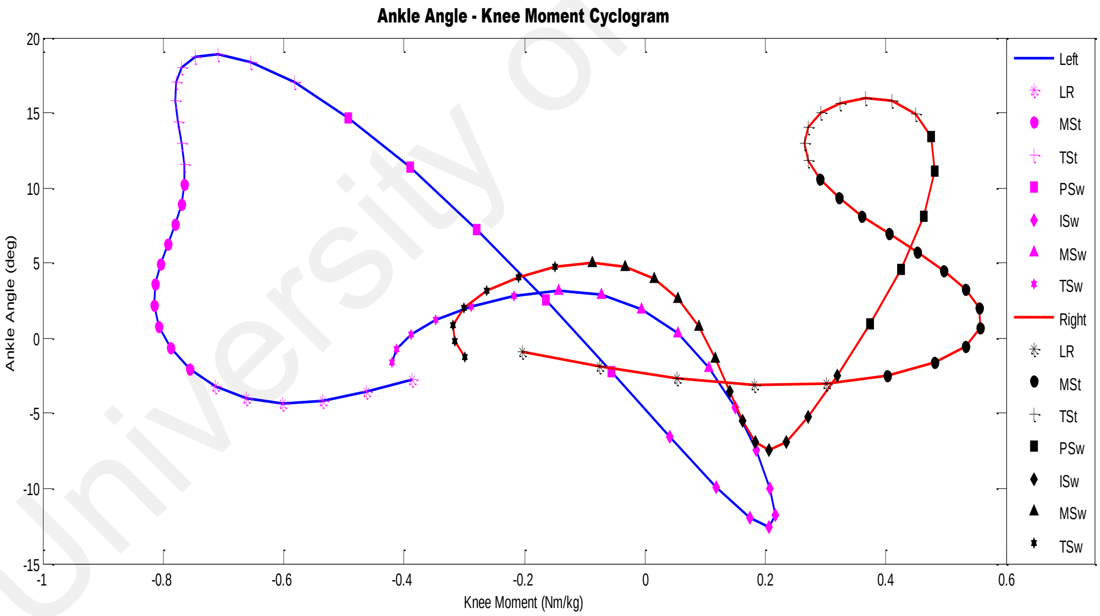
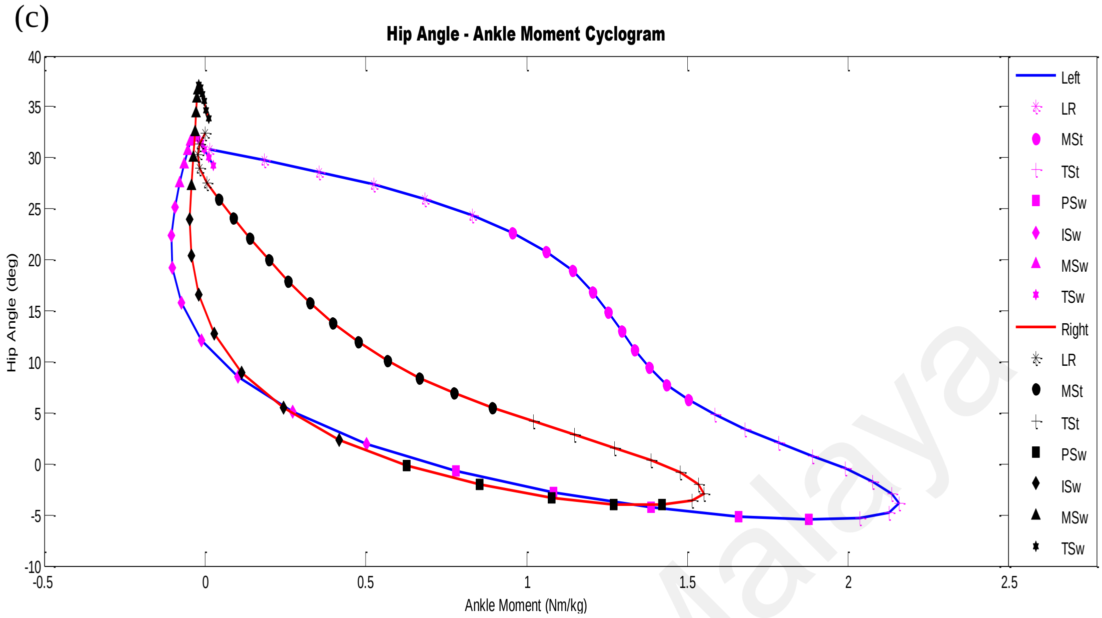


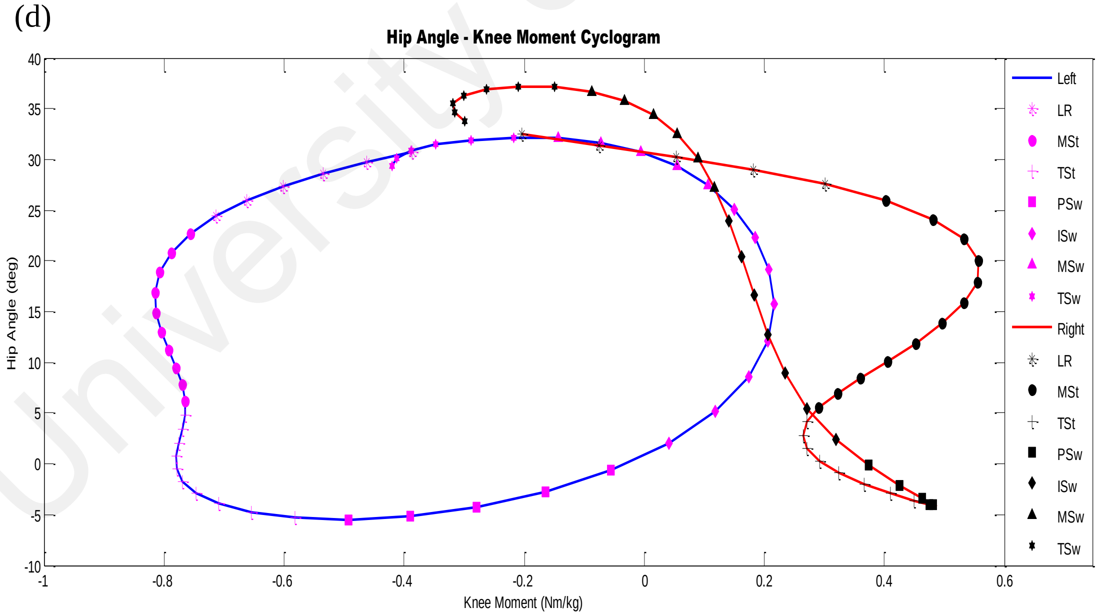
Figure 4.5: Angle and moment relationship across the two joints pair for both left and right leg with gait sub-phases (a) Ankle Angle – Hip Moment cyclogram, (b) Ankle Angle – Knee Moment cyclogram, (c) Hip Angle – Ankle Moment cyclogram, (d) Hip Angle – Knee Moment Cyclogram, (e) Knee Angle – Ankle Moment cyclogram, (f) Knee Angle – Hip Moment cyclogram

(c)



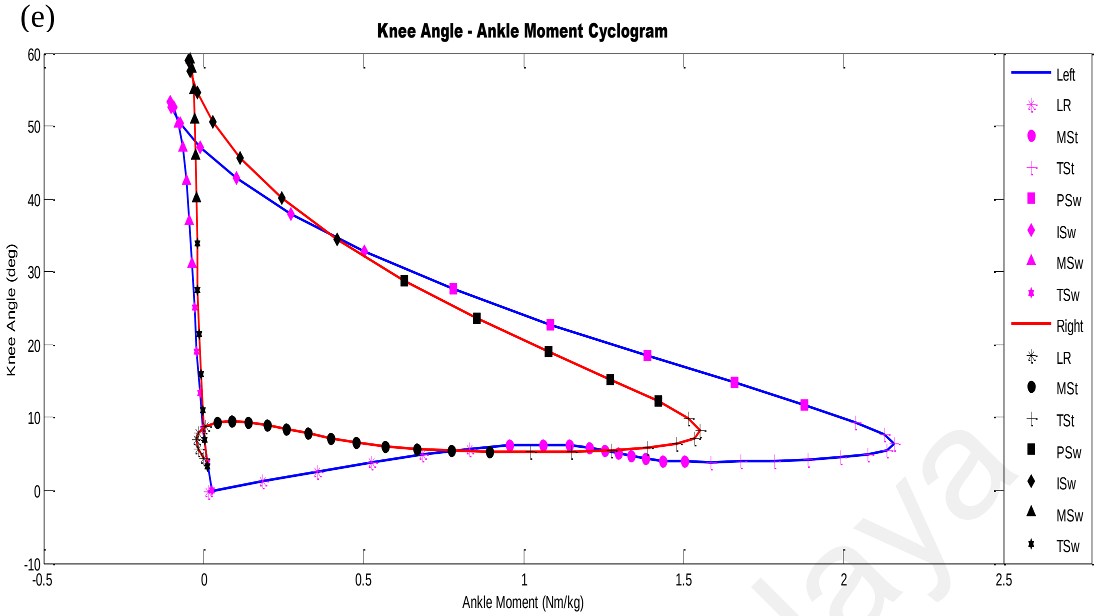
'Figure 4.5, continued'

(d)



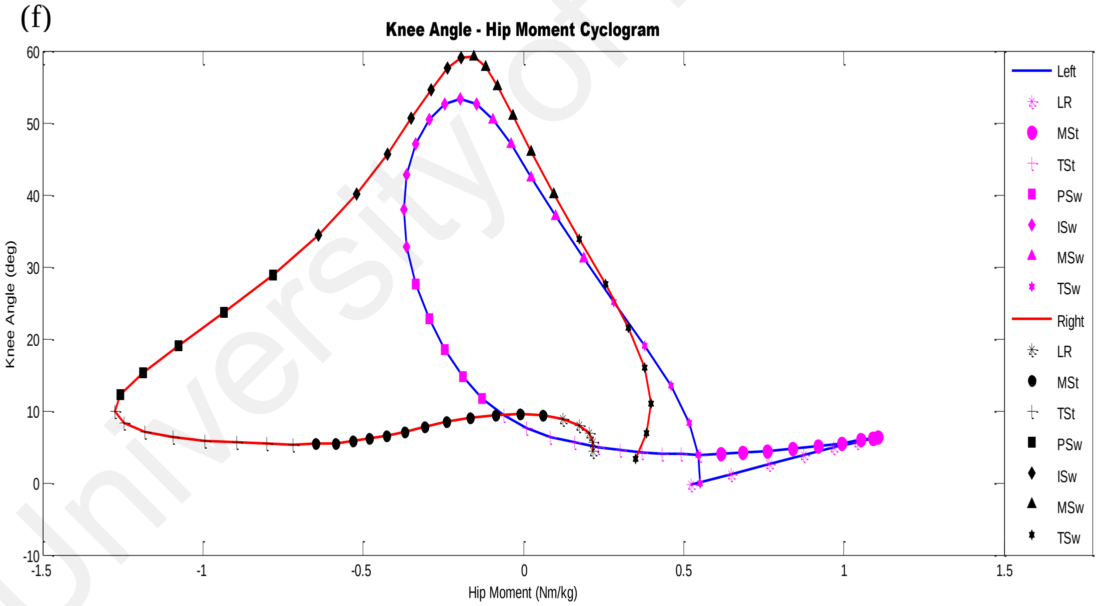
'Figure 4.5, continued'

(e)



'Figure 4.5, continued'

(f)



'Figure 4.5, continued'

4.1.5. Angle-power cyclograms

From Figure 4.6 (a) – (c), the cyclograms for angle and power pairs within the joint is shown. The result reveals that the power generation are largely occur at the joint dorsiflexion/flexion angle. The travelling direction of the parameter pairs of the joint were in opposite direction starting from loading response for each side except for ankle joint. The hip joint showed change in direction from end of mid-stance until end of terminal-swing on the left side. Meanwhile, the knee joint exhibit change in direction from mid-swing until terminal-swing.

(a)

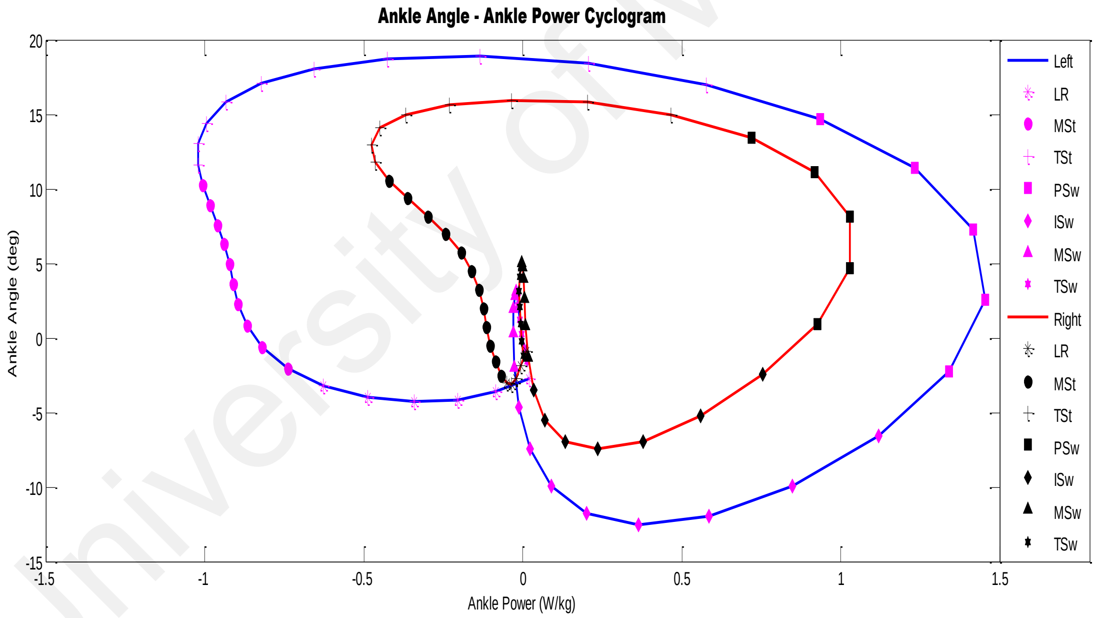
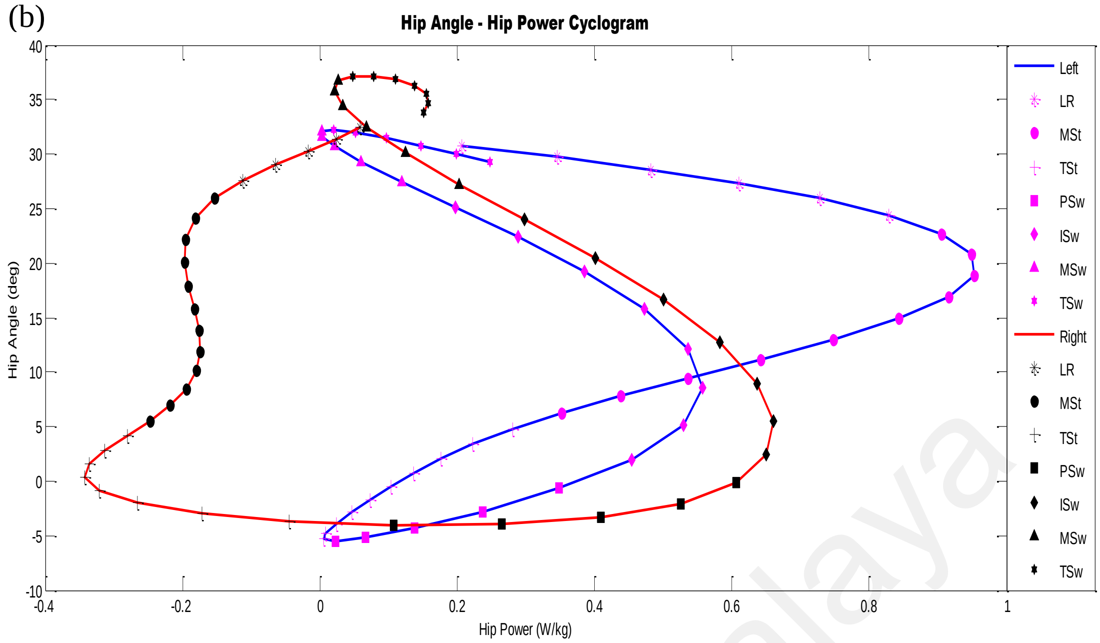


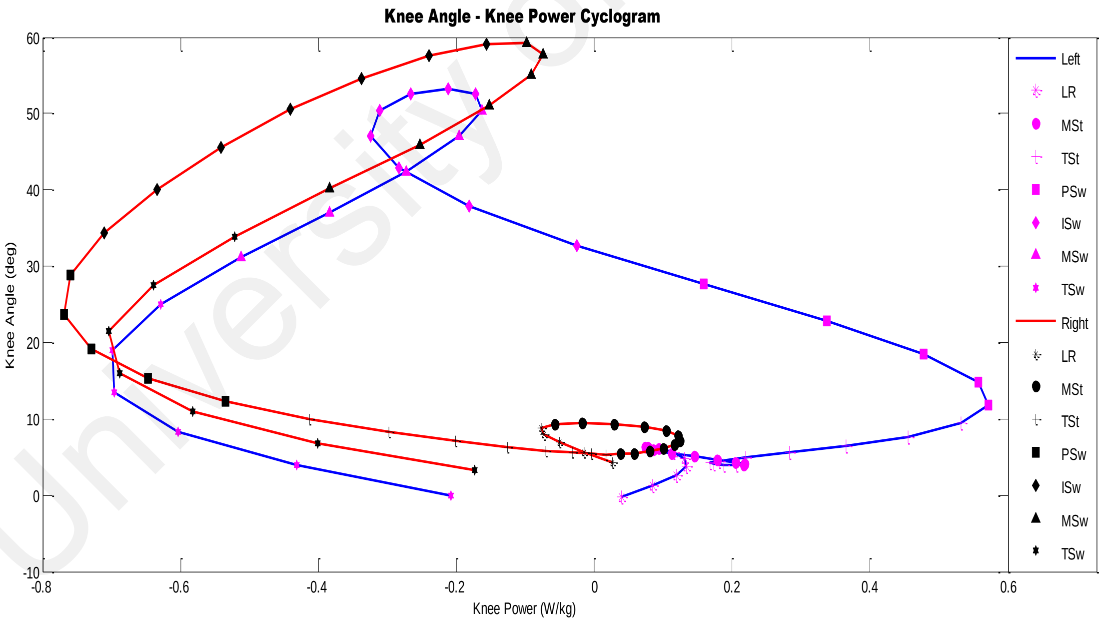
Figure 4.6: Angle and power relationship within the lower limb joint for both left and right leg with gait sub-phases (a) Ankle Angle – Ankle Power cyclogram, (b) Knee Angle – Knee Power cyclogram, (c) Hip Angle – Hip Power cyclogram

(b)



'Figure 4.6, continued'

(c)



'Figure 4.6, continued'

The angle and power cyclograms across the two joints pair were shown in Figure 4.7 (a) – (f). Similar properties with moment, the results showed that the absorption or generation power does moves along with both plantarflexion/extension angle and dorsiflexion/flexion at both sides. All the cyclograms travels in the opposite direction for each side except for hip angle – ankle power relationship and knee angle – ankle power relationship. The other pairs that move in opposite direction from each side exhibit an obvious change in travelling direction from mid-swing until terminal swing, where one side moves in the same direction as the other side within this sub-phases. It was also observed that during the angle changes from plantarflexion to dorsiflexion for ankle joint and from extension to flexion for knee and hip joint, one side of the leg absorb the power while the other side generate the power.

(a)

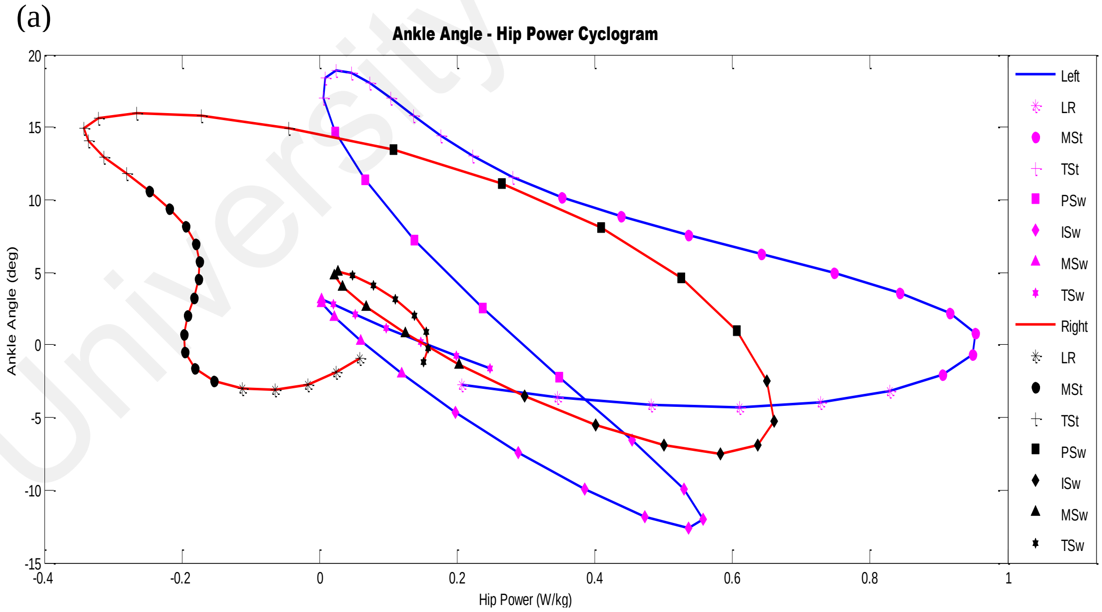
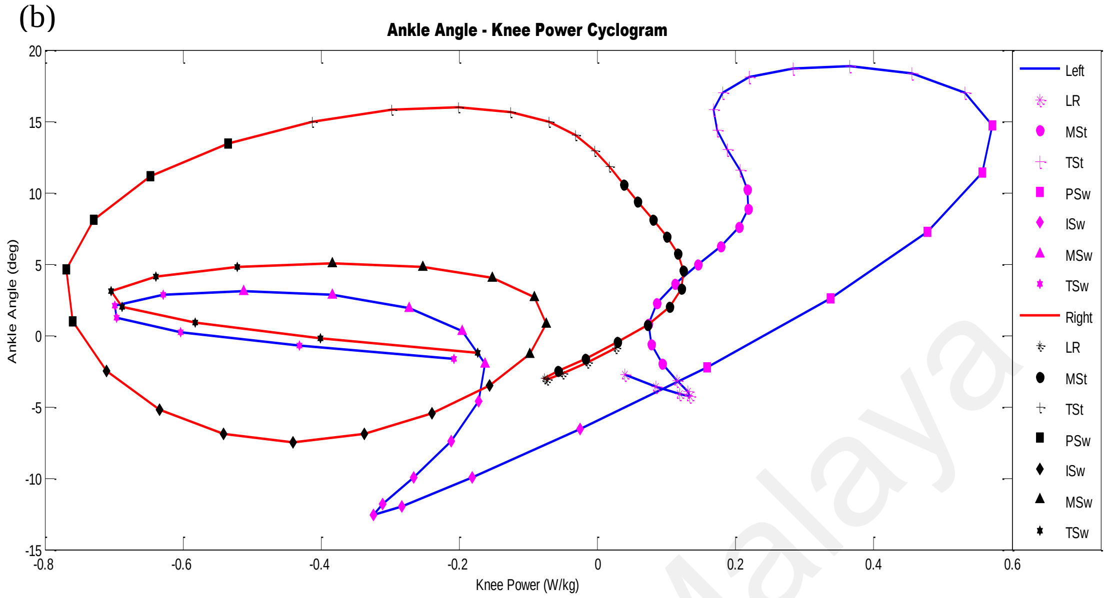


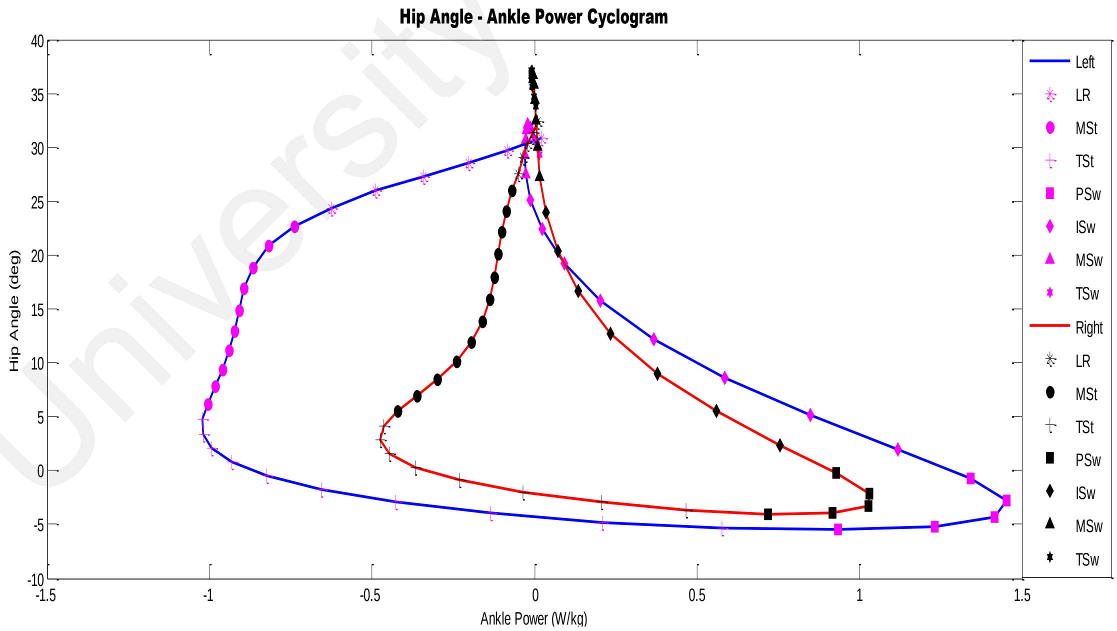
Figure 4.7: Angle and power relationship across the two joints pair for both left and right leg with gait sub-phases (a) Ankle Angle – Hip Power cyclogram, (b) Ankle Angle – Knee Power cyclogram, (c) Hip Angle – Ankle Power cyclogram, (d) Hip Angle – Knee Power cyclogram, (e) Knee Angle – Ankle Power cyclogram, (f) Knee Angle – Hip Power cyclogram

(b)



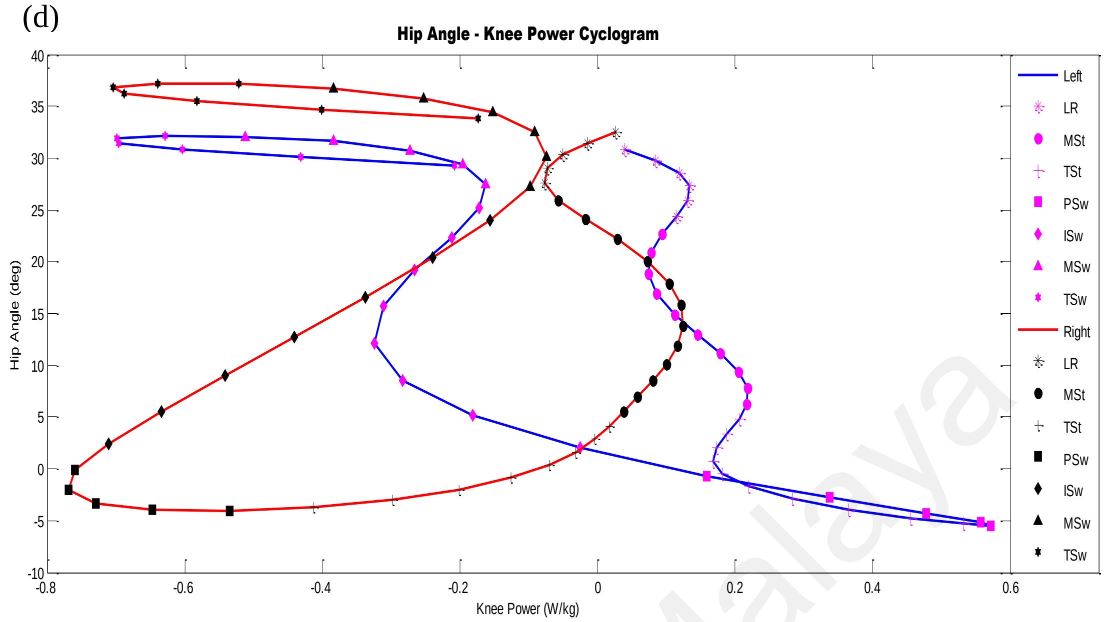
'Figure 4.7, continued'

(c)



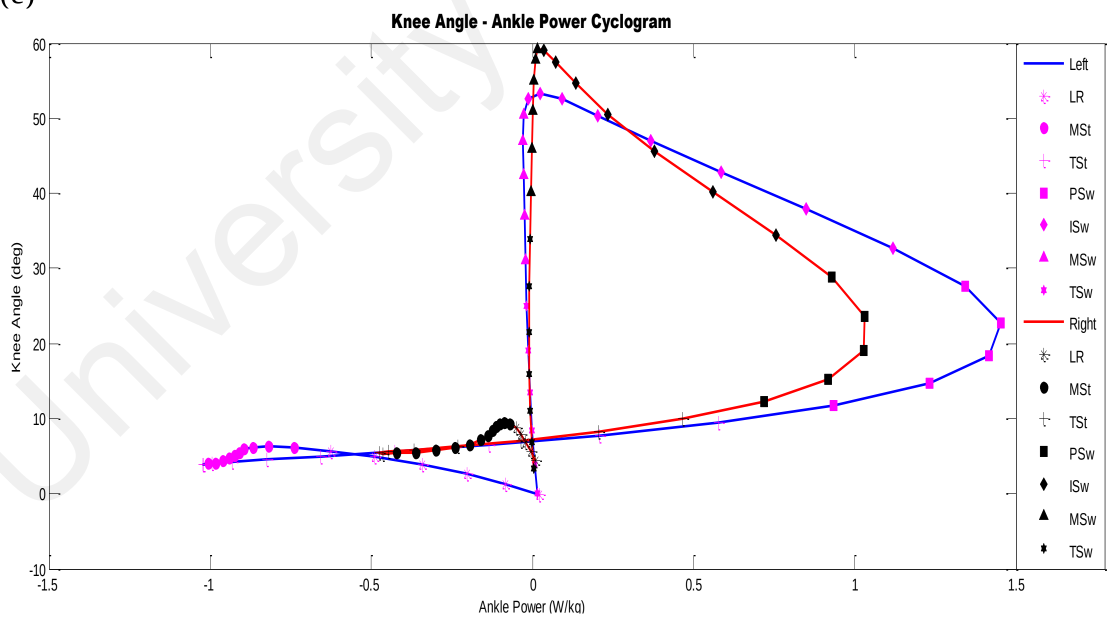
'Figure 4.7, continued'

(d)



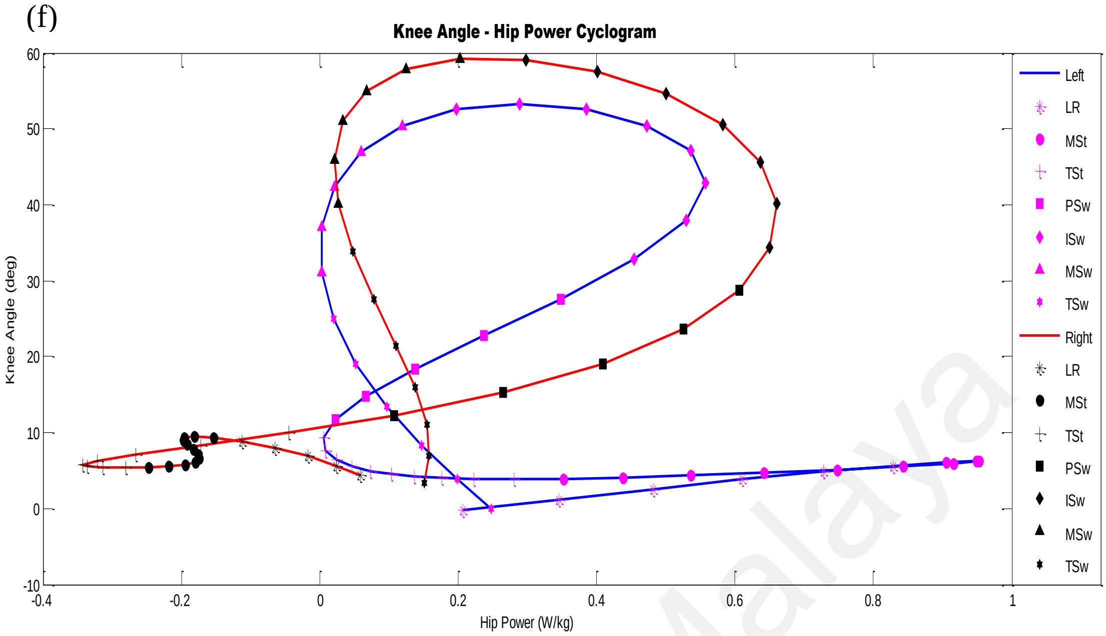
'Figure 4.7, continued'

(e)



'Figure 4.7, continued'

(f)



'Figure 4.7, continued'

4.1.6. Moment-power cyclograms

From Figure 4.8 (a) – (c), the cyclograms for moment and power pairs within the joint was shown. The result reveals that the power absorption or generation does not necessarily directly relate to either one of plantarflexion/extension moment or dorsiflexion/flexion moment. Except for the ankle joint, the travelling direction of the parameter pairs of the knee and hip joint were in opposite direction starting from loading response for each side, and the direction on the left side make a turn and travel the same direction as the right side starting from mid-swing until terminal-swing.

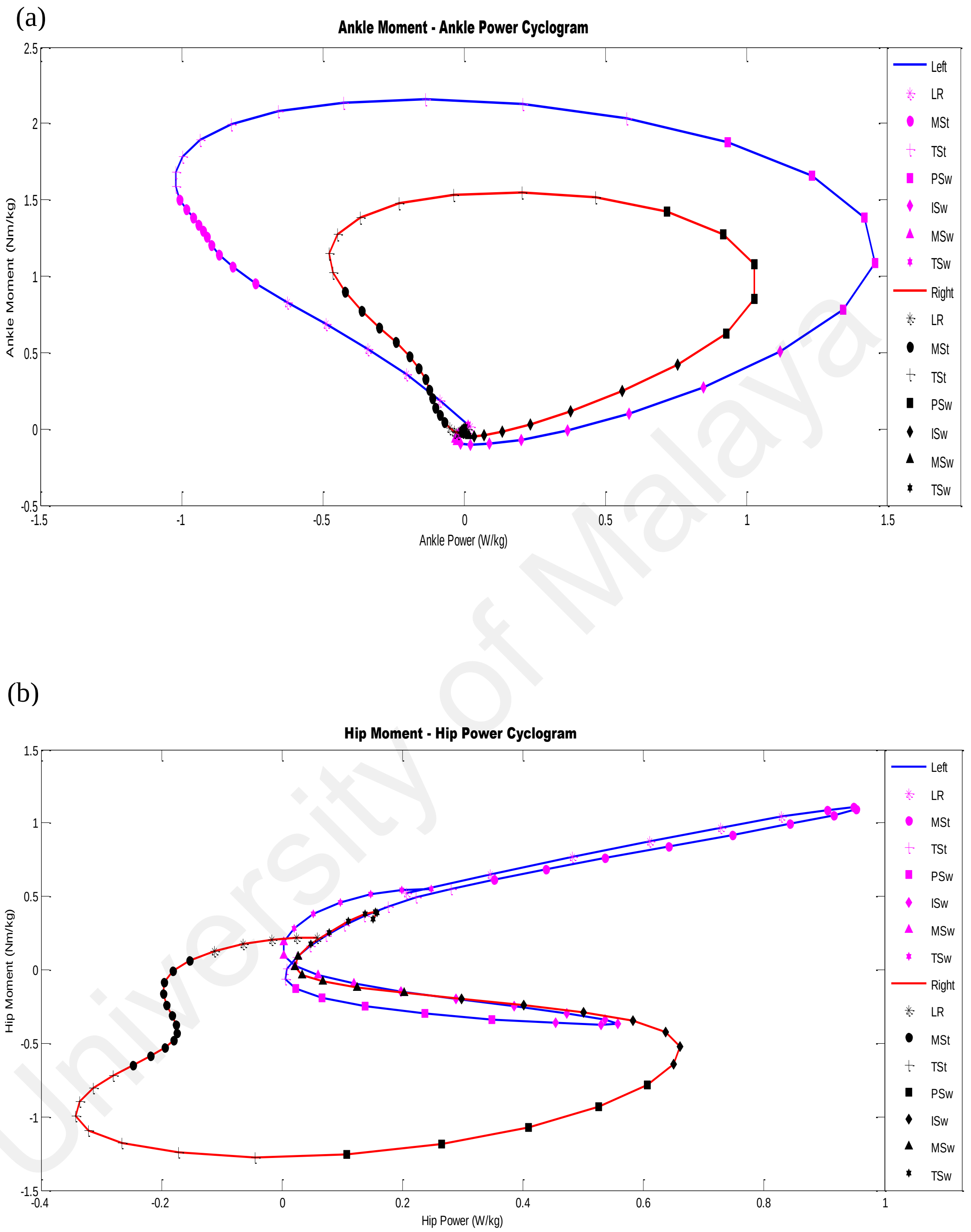
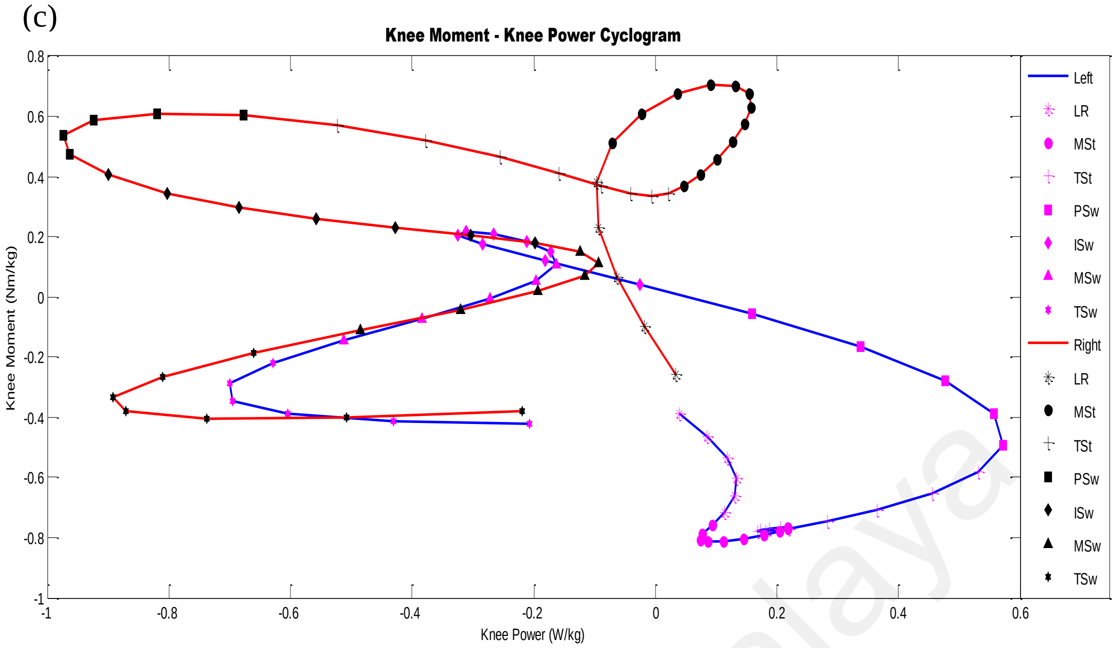


Figure 4.8: Moment and power relationship within the lower limb joint for both left and right leg with gait sub-phases (a) Ankle Moment – Ankle Power cyclogram, (b) Knee Moment – Knee Power cyclogram, (c) Hip Moment – Hip Power cyclogram

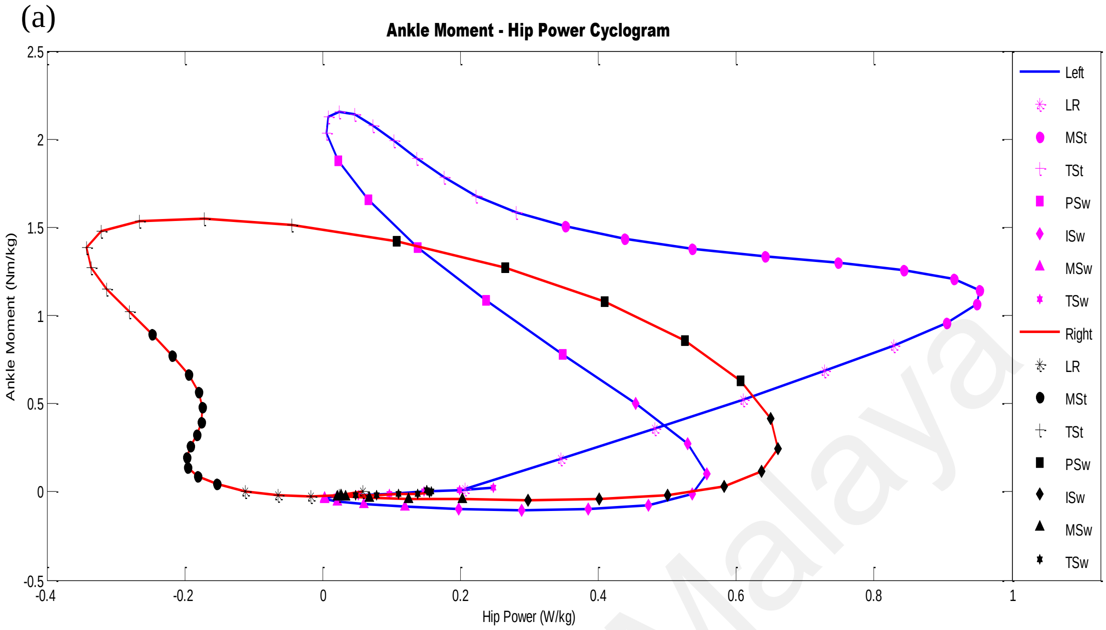
(c)



'Figure 4.8, continued'

The moment and power cyclograms across the two joints pair were shown in Figure 4.9 (a) – (f). The similar properties when the two parameters were paired within the joint, where the absorption or generation of power does not necessarily relate to either one of the moment also found when the parameter was paired across the two joints. All the cyclograms travels in the opposite direction for each side from loading response until terminal swing, except for hip moment – knee power relationship and knee moment – hip power relationship. These two pairs exhibited turn in travelling direction from initial-swing until terminal swing, where one side moves in the same direction as the other side within these sub-phases. It was also observed that during the moment changes from plantarflexion to dorsiflexion for ankle joint and from extension to flexion for knee and hip joint, one side of the leg absorb the power while the other side generate the power.

(a)



(b)

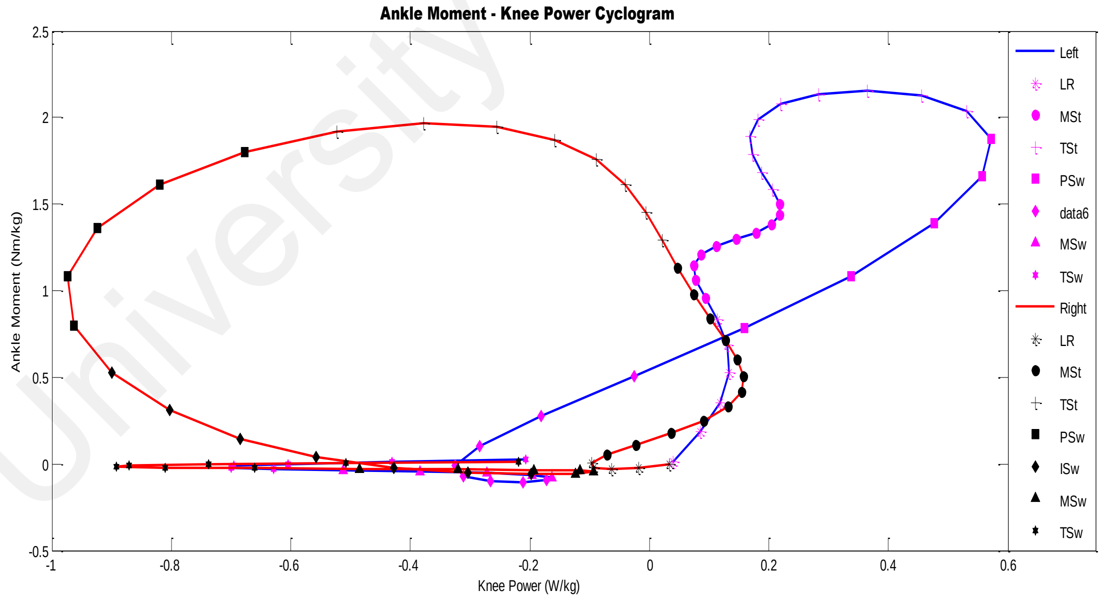
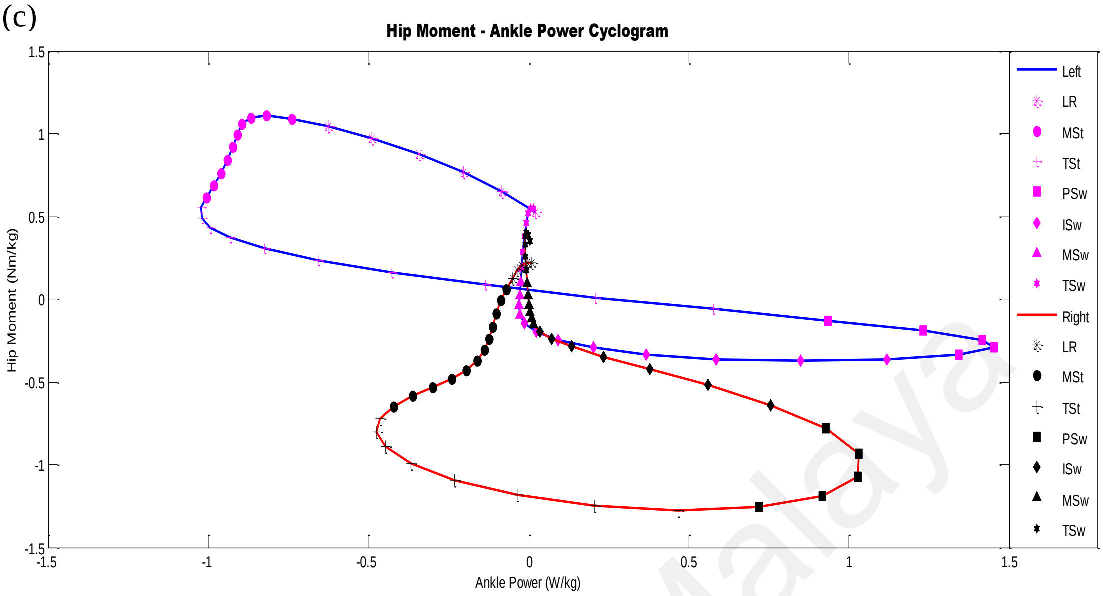


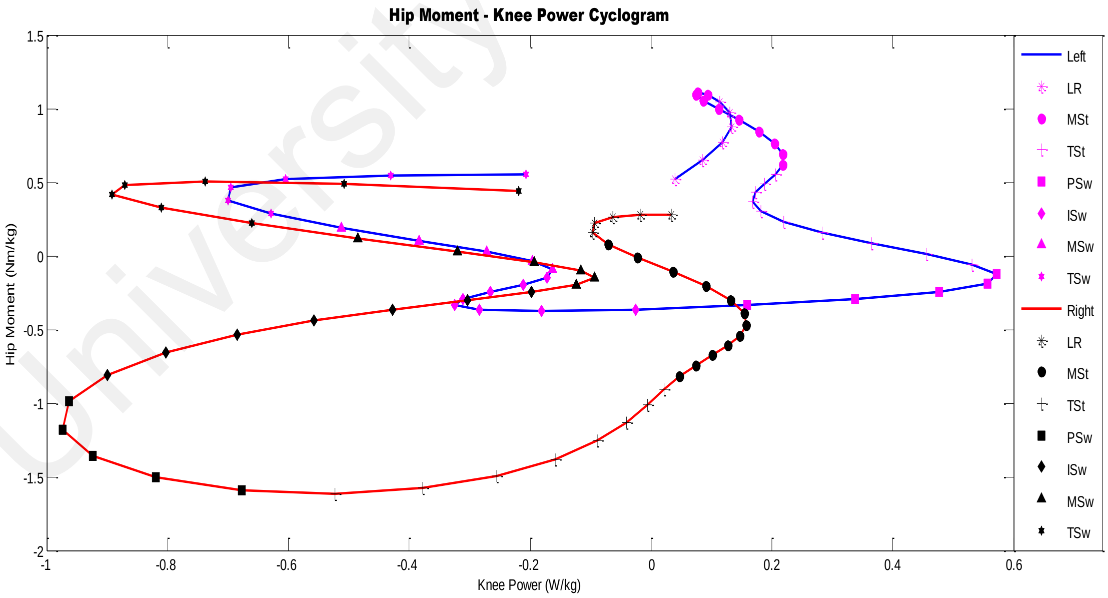
Figure 4.9: Moment and power relationship across the two joints pair for both left and right leg with gait sub-phases (a) Ankle Moment – Hip Power cyclogram, (b) Ankle Moment – Knee Power cyclogram, (c) Hip Moment – Ankle Power cyclogram, (d) Hip Moment – Knee Power cyclogram, (e) Knee Moment – Ankle Power cyclogram, (f) Knee Moment – Hip Power cyclogram

(c)



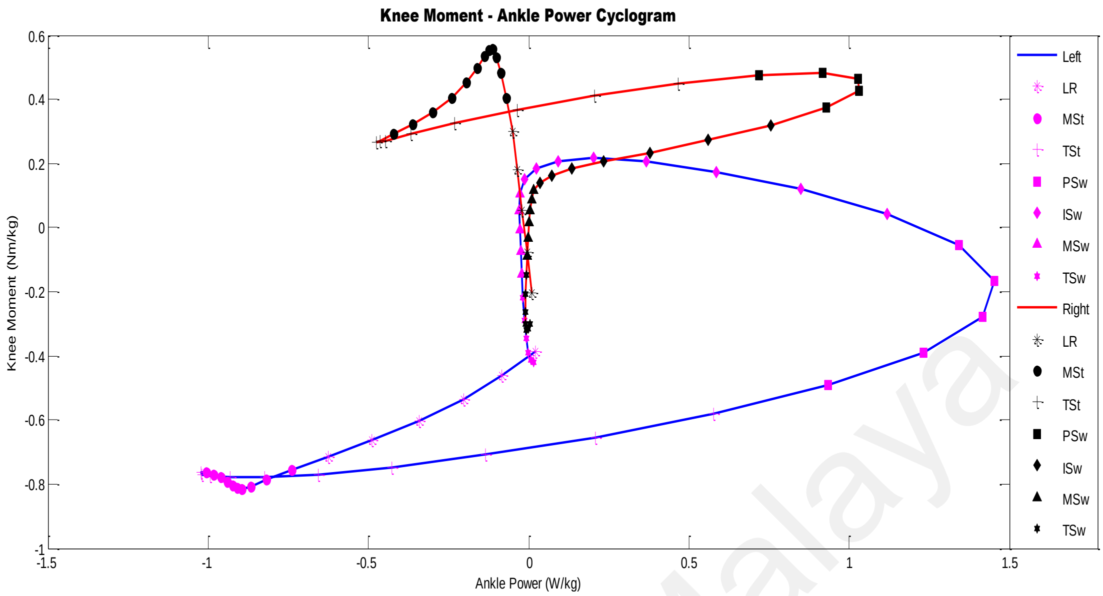
'Figure 4.9, continued'

(d)



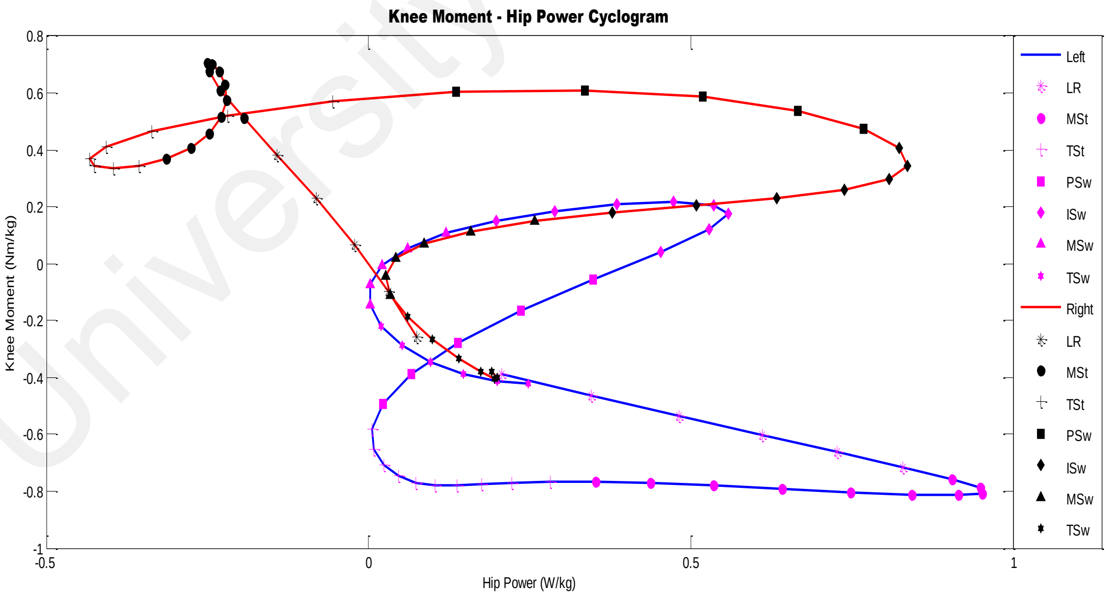
'Figure 4.9, continued'

(e)



'Figure 4.9, continued'

(f)



'Figure 4.9, continued'

4.2. Phase 2: Gait disparity at each sub-phase for each subjects in term of cyclograms' paired variables

The raw result obtained from NN was presented in **Appendix E**. The cyclograms relationship that contributed to the highest mean normalized error at each gait sub-phase for each subject was summarized in Table 4.1. At loading response (LR), the kinematics-kinetics relationship shows high mean normalized error for each of the subject. The kinetics variable of the pair indicated in red colour contributes to the highest mean normalized error, except for subjects TT3 (ankle angle, Aθ) and TT5 (knee angle, Kθ).

At mid-stance (MSt) phase, the result indicated that the kinematics-kinetics relationship has the highest mean normalized error for each of the subject, except for TT5 (AM-HP), TT6 (AM-HP) and TT8 (AM-HP), which shows the kinetics-kinetics relationship. Nevertheless, the variable of the pairs that contributes the highest mean normalized error at this phase were all came from the kinetics variable (knee power/hip power/hip moment). Except for TT5, TT6, TF4 and TF5 which shows that kinetics-kinetics relationship has high mean normalized error at terminal-stance (TSt), the rest shows that the kinematics-kinetics pair exhibits high mean normalized error. Similar with the MSt phase, the kinetic variable (knee power/hip power/hip moment) of the pairs has the highest mean normalized error in TSt phase compare to the kinematic variable.

Similar cyclograms' relationship profile as the aforementioned MSt and TSt were found for pre-swing (PSw), initial-swing (ISw) and mid-swing (MSw), whereby most of the relationships that yield the high mean normalized error were of kinematics-kinetics pair except for TF4 (AM-HP) in pre-swing and TT2 (AM-HP) in ISw. As for terminal-swing (Tsw), 10 out of the 15 amputee subjects showed unanimously that the kinematics of knee angle variable yield the highest mean normalized error. This contradicted with the results of previous gait sub-phases in which kinetics variable (ankle moment/ankle power/knee moment/knee power/hip moment/hip power) of the pair contribute to the highest mean normalized error.

Table 4.1: Summary of the paired variables that contribute to the highest mean normalized error at respective gait sub-phase for each of the amputee subject

Subjects	Cyclograms relationship that contribute to highest mean normalized error **(mean normalized error of one of the paired variable, Ē)**						
	LR	**MSt**	**TSt**	**PSw**	**ISw**	**MSw**	**TSw**
TT1	Kθ-AM **(17.72)**	Hθ-HM **(10.88)**	Hθ-HM **(115.16)**	Aθ-KP **(41.40)**	Hθ-HP **(56.37)**	Hθ-HP **(579.25)**	Kθ-AM **(430.12)**
TT2	Hθ-KP **(10.63)**	Hθ-HM **(9.08)**	Hθ-HM **(141.10)**	AM-HP **(140.47)**	AM-HP **(36.37)**	Hθ-HP **(369.53)**	Kθ-KP **(245.60)**
TT3	Aθ-HM **(51.69)**	Aθ-KP **(50.31)**	Hθ-HP **(156.78)**	Aθ-KP **(38.67)**	Aθ-HP **(223.30)**	Aθ-HP **(367.81)**	Kθ-AM **(706.88)**
TT4	Kθ-AP **(13.89)**	Hθ-HM **(6.65)**	Hθ-HM **(104.56)**	Hθ-HP **(64.19)**	Hθ-HM **(50.44)**	Hθ-HP **(455.88)**	Kθ-AP **(191.65)**
TT5	Kθ-KM **(11.16)**	AM-HP **(8.48)**	AM-HP **(114.92)**	Hθ-HM **(49.71)**	Hθ-HP **(1181.79)**	Kθ-AP **(294.89)**	Kθ-AM **(921.14)**
TT6	Hθ-KP **(10.70)**	AM-HP **(14.42)**	AM-HP **(76.40)**	Aθ-HP **(36.98)**	Hθ-HP **(85.94)**	Hθ-HP **(207.19)**	Kθ-AP **(365.22)**
TT7	Hθ-HM **(8.85)**	Hθ-HM **(11.59)**	Hθ-HP **(156.96)**	Kθ-AM **(26.04)**	Hθ-HM **(85.01)**	Hθ-HP **(360.35)**	Kθ-AM **(255.87)**
TT8	Hθ-HM **(13.37)**	AM-HP **(15.46)**	Hθ-HM **(73.98)**	Hθ-HM **(10.24)**	Kθ-AP **(73.85)**	Hθ-HP **(523.18)**	Kθ-AP **(224.12)**
TT9	Aθ-KP **(7.93)**	Hθ-HP **(8.15)**	Hθ-HP **(136.23)**	Hθ-HM **(19.62)**	Hθ-HM **(39.38)**	Hθ-HP **(509.18)**	Kθ-AP **(186.91)**
TT10	Aθ-KP **(9.43)**	Hθ-HM **(9.45)**	Hθ-HP **(125.66)**	Kθ-AM **(22.24)**	Kθ-AP **(69.57)**	Hθ-HP **(404.98)**	Kθ-AP **(349.92)**
TF1	Kθ-AM **(16.11)**	Hθ-HM **(9.50)**	Hθ-HM **(225.66)**	Hθ-HP **(43.74)**	Kθ-AP **(127.43)**	Hθ-HP **(525.05)**	Hθ-Kθ **(402.20)**
TF2	Kθ-AM **(15.17)**	Hθ-HM **(8.33)**	Hθ-HM **(132.96)**	Hθ-HP **(51.44)**	Hθ-HM **(87.00)**	Hθ-HP **(570.20)**	Hθ-Kθ **(499.66)**
TF3	Hθ-HM **(13.46)**	Hθ-HP **(26.83)**	Hθ-HP **(400.53)**	Hθ-HP **(143.48)**	Kθ-AP **(70.98)**	Hθ-HP **(525.00)**	Hθ-Kθ **(489.07)**
TF4	Kθ-AM **(12.71)**	Hθ-HM **(9.71)**	AM-HP **(230.08)**	AM-HP **(87.39)**	Hθ-KM **(33.77)**	Hθ-HP **(520.47)**	Kθ-AP **(502.44)**
TF5	Kθ-AM **(15.52)**	Aθ-KP **(6.71)**	AM-KP **(12.92)**	Hθ-HP **(133.40)**	Hθ-HM **(38.50)**	Hθ-HP **(329.21)**	Kθ-AP **(432.54)**

Abbreviation: A – Ankle, K – Knee, H – Hip, θ - Angle, M – Moment, and P – Power;
Note: Red-coloured words represent the variable correspond to yielding the highest mean normalized error

4.3. Phase 3: Using Manipulated Cyclograms to Identify Effective Control Parameter in term of Gait Sub-phases for Prosthetic Knee by Means of Neural Network

The result obtained from manipulating each of the parameter of the coupled pair at of the gait sub-phase can be referred in **Appendix F**. An example of the result obtained by manipulating the parameter at loading response phase is presented as in Table 4.2.

Table 4.2: Example of result obtained from manipulating each one of the parameter of the coupled pair at loading response sub-phase

SUB.	PAIR	VAR.	LR	MSt	TSt	PSw	ISw	MSw	TSw
TF1	KΘ-AM	KΘ	6.17	3.68	3.67	1.98	1.37	1.66	310.98
		AM	16.08	1.55	1.23	24.39	28.17	18.70	92.24
	KΘ-AM	KΘ	6.15	3.68	3.67	1.98	1.37	1.66	310.98
		AM	9.56	1.55	1.23	24.39	28.17	18.70	92.24
TF2	KΘ-AM	KΘ	10.55	7.09	6.98	2.27	1.51	1.74	388.10
		AM	15.14	1.86	1.50	7.49	12.67	28.89	223.18
	KΘ-AM	KΘ	6.14	7.09	6.98	2.27	1.51	1.74	388.10
		AM	9.57	1.86	1.50	7.49	12.67	28.89	223.18
TF3	HΘ-HM	HΘ	0.37	0.90	2.88	2.34	0.76	0.31	0.23
		HM	13.19	23.78	276.91	37.63	16.51	35.91	10.58
	HΘ-HM	HΘ	0.29	0.90	2.88	2.34	0.76	0.31	0.23
		HM	9.00	23.78	276.91	37.63	16.51	35.91	10.58
TF4	KΘ-AM	KΘ	8.34	5.45	4.89	0.97	0.01	0.30	422.86
		AM	12.67	1.73	1.47	7.06	28.82	71.68	137.98
	KΘ-AM	KΘ	6.15	5.45	4.89	0.97	0.01	0.30	422.86
		AM	9.56	1.73	1.47	7.06	28.82	71.68	137.98
TF5	KΘ-AM	KΘ	11.90	4.45	4.61	1.53	0.17	0.48	339.39
		AM	15.51	1.10	1.19	1.06	37.27	38.54	123.07
	KΘ-AM	KΘ	7.82	4.34	4.61	1.53	0.17	0.48	339.39
		AM	11.15	1.09	1.19	1.06	37.27	38.54	123.07

Note: The column with yellow colour filled represent the gait sub-phase that being manipulated; the red-coloured words represent the first manipulated variable result, the blue-coloured words represent the second manipulated variable result.

'Table 4.2, continued'

SUB.	PAIR	VAR.	LR	MSt	TSt	PSw	ISw	MSw	TSw
TT1	KΘ-AM	KΘ	3.45	0.54	1.79	0.45	0.13	0.62	201.10
		AM	17.72	1.11	1.18	15.74	31.54	83.10	430.12
	KΘ-AM	KΘ	7.82	0.69	1.79	0.45	0.13	0.62	201.10
		AM	11.15	1.13	1.18	15.74	31.54	83.10	430.12
TT2	HΘ-KP	HΘ	0.14	0.06	0.60	1.38	0.06	0.04	0.16
		KP	7.46	7.65	4.61	14.98	6.80	3.62	1.84
	HΘ-KP	HΘ	0.02	0.06	0.60	1.38	0.06	0.04	0.16
		KP	8.83	7.65	4.61	14.98	6.80	3.62	1.84
TT3	AΘ-HM	AΘ	51.69	12.46	8.91	5.84	98.04	71.95	180.25
		HM	1.67	1.61	30.15	9.25	0.37	5.29	2.27
	AΘ-HM	AΘ	0.75	12.46	8.91	5.84	98.04	71.95	180.25
		HM	0.41	1.61	30.15	9.25	0.37	5.29	2.27
TT4	KΘ-AP	KΘ	8.38	1.23	1.48	0.11	0.21	0.65	191.65
		AP	14.86	2.55	2.73	0.55	21.89	68.64	159.26
	KΘ-AP	KΘ	19.70	1.88	1.48	0.11	0.21	0.65	191.65
		AP	15.79	2.84	2.73	0.55	21.89	68.64	159.26
TT5	KΘ-KM	KΘ	11.16	2.59	0.84	0.18	0.67	1.32	170.42
		KM	0.63	0.69	0.95	2.28	42.69	6.66	3.96
	KΘ-KM	KΘ	1.89	2.36	0.84	0.18	0.67	1.32	170.42
		KM	0.81	0.71	0.95	2.28	42.69	6.66	3.96
TT6	HΘ-KP	HΘ	0.83	3.04	6.98	1.68	0.37	0.74	1.04
		KP	5.57	0.77	3.25	8.33	2.23	0.80	0.52
	HΘ-KP	HΘ	0.11	3.04	6.98	1.68	0.37	0.74	1.04
		KP	10.70	0.77	3.25	8.33	2.23	0.80	0.52
TT7	HΘ-HM	HΘ	0.13	2.14	4.08	0.31	0.10	0.04	0.15
		HM	8.86	11.59	108.29	24.01	85.01	86.06	13.15
	HΘ-HM	HΘ	0.26	2.14	4.08	0.31	0.10	0.04	0.15
		HM	7.38	11.59	108.29	24.01	85.01	86.06	13.15
TT8	HΘ-HM	HΘ	0.22	0.24	2.57	0.81	0.22	0.21	0.08
		HM	13.37	14.67	73.98	10.24	70.32	108.92	20.65
	HΘ-HM	HΘ	0.26	0.24	2.57	0.81	0.22	0.21	0.08
		HM	7.53	14.67	73.98	10.24	70.32	108.92	20.65
TT9	AΘ-KP	AΘ	4.01	0.62	0.18	1.15	3.37	10.92	9.70
		KP	7.58	4.17	2.85	5.31	3.02	1.51	0.01
	AΘ-KP	AΘ	0.58	0.62	0.18	1.15	3.37	10.92	9.70
		KP	5.18	4.17	2.85	5.31	3.02	1.51	0.01
TT10	AΘ-KP	AΘ	1.41	0.18	0.46	1.45	3.33	1.81	5.25
		KP	9.41	4.50	2.96	9.08	1.84	1.18	2.10
	AΘ-KP	AΘ	0.34	0.18	0.46	1.45	3.33	1.81	5.25
		KP	4.51	4.50	2.96	9.08	1.84	1.18	2.10

Note: Please refer to **Appendix F** for the raw result of the subsequent phases

The results of the manipulated variable that showed the lowest mean normalized error were translated as the variable that induced closest-to-normal cyclograms curve compared to the after-effect of manipulating the other parameters. The overall results were summarized as in Table 4.3. The results indicated that at the LR phase, when the knee power was manipulated, i.e. replaced with normal values, the mean normalized error was reduced at the phase and consequently the other phases along the gait cycle were also improved. At MSt phase, the result showed that manipulating ankle angle and knee power produced the lowest mean normalized error. The results obtained from NN showed that manipulating either one of these two parameters would yield the same result along the whole gait cycle. This indicated that controlling either one of the parameter is sufficient to produce close to normal gait profile during MSt. For TSt, ankle angle was the manipulated parameter that demonstrated the lowest mean normalized error. While at PSw and ISw, hip power and hip angle respectively showed the lowest mean normalized error.

Table 4.3: Summary of the parameter that yield the lowest mean normalized error

Gait Sub-phase	LR	MSt	TSt	PSw	ISw	MSw	TSw
Manipulated parameter that yield the lowest mean normalized error, $\bar{E}$	Knee Power	Ankle Angle, Knee Power	Ankle Angle	Hip Power	Hip Angle	-	Knee Power

Manipulation of any one of the parameters at MSw does not improve the sub-phase normalized errors. Observation at this phase indicated that the manipulation of parameter at this phase consequently caused the neighbouring phases to yield a large mean normalized error. Therefore, no parameter was selected for manipulation at this sub-phase. Finally, for the TSw, knee power parameter was selected as it demonstrated the lowest mean normalized error when being manipulated.

All the resulting best control parameters were successfully identified through this method to be either hip, knee or ankle parameters. However, the aim of control method in this study was to minimize gait disparity through the control of knee parameters only, as the hip is an intact limb and cannot be artificially controlled, and to modify or control the ankle requires a microprocessor-controlled ankle – which is beyond the scope of this study. Therefore, results related to hip and ankle parameters were revisited to identify the appropriate knee parameters for control application. This was done by referring to the values of mean normalized error at Phase 2 between hip and ankle variables paired with knee variables. The knee variables that yield the least mean normalized error when paired with hip and ankle variables of the result as in Table 4.3 was extracted as the control knee parameter at that particular sub-phase. The revised result, i.e. for control via knee parameters only, is presented in Table 4.4.

Table 4.4: Revised parameter to be controlled at each of the gait sub-phase for prosthetic knee control

Gait Sub-phase	LR	MSt	TSt	PSw	ISw	MSw	TSw
Manipulated parameter that yield the lowest mean normalized error, $\bar{E}$	Knee Power	Knee Power	Knee Moment, Knee Angle	Knee Angle, Knee Power	Knee Angle	-	Knee Power

CHAPTER 5: DISCUSSIONS

5.1. Cyclograms of Normal Subjects

The tread of cyclograms for human walking gait has been started since decades ago in the literature. However, this cyclic representation of gait does not widely applied in the biomechanics or rehabilitation community, thus the information regarding this concept is not frequently found in the literature. It has been proved that a tightly coordinated locomotion such as walking is better represented with a cyclic trajectory such as cyclogram (Grieve, 1968; Grieve, 1969). This study includes the 2D presentation of coupled gait's kinematics and kinetics variables on the sagittal plane, addressing all the lower limb joints for 20 normal subjects

The cyclograms in this study are presented for both side of the leg. Basically, the normal curves of conventional single-variable versus gait percentage for both left and right leg are shifted from one and another. This is also applied to the cyclograms. However, compared to conventional single-variable plot, cyclograms provide more information about the interactions of two co-existing variables simultaneously. The axes provide the distance information between minimum and maximum values for both variables along the gait cycle in a single cyclograms. The geometric shape of the cyclograms represents the interaction and changes that occur between the two variables along the gait cycle. In this study, the auxillary information of the gait, which is the gait sub-phases is also presented on the cyclogram's plot. Therefore, the travelling profile of the two variables corresponding to the interaction between the variables at each of the gait sub-phase is well presented in the cyclograms. As the geometric shape of the cyclogram change as there is changes in travelling direction at one of the leg, thus, it can be deduced that the interaction between the two variables are different between left and right side.

The geometric difference between left and right side of the leg occur at most of the kinematics-kinetics and kinetics-kinetics cyclograms. Primarily, this geometric difference is influenced by the limb dominance effect on the normal walking gait. The dominant limb is the preferred limb (leading limb) that used for mobilizing or propulsion; while in contrast, the non-dominant limb is the non-preferred limb (trailing limb) that is used to support the actions, i.e. stability control (Peters, 1988; Gabbard, 1989; Dargent-Pare et al., 1992). This support and mobility task performed by each leg is interpreted as gait asymmetry that is normal to occur even to healthy able-bodied subjects (Hirasawa, 1979; Vanden-Abeele, 1980). The cyclogram's geometric changes on each limb side which associated with the pair that consist of at least one the kinetics variables is further verified by the evaluation study by Matsusaka et al. (1985), where it was conclude that left limb functioned as the balance control upon evaluating the lateral ground reaction force profile. Therefore, the travelling direction of the joint moment at left side during the transition from stance (Terminal-stance) to swing (Pre-swing) is observed to be different from the right side. The coupled pair that consists of joint's power variable is also an essential contributor to the definition of functional propulsion and support task in bilateral movement. In this study, the power profile for the right leg shifted more towards the generation side, while the on the left side shifted more towards the absorption side, especially between ankle joint and hip joint relationship where the joint is far from each other. This has been justified that the leg that related with propulsion contributes on the power generation while the one that function as support limb contribute on the power absorption (Sadeghi et al., 1997).

The necessity of defining which limb contributes to propulsion or support task is important in this study in order to select the reference cyclograms that identical to the functional role of the prosthetic and the intact side for amputees. It has been revealed in the study by Carpenter et al. (2012) that the transtibial amputees who undergone osteomyoplastic amputation (Ertl) rely on the prosthetic side to support, while the intact side function to propel the body forward. This is further supported by the study that revealed the unilateral amputees experience increased asymmetry in their intact limb during loading and stance time due to the loss of ankle plantarflexors which contribute to body propulsion and swing initiation (Neptune et al., 2001; Neptune et al., 2004; Liu et al., 2006). Therefore, the subsequent phases in this study make use of the cyclograms on the left side to study the deviation that occur on the prosthetic side of the amputee. The association between dominant-non dominant limb of normal subject and intact-prosthetic side is illustrated as in Figure 5.1.

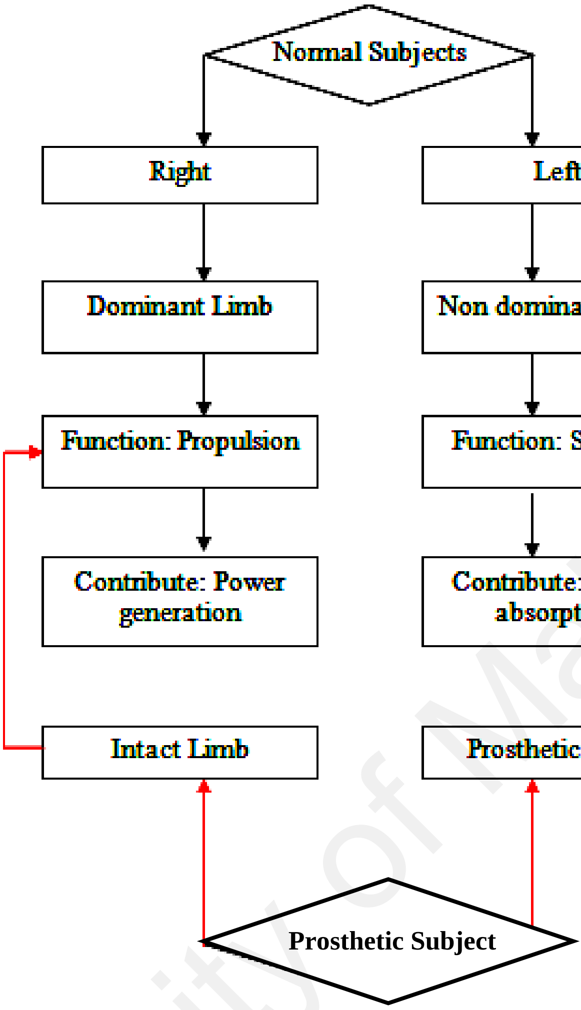


Figure 5.1: The identical functional role of the intact limb and dominant limb, and prosthetic limb and non dominant limb

5.2. Gait Disparity at Each Gait Sub-phase in term of Cyclograms Relationship

Each of the gait sub-phases has distinct functional tasks in order to move the body forward during walking. Loading response is the double support period where the foot strike the ground to the opposite limb toe-off. At this particular period, the ankle is in plantarflexion position to lower the foot to the ground. This is the period where a sharp increase occurs at the ground reaction force indicating the weight acceptance process. From the result in phase 2, the kinematics-kinetics cyclograms relationships are found to have the highest mean normalized error, especially the kinetics variable. In normal individual, the external plantarflexor moment produced by the posterior placement of the force vector is resisted by an internal dorsiflexor moment produced by tibialis anterior. The tibialis anterior contracts eccentrically to absorb the power and allowing the foot to be lowered smoothly onto the ground (Whittle, 2007). However, for the amputees especially transfemoral amputees, the tibialis anterior to generate sufficient moment are absent, thus the error would largely occur at the ankle moment. As for the transtibial subject, the weak-to-non tibialis anterior on their residual leg is largely compensated by the knee and hip joints, thus exhibit large error contribution at these two joints.

Mid-stance is the period occur in between opposite toe off and hell rise. At this period, the opposite limb would passes the mid-stance leg corresponding to feet adjacent in the swing phase for opposite leg. From the result, the cyclograms relationships that contribute to the largest disparity at this sub-phase consist of kinematics and kinetics variable, especially hip angle – hip moment and hip angle – hip power relationship. The hip moment and hip power variable contribute more mean normalized error than the hip angle in the mid-stance phase. In normal subject, the external flexor moment at the knee produced by force vector is opposed by an internal extensor moment produced by quadriceps contraction. Perry (1992) stated that only vasti femoris are active at this time, not the rectus femoris. As the knee motion changes from flexion to extension, power generation at the knee would takes place. The fact that the transfemoral amputee loss the knee's motion function causes inability to resist the external flexor moment, so they must walk with the knee in full extension. Therefore, in order to keep the knee fully extended, they use gait modification by anterior trunk bending, which cause the hip internal extensor, rather than declining and disappear, has remain in order to support the trunk bending. The similar deviations in hip moment and hip power are also exhibited by the transtibial amputee. The loss of triceps surae to contract eccentrically and absorb the power during mid-stance forcing the hip internal extensor moment works to shift the body forward in order to move the force vector to forefoot.

At terminal-stance phase, stability is a major issue to be accomplished as the body centre of pressure shifted forward. This stability is achieved by the triceps surae. As the force vector is majorly concentrated at the forefoot, the ankle joint thus generates a maximal dorsiflexion moment. Both soleus and gastrocnemius respond rapidly and disappear abruptly as the single support period is terminated and the body weight is transferred to the other foot. However, the lost of ankle joint, and even soleus and gastrocnemius in the amputees cause the stability control is transferred to the hip joint. The hip is supposed to have no hip extensor activity during the terminal stance, however, in amputee this hip extensor moment instead functioned to resist the body from stumbling. Thus, hip moment and hip power contribute largely to the mean normalized error at terminal-stance for the amputees.

For transfemoral amputee, the control of the knee joint at swing phase is very important. If the knee joint is let to be completely free, the knee would extend too rapidly following toe-off, and stopping abrubtly as it reach the end stop in hyperextension (Whittle, 2007). In contrast, a knee which does not permits flexion or extension requires the whole leg to be accelerated and decelerate in one piece, which cost high demands on the hip musculature and leads to high energy expenditure in walking (Saunders et al., 1953). The subjects of this study depends largely on their hip joint during the swing phase, thus high normalized error occur at hip moment or hip power for pre-swing, initial-swing and mid-swing phase. As for the terminal swing, the large normalized error occur at the knee angle for the coupled variable, which could be expected as the knee should be in full extension at this phase as in normal subjects.

5.3. Control Parameter at Each of the Gait Sub-phase: Application for Prosthetic Knee Control

The result in phase 3 revealed that manipulating the knee power at LR yield a closer-to-normal cyclograms curve. The primary goal at this particular sub-phase is acceptance of body weight to ensure the limb stability and still permits the subsequent progression. As the body weight started to drop onto the limb, two significant motion patterns initiated by the heel rocker actions occur – the action at the ankle during initial contact and transferred to the action occur at the knee (Perry, 1992). In normal people, the tibialis anteriors contracts eccentrically to absorb the power and allowing the foot to be lowered smoothly onto the ground (Whittle, 2007). In the case of transfemoral amputee where the tibialis anterior to generate sufficient moment was absent, and given that the ankle joint was stiff, the action would be dependent on the performance of the knee joint. At this phase, knee joint as the closest joint has to be responsible to replace the angular displacement of the ankle joint to plantarflex the foot initiating the heel rocker actions and also producing sufficient moment to initiate forward body momentum and single limb support progression. Thus, the result obtained in this study was clinically justified where the knee power, which is a product of knee angular displacement and moment, should be controlled in the prosthetic knee control design. Thus, at this loading response phase, the control system of the prosthetic knee comprise of the controlling the product from angle/position sensor and the motor torque as illustrated in Figure 5.2.

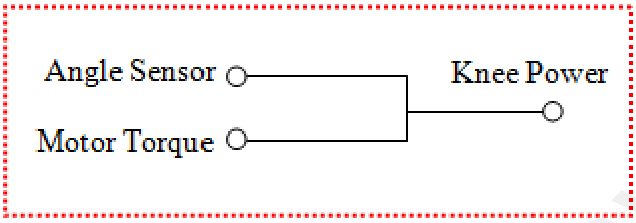


Figure 5.2: Product from angle sensor and motor torque to produce the desired knee power at loading response

The result at MSt showed that the ankle angle and knee power were two parameters that should be controlled at this sub-phase. This is the phase where the single-limb support begins where maximum stability is achieved by placing the foot in stationary and in total contact with the floor and the knee motion changes from flexion to extension. The forward momentum created by the contralateral swing limb produces an extension torque to stop the quadriceps activity even though the knee is not fully extended (The Pathokinesiology Service and The Physical Therapy Department, 2001).Thus, this proved that both ankle angle and knee power as obtained from the result were crucial to control the MSt phase. However, as this study was focused only on the application to the prosthetic knee control, the control on the ankle angle was eliminated assuming that the prosthetic foot has stiff or semi-stiff ankle joint, leaving only knee power to be controlled, and allowing control continuity from the previous phase.Similar with the loading response application, the knee power at mid-stance has to be controlled by multiplying the angular displacement from the sensor and moment torque from the motor, the same configuration as in Figure 5.2

TSt phase is where the primary goal to generate propulsive force by forward fall occurs. At this particular phase, forefoot serves the purpose as progression rocker, with the body falling forward of its area of support, consequently creates the primary propulsive force for walking (Perry, 1992; Winter, 2005). Thus, throughout the TSt, the ankle and foot plays crucial role of action. This validates the result obtained in phase 2, where the analysis shows that ankle angle was the variable that should be controlled at this phase. In order to transfer the ankle angle function during TSt to the prosthetic knee joint, the results obtained in Phase 2 were revisited to determine the knee variable that paired with the ankle angle yield the least mean normalized error at TSt phase. Nine subjects showed the pair with knee moment yields the least mean normalized error, while the rest showed the pair with knee angle. The deduction that could be made from this result was that in order to have the prosthetic knee to control the TSt, the control system must be designed in parallel for two parameters, i.e. separately controlling the knee angle and knee moment (torque) at the same time instead of controlling the knee power (i.e. the product of knee angular displacement and knee moment) as presented in Figure 5.3.. In the case of stiff forefoot worn by the amputee, angular rotation of the knee joint serves the function of rolling the forefoot forward and generation of knee torque would be required to create the propulsive force to actively propel the body forward to prepare for the swing and the initial contact of contralateral limb.

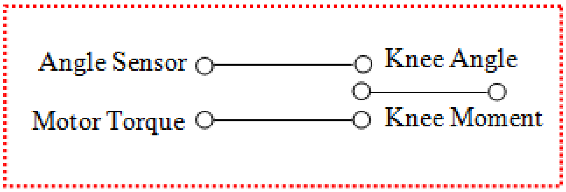


Figure 5.3: The parallel control configuration of sensor and motor to produce knee angle and knee moment respectively at terminal-stance

Through the method analysis presented in this study, it was found before revision that manipulating the hip joint's (i.e. the only intact joint for transfemoral amputee) power during PSw and hip joint's angle during ISw brought closer-to-normal gait profile. This indicates that the workload during these phases would largely be borne by the hip joint in order to initiate the close-to-normal swing of the prosthetics leg. Previous studies investigated that the angular range of motion of the pelvis in transfemoral amputees was significantly higher in the sagittal and frontal planes than that of able-bodied individuals, while the range of motion of the trunk was significantly higher in all three planes in the transfemoral amputees (Bae et al., 2007; Goujon-pillet, 2008). Additional element such as the prosthesis weight and gravitational pull were also concerns that could add burden to the hip joint during swinging. Thus, revisiting the results obtained from phase two was purposely to identify the knee parameters that yield the closest-to-normal gait profile (i.e., lowest mean normalized error) when coupled either with hip power or hip angle. The knee parameter that co-exist with the hip parameter (as in Table 4(b)) can be claimed as the most suitable parameter to be controlled at that particular gait sub-phase to reduce the functional load by the hip joint; reducing long-term osteoarthritis risk on the hip joint (Gailey et al., 2008). The rehabilitation prospective that could be obtained from this replacement was the control design of a prosthetics knee that not only serves to improve ambulatory function for the amputee, but also harmonize the motion and loads that has to be borne by intact anatomical joints. This is contrary to the conventional rehabilitation practice for the amputee in which they are required to adjust with the motion and power setting of the microprocessor-controlled prosthetics knee (Herr and WIlkenfeld, 2003; Zahedi et al., 2005; Bellmann et al., 2009). In addition, the intact joint(s) have to produce compensatory movements for the amputees to ambulate using the prosthetic knee, which in turn induced further movement deviation of the intact joint (van Velzen et al., 2006). Thus, this study suggested a prosthetic knee control design that could serve as complementary element to the intact joint and limb, and minimize unnecessary compensatory movement by the intact joint.

During the PSw phase, the limb is prepared for swing as it action goal. The opposite foot initiates the floor contact at this interval of terminal double support, causing a rapid transfer of body weight to that limb taking action (Whittle, 2007). The result obtained from this study shows that the manipulation of hip power reduced the mean normalized error. However, the critical area of response at this phase is the knee, which met our purpose of study. Thus, the knee variable pair with the hip power is referred as phase 2 results as mentioned previously. A mixed result acquired where 6 subjects gives the pair with knee angle, another 6 subjects gives the pair with knee power, and the other 3 subjects shows the pair with knee moment that yield the least mean normalized error. As the PSw knee flexion contributes significantly to the knee flexion required for limb clearance, thus, the control parameter that serve the controlling purpose during pre-swing are knee angle and knee power. The control design for these two parameters should be in parallel in order to achieve the goal of pre-swing. ISw represents the state of recovery from a trailing posture. The critical action at this phase includes the flexion of both the hip and the knee. From the result, it shows that controlling the hip angle demonstrates the closest to normal cyclograms curve. Repeating the procedure of referring back to the phase 2 results, the pair of hip angle with knee angle shows the least mean normalized error, unanimously for all 15 subjects. Therefore, the control on the knee angle at this phase is sufficient to produce the action in ISw phase.

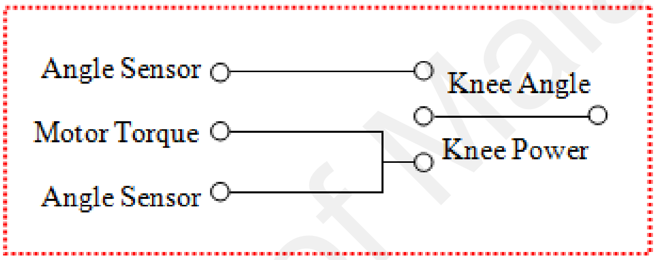


Figure 5.4: The parallel configuration between the angle sensor and the product output from motor torque and angle sensor in the pre-swing phase

Another highlight of the finding in this study which has never been claimed anywhere previously was the results of MSw gait phase modified behaviour manipulation of both parameters in the coupled pair that was found to have the largest mean normalized error in MSw phase did not improve the performance at that particular phase. Worse is, the control of either parameter at the MSw phase caused the neighbouring sub-phases (ISw and TSw) yield larger mean normalized error. This provided strong justification of not controlling any parameters during MSw phase, which can be biomechanically explained by the momentum and gravity influence. During walking, at MSw phase, knee extension is created by momentum and gravity (The Pathokinesiology Service and The Physical Therapy Department, 2001). Therefore, there is no necessity to control the MSw phase for the knee control design. The prosthetic knee should be left independent to extend by the momentum produced by its weight and the gravity at the mid-swing in order to connect the end of initial-swing phase with the beginning of terminal-swing as illustrated in Figure 5. This concept has been discussed as “ballistic synergy” concept introduced by Pitkin (2010) that allows for the control simplification and reduces the power supplies demand (Mochon & McMahon, 1979; McGeer, 1990; Goswami et al., 1996; Dankowicz et al., 2001) when compared with robots for which all its degrees of freedom in motion are controlled during the entire gait (Miura & Shimoyama, 1984; Yamaguchi et al., 1996). Therefore, the results obtained from this study strongly supported the intentional release of the gait profile during swinging particularly at MSw phase, i.e. to not impose any control algorithms during that phase thus letting it occur naturally in the prosthetics knee control design. This would make the kinematics and kinetics match with normal human ballistic gait synergy.

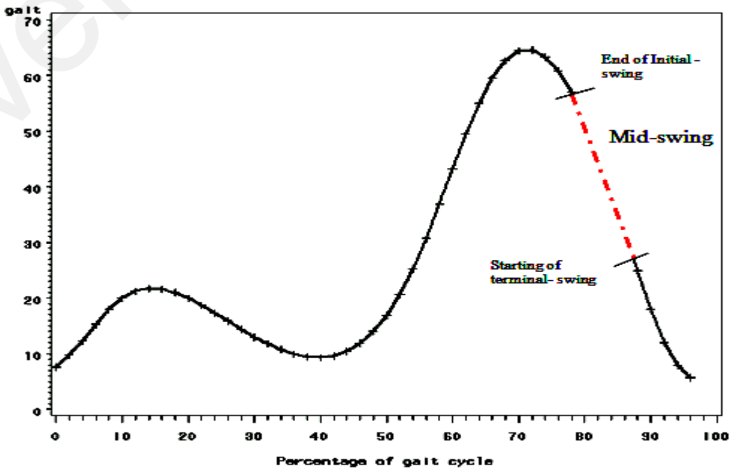


Figure 5.5: Illustration of how the mid-swing phase connect the end of intial-swing with the start of terminal swing

TSw phase is the phase where the limb advancement is terminated and the limb is prepared for stance. The crucial event at this phase is the complete knee extension. To ensure the full knee extension, the quadriceps is in concentric, yielding the knee extensor moment. Thus, both knee angle and knee moment plays important role in achieving the terminal-swing movement. This agreed with the findings from phase 3 where the result showed the control of knee power produced the closer-to-normal output. As the TSw moves back into the stance phase, the control for the knee power is maintained in LR as discussed earlier. This illustrates a continuity of the control mechanism for the prosthetic knee that can be designed as a simplified closed-loop control system as Figure 5.6.

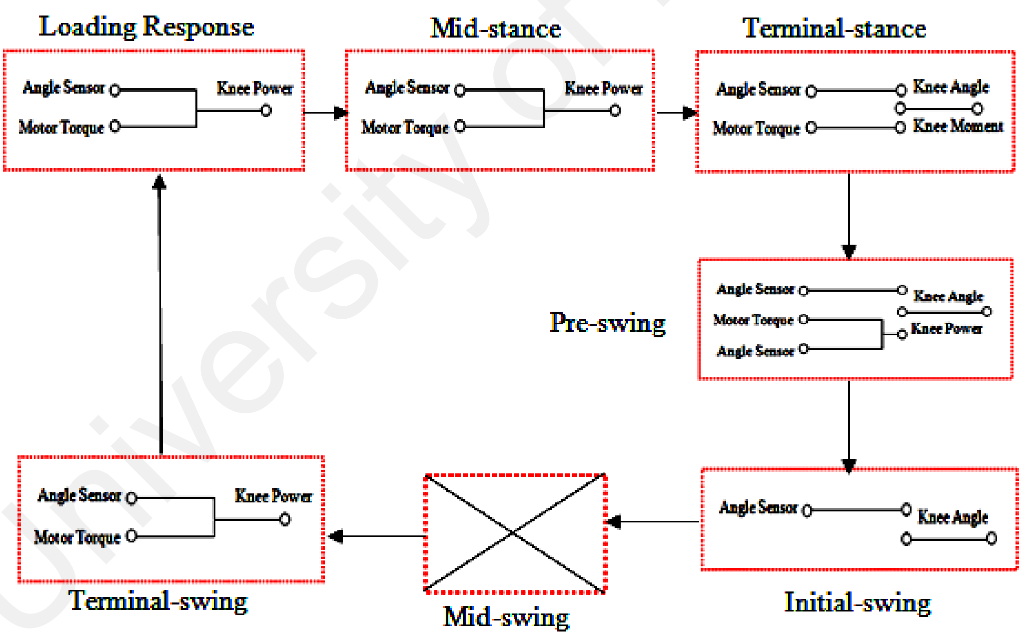


Figure 5.6: The closed-loop configuration for the prosthetic knee control obtained from the this study

Apparently, most of the discussed nature of available microprocessor-controlled prosthetic knee favoured specific functionality of each design (Herr and WIlkenfeld, 2003; Zahedi et al., 2005; Bellmann et al., 2009), which often stressed on the ability of the design to reduce compensatory action by the sound limb (Gailey et al., 2008). Although lessening the load carried by the sound limb is necessary to reduce the energy consumption for the user while wearing the prosthetic knee, the concerns on the remaining joint on the residual side, especially hip joint for transfemoral amputee must be prioritized. While we are trying to design the prosthetic knee in favour of accommodating the sound limb, we must take note that there are several variables that co-exist across the joints that may affect one and the other. The possibility that the control feature designed for the prosthetics knee would cause unintentional additional pathological effect on the intact joint on residual limb should be taken into account. It has been recommended in a previous study that a more prospective intervention studies that take into account the multifactorial nature on the amputees walking ability should be conducted (van Velzen et al., 2006). Thus, we proposed the use of studying the 'cause-and-effect' of two-variables interaction that co-exist during a gait cycle, especially variables across two-joints which provide an insight of how controlling one variable would have an effect to another variable at the other joint during walking for an amputee.

The number of recruited transfemoral amputees was relatively small as compared to the transtibial amputees. This was due to the difficulty in recruiting transfemoral amputees under the study's requirement of their ability to walk without upper extremity's aid or assistance. It is crucial to adhere to this requirement during the recruitment of transfemoral amputee to solely assess their walking performance using the prosthetic leg without interference of external factor. Therefore, most of other available transfemoral amputees were excluded from the study due to their inability to walk without upper extremity's aid and other factors such as having bad eyesight that would affect their gait.

Since this study was aimed to identify the knee parameters that would contribute to a more natural gait pattern through the afore-explained method for application to the prosthetic knee design, and not to evaluate the performance of a particular prosthetic leg fitted to the amputee, therefore, the recruitment of transtibial amputees was found necessary to associate the intact knee profile with other joint's co-existing parameter of the residual limb.

CHAPTER 6: CONCLUSION

Gait analysis has been regarded a novel method in deducing the relation between the human gait characteristics with the technical specification of a prosthetic leg design, whether it is before or after a certain design has been produced. However, the vision towards realizing the truly optimal, humanly-like prosthesis design that could adapt to the general amputee population is still far-fetched. Therefore, the need to develop a different intervention method in studying gait analysis should be of concern in order to escape from the typical ways, thus creating an opening to the better characterization of a smart prosthetic leg.

The option of utilizing the cyclograms to determine the gait disparity and subsequently to determine the suitable control parameter at each of the gait sub-phase provide a new insight to examine the gait as an interaction between two parameters. The holistic study involving all the joints and its respective parameters can further provide us with the information of how the coordinated movement in walking could be simplified to be applied into the prosthetic design.

This study concluded that, in order to define the control design for the prosthetic knee, one should control at each gait sub-phase: Loading response – knee power, Mid-stance – Knee power, Terminal-stance – knee moment and knee angle, Pre-swing – Knee angle and knee power, Initial-swing – knee angle, Mid-swing – independent (no control), and terminal-swing – knee power.

By controlling the knee parameters with respect to its affected joint kinematics and kinetics using artificial intelligence such as neural network, more natural gait can be achieved towards the application in tlhe prosthetic leg control design.

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APPENDIX A

Medical Ethics Approval Letter

UNIVERSITI MALAYA

PUSAT PERUBATAN UM

MEDICAL ETHICS COMMITTEE
UNIVERSITY MALAYA MEDICAL CENTRE
ADDRESS: LEMBAH PANTAI, 59100 KUALA LUMPUR, MALAYSIA
TELEPHONE: 03-79493209 FAXIMILE: 03-79494638

NAME OF ETHICS COMMITTEE/IRB: Medical Ethics Committee, University Malaya Medical Centre **ADDRESS:** LEMBAH PANTAI 59100 KUALA LUMPUR	**ETHICS COMMITTEE/IRB REFERENCE NUMBER:** 908.36
PROTOCOL NO: **TITLE:** Patient gait characterization for design considerations of a smart prosthetic leg	
PRINCIPAL INVESTIGATOR: Cik Nor Elleeiana Mohd Syah **TELEPHONE:** **KOMTEL:**	**SPONSOR:** HIRG

The following item [✓] have been received and reviewed in connection with the above study to be conducted by the above investigator.

[✓] Application Form Ver date: 16 Feb 12
[✓] Study Protocol Ver date:
[ ] Investigator Brochure Ver date:
[✓] Patient Information Sheet
[✓] Consent Form
[ ] Questionnaire
[✓] Investigator (s) CV's (Cik Nor Elleeiana Mohd Syah)

and have been [✓]

[✓] Approved
[ ] Conditionally approved (identify item and specify modification below or in accompanying letter)
[ ] Rejected (identify item and specify reasons below or in accompanying letter)

Comments:

Investigator are required to:

1) *follow instructions, guidelines and requirements of the Medical Ethics Committee.*
2) *report any protocol deviations/violations to Medical Ethics Committee.*
3) *provide annual and closure report to the Medical Ethics Committee.*
4) *comply with International Conference on Harmonization – Guidelines for Good Clinical Practice (ICH-GCP) and Declaration of Helsinki.*
5) *note that Medical Ethics Committee may audit the approved study.*

Date of approval: 21st MARCH 2012

c.c Head
Department of Biomedical Engineering
Faculty of Engineering, UM

Deputy Dean (Research)
Faculty of Medicine

Secretary
Medical Ethics Committee
University Malaya Medical Centre

....
PROF. DATUK LOOI LAI MENG
Chairman
Medical Ethics Committee

APPENDIX B

RESEARCH PROTOCOL AND AMENDMENT

MOTION ANALYSIS WITH ORTHOSES SUBJECTS AND TRANSTIBIAL AND TRANSFEMORAL AMPUTEES

OBJECTIVES

- To study the variation of parameters involved in gait analysis for different lower limb prosthetics and orthotics users.

PERSONNEL

- Certified Prosthetist and Orthotist (CPO) or Medical Officer (MO) – to ensure the patient safety and give advice on the proper way to handle the patient.
- Maximum of 3 investigators – to give instruction to the patient, to handle the system while executing the experiment and to conduct the subject calibration.

EQUIPMENTS

- Vicon Nexus Motion Analysis System
- Force plate
- Reflective markers
- T-frame

STUDY DESIGN & PROCEDURE

a) **System Preparation and calibration**

1. First, empty the space within the camera view range and remove any reflective items.
2. Go to "System Preparation tools pane" and make sure the 5 Marker Wand and T-Frame is selected from the "Wand" and "T-frame" drop-down menu.
3. Place the static calibration object flat on the floor in the center of the capture volume at the desired origin position.

4. In the Aim MX Cameras Calibration section, click Start to begin the MX camera aiming process. (Note: Nexus starts attempting to identify the calibration object in each camera view, and the Start button switch to its Stop setting.)
5. Under “Resource” Pane, select the “System” tab and expand the MX camera node. Select all MX cameras.
6. Change the view pane mode from “3D perspective” to “Camera”.
7. Remove any unwanted reflection registered in any of the camera view or mask them by clicking “Start” the “Stop” under the “Create MX camera Masks”.
8. Then, get someone to wave the 5 Marker Dynamic Calibration frame (T-frame) throughout the capture volume as soon as you hit start under “Calibrate MX Cameras”. (Note: swing the T-frame from head-to-toe and right-to-left alternately, and walk around the space within the camera view range)
9. Wait until the automatic stop feature enabled and the image error value displayed. (Note: ensure that the error value for all the cameras is at most ±0.2%. If exceed, the please repeat step 8)
10. After that, place the calibration wand at the capture volume origin. (Note: place the wand on the force plate)
11. Ensure that no one is standing in the capture volume, and then click on “Start” under “Set Volume Origin”.
12. Reverting back to the “3D Perspective” View and zooming out, so that the cameras are in view. Ensure that Nexus has registered the correct position of all the cameras in the capture volume.

b) Subject Preparation

- Measure the patient’s body mass, height, leg length, knee width, and ankle width. (Note: Jot down the value and do the measurement for both sides)
- Place the markers (16 markers) according to the recommended marker placement template for Vicon Nexus

c) Subject Calibration and Trial Reconstruction

1. In the Subjects resources pane toolbar, click the Create a new Subject from a Template button.
2. Choose PlugInGait.vst from the dropdown menu.
3. Enter the name of your new subject and click OK.
4. In the Resources pane, ensure Nexus is in Live mode.
5. In the capture volume, have the subject stand in a stationary neutral pose (T-pose).
6. Select static plug-in gait from the dropdown menu.
7. In the Subject Capture section, click Start to begin capturing subject data and then Stop after 1-2 seconds of data capture.
8. Reconstruct the trial.
9. From data Management window, open the desired trial file containing reconstructed markers.

10. On the Time Bar ruler, place the Current Time Cursor on the first frame of the trial in which the subject is standing in a stationary neutral pose to enable the Vicon system to determine the location of key markers.
11. Ensure that the subject node you created from the template is the only entry enabled for capture in the Subject resources tree.
12. In the Label/Edit tools pane, from the Subject list select the subject to be manually labeled.
13. From the Manual Labeling section, select Auto advance selection.
14. From the list in the Manual Labeling section, click on the label you wish to use.
15. In the 3D Perspective view pane click on the marker you want to assign the label to.
16. Repeat step 14-15 until you have assigned all of the labels to markers. (Note: The stick figure in the 3D Perspective view pane should resemble a skeleton of the subject type defined in the .vst file.
17. Verify that the manual labeling was successful by checking that all markers are connected by sticks and that the sticks on the **left** side of the subject are **red** and those on the **right** side are **green**.
18. Click Save button.

d) Gait Assessment and Process Trial

1. Before proceed with the trial, estimate a distance for the patient to stand from the force plate by projecting the way the patient walk a complete gait cycle on the force plate.
2. In the Resources pane, ensure Nexus is in “Live mode”.
3. Display a 3D Perspective view pane.
4. In the Capture tools pane, under the Capture Configuration Management section select an existing capture configuration for the trial from the Trial Type list or create a new one.
5. In the Next Trial Setup section, fill in the details for storing your trial data in the active session.
6. In the System resources tree, select Local Vicon System and then in its Properties section under Core Processor, set Processing Level to Kinematic Fit.
7. In the capture volume, have the subject with the Vicon markers attached perform the gait.
8. In the Capture tools pane, under the Capture section click Start.
9. After you have acquired the data you need, click Stop.
10. Repeat step 7-9 until you have obtained at least 20 trials to ensure a complete gait cycle is obtained on the force plate. (Note: ensure the patient get enough rest before proceed to another trial)

APPENDIX C

PARTICIPANT INFORMATION STATEMENT

You are cordially invited to participate in a research study of Characterization of patient's gait and evaluation of the overall workings of the lower limb prosthesis or orthoses. The aim of this study is to test evaluate the gait of a person wearing a prosthesis or an orthotics device.

Research Procedure

The involvement of this research includes Motion Analysis Laboratory and Braces and Limbs Laboratory of Biomedical Engineering. You will be asked to do some walking using existing prosthesis or orthoses to assess the gait pattern and several other related gait analysis parameters. If there is no movement/ not achieved any of the criteria of task given, you will be excluded from partaking of this study. The significant of such procedure to the study is to evaluate the locomotion defect while using prosthesis as comparing to the normal in order to characterize the strategy involve that should be manifested towards designing a smart prosthetic leg.

Next, if you agree to participate in this study, you are required to walk on a force plate with several infra-red cameras surround the space to capture real-time motion of your walk. Time allocation for each task is approximately 15 minutes and the whole session may take up to 2 hours in total. You will need to attend at least 1 session only.

We will investigate your gait pattern with the prosthesis or orthoses by the VICON Motion Analysis System and your external force exerted on the ground by using Kistler’s force plate. Each task will be performed according to schedule and the procedures are complying with the ethical commitment outlined by the UMMC Ethics Committee.

Risks and Side Effects

Any part of the research that may harm to you must be well sentient. You should be aware of performing the test with your prosthesis; or with and without your orthoses. You may also experience some physical fatigue due to any of task given to you.

Confidentiality

All aspects of the study, including results, will be strictly confidential and only the investigators will have access to information on participants, except as required by law. A report of the study may be submitted for publication, but individual participants will not be identifiable in such a report.

Payment

This project involves research with scientific approach. Therefore, payment would be provided for your participation. The payment rate is RM30/hour. This includes your transportation fare.

Freedom of Consent

You should understand that your participation in this research study is completely voluntary. You may withdraw from any or all parts of the study without penalty at any time. You may be withdrawn from the study by the researchers if further participation would be unhealthy for you. Any further inquiries, you may contact Ms. Nor Elleeiana Bt. Mohd Syah at 03-79676871

APPENDIX D

CONSENT FORM

Consent Form

Subject Name : ____________________
I/C. No. : ____________________
H/P No. : ____________________
Address : ____________________
____

1. I confirm that I have read and undertsand about the project. I understand that there are members of this project who will answer any questions I may have. ☐ Please Tick

2. I understand that my participation is voluntary and I may withdraw at anytime and this project will not interfere with any treatment I'm receiving ☐ Please Tick

3. I understand that this project has been given permission by the Biomedical Engineering, Faculty of engineering, University of Malaya ☐ Please Tick

4. I understand that the informations from the questionnaire survey forms completed will be saved in SPSS and the confidential is guaranteed. I understand that the information collected only for scientific use and my name will not be published in books and journals. ☐ Please Tick

5. I give permission to the project's Coordinator and National Project's Coordinator to view the information that I have given in this study. ☐ Please Tick

6. I agree to take part in this study. ☐ Please Tick

Subject's Signature,

____
Name:
I/C No.:

Witness's Signature,

____
Name:
Position:
Department:

APPENDIX E: RAW RESULT OF PHASE 2

TT1:

Relationship	Variables	Normalized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
HΘ-AΘ	HΘ	0.38	2.80	7.80	2.12	0.67	0.37	0.28
	AΘ	2.36	0.34	0.13	0.92	0.37	1.27	6.34
AΘ-KΘ	AΘ	2.63	0.39	0.14	0.91	0.93	1.65	6.79
	KΘ	8.33	0.11	1.21	0.28	0.02	0.34	180.07
HΘ-KΘ	HΘ	0.23	2.15	6.89	1.91	0.36	0.11	0.13
	KΘ	3.28	0.51	2.03	0.44	0.06	0.40	88.73
HM-AM	HM	0.84	0.85	0.59	1.33	0.93	0.52	0.80
	AM	1.89	1.07	1.05	0.26	0.88	2.04	23.04
AM-KM	AM	1.20	1.02	1.00	1.51	1.69	4.11	29.19
	KM	1.01	1.02	1.01	1.00	2.41	0.97	1.02
HM-KM	HM	0.58	0.62	1.97	1.54	0.97	0.63	0.94
	KM	1.23	1.10	1.08	0.92	3.32	0.98	0.95
HP-AP	HP	0.41	0.98	26.64	2.82	12.25	78.34	0.32
	AP	0.41	0.77	0.80	0.98	8.43	6.09	5.53
AP-KP	AP	0.58	0.06	0.54	2.15	18.85	38.60	39.24
	KP	1.04	5.53	1.12	4.61	2.58	2.55	1.37
HP-KP	HP	0.56	0.72	6.20	1.03	19.30	172.95	0.15
	KP	0.99	0.77	0.98	1.59	1.25	0.68	0.93
AΘ-AM	AΘ	3.31	0.15	0.07	1.03	1.66	2.53	9.42
	AM	5.67	1.19	1.12	1.41	1.77	4.03	31.46
HΘ-HM	HΘ	0.23	0.77	0.49	0.24	0.27	0.27	0.25
	HM	9.77	10.88	115.16	30.43	23.90	42.00	11.63
KΘ-KM	KΘ	8.28	1.04	0.53	0.04	0.26	0.69	257.99
	KM	0.70	1.03	0.97	0.79	0.80	0.72	1.18
HΘ-AM	HΘ	0.19	1.47	4.54	1.18	0.33	0.14	0.08
	AM	0.33	0.84	0.74	3.75	1.85	2.36	21.57
KΘ-AM	KΘ	3.44	0.54	1.79	0.45	0.13	0.62	201.10
	AM	17.72	1.11	1.18	15.74	31.54	83.10	430.12
AΘ-HM	AΘ	3.30	0.11	0.23	0.92	2.69	3.15	11.38
	HM	0.52	0.54	2.08	1.70	2.89	0.01	0.88
KΘ-HM	KΘ	7.87	1.12	0.41	0.05	0.20	0.62	277.71
	HM	0.50	0.47	4.97	2.02	0.37	0.35	0.15
AΘ-KM	AΘ	3.26	0.24	0.02	1.07	1.82	2.19	8.09
	KM	0.68	0.91	0.90	1.34	4.14	1.34	0.92
HΘ-KM	HΘ	0.12	1.05	3.39	0.90	0.28	0.08	0.02
	KM	5.26	3.25	2.04	2.09	54.37	16.25	5.35

Relationship	Variables	Normalized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
AΘ-AP	AΘ	4.22	0.05	0.38	0.91	1.93	2.31	9.30
	AP	2.51	0.10	0.25	0.71	7.35	8.61	30.91
HΘ-HP	HΘ	0.47	2.42	6.49	2.56	0.79	0.39	0.29
	HP	6.16	3.32	110.76	16.27	56.37	579.25	14.54
KΘ-KP	KΘ	5.95	0.23	0.44	0.94	0.15	0.02	39.32
	KP	2.63	0.36	4.40	21.28	2.18	2.09	1.11
HΘ-AP	HΘ	0.08	0.59	1.77	2.42	0.23	0.09	0.09
	AP	0.07	1.10	0.68	0.02	3.78	6.01	15.33
KΘ-AP	KΘ	0.91	0.94	1.14	0.69	0.21	0.60	66.38
	AP	5.41	1.95	0.19	3.09	6.74	7.35	34.49
AΘ-HP	AΘ	2.27	0.27	0.12	1.09	2.07	1.59	6.08
	HP	2.45	0.26	6.77	1.31	12.20	165.43	0.52
KΘ-HP	KΘ	2.22	0.38	1.39	0.36	0.11	0.52	111.11
	HP	0.16	0.94	5.78	0.74	5.53	40.82	1.02
AΘ-KP	AΘ	2.97	0.47	0.06	1.30	0.13	1.29	7.44
	KP	0.88	0.79	9.14	41.40	4.99	2.89	1.48
HΘ-KP	HΘ	0.11	1.41	3.76	0.32	0.26	0.12	0.05
	KP	6.54	6.04	3.66	5.42	2.58	1.98	2.83
AM-AP	AM	1.03	0.95	0.92	0.26	1.93	2.46	6.69
	AP	0.52	0.55	0.08	0.06	3.50	3.35	1.91
HM-HP	HM	0.66	1.27	2.70	2.34	2.37	2.04	0.90
	HP	0.35	0.51	5.13	0.81	7.54	57.72	0.25
KM-KP	KM	1.03	0.93	1.24	0.39	7.33	1.65	0.66
	KP	0.18	1.98	0.91	0.13	0.04	1.08	0.95
HM-AP	HM	1.03	1.00	0.52	1.24	0.84	0.79	0.85
	AP	1.56	0.93	0.94	0.54	1.23	0.84	4.44
KM-AP	KM	1.51	1.47	1.40	0.74	0.97	0.79	0.89
	AP	2.18	0.31	0.02	0.17	5.35	5.32	5.42
AM-HP	AM	1.68	1.30	0.76	2.00	4.16	8.18	28.39
	HP	1.74	1.15	42.57	5.06	12.50	23.56	3.87
KM-HP	KM	1.17	1.05	0.80	0.57	2.47	1.71	0.86
	HP	0.69	0.66	5.07	0.19	12.09	109.59	0.37
AM-KP	AM	0.62	0.92	1.05	2.22	2.34	9.67	31.97
	KP	0.70	1.79	0.74	0.78	0.42	1.11	0.70
HM-KP	HM	0.94	0.43	4.17	4.33	2.62	3.56	1.41
	KP	3.50	4.86	0.89	16.34	5.37	2.76	1.60

TT2:

Relationship	Variables	Normalized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
HΘ-AΘ	HΘ	0.13	0.75	1.66	2.09	0.24	0.10	0.04
	AΘ	1.80	0.72	0.74	1.09	2.33	5.09	2.74
AΘ-KΘ	AΘ	1.32	0.90	0.82	0.84	1.37	2.51	1.90
	KΘ	2.41	0.50	0.24	0.33	0.13	0.04	118.66
HΘ-KΘ	HΘ	0.04	0.57	1.45	1.93	0.25	0.12	0.04
	KΘ	1.02	0.57	1.63	0.45	0.17	0.46	57.50
HM-AM	HM	0.85	0.87	0.25	1.41	1.48	0.30	0.81
	AM	1.79	1.05	1.07	1.19	3.32	2.19	20.21
AM-KM	AM	1.16	0.99	1.00	0.77	2.63	3.65	25.63
	KM	1.01	1.01	1.01	1.07	1.00	1.11	0.99
HM-KM	HM	0.60	0.69	2.71	2.15	1.70	0.27	0.90
	KM	1.23	1.12	1.15	1.02	0.81	1.85	0.92
HP-AP	HP	0.70	1.46	32.92	14.92	0.35	36.17	0.41
	AP	0.43	0.86	0.70	1.18	10.20	13.57	18.24
AP-KP	AP	1.35	0.74	0.65	1.01	2.37	9.07	9.90
	KP	1.28	1.17	1.29	7.61	1.35	1.21	0.71
HP-KP	HP	0.49	1.50	28.24	3.81	1.41	16.75	0.22
	KP	1.26	1.01	0.86	10.29	1.53	0.89	0.11
AΘ-AM	AΘ	1.85	0.61	0.73	1.07	1.85	2.04	2.50
	AM	4.15	1.16	1.12	1.46	4.65	3.05	28.12
HΘ-HM	HΘ	0.49	0.92	1.24	0.96	0.05	0.20	0.40
	HM	9.09	9.08	141.10	43.45	29.02	32.62	11.91
KΘ-KM	KΘ	3.79	1.46	0.82	0.12	0.07	0.08	154.82
	KM	1.03	1.01	0.90	0.75	0.70	0.08	0.24
HΘ-AM	HΘ	0.04	0.22	0.71	1.10	0.21	0.01	0.08
	AM	0.08	0.79	0.81	0.46	17.23	7.46	27.92
KΘ-AM	KΘ	0.60	0.23	1.64	0.56	0.04	0.30	52.37
	AM	1.64	1.06	1.08	0.60	25.66	39.18	131.10
AΘ-HM	AΘ	2.25	0.58	0.56	0.92	2.13	9.29	3.90
	HM	0.54	0.61	3.46	2.32	2.19	0.24	0.77
KΘ-HM	KΘ	4.00	1.46	0.80	0.06	0.03	0.04	145.72
	HM	0.55	0.62	4.99	2.53	1.49	1.06	0.06
AΘ-KM	AΘ	2.02	0.62	0.68	1.01	1.93	3.64	2.63
	KM	0.81	0.90	0.93	1.11	1.30	1.00	0.94
HΘ-KM	HΘ	0.15	0.03	0.12	0.54	0.01	0.07	0.16
	KM	5.06	3.35	2.70	2.86	1.90	29.35	6.53

Relationship	Variables	Normalized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
AΘ-AP	AΘ	2.31	0.22	0.52	1.02	2.19	4.58	3.77
	AP	2.38	0.33	0.05	1.06	3.29	19.01	33.87
HΘ-HP	HΘ	0.19	0.75	1.26	1.25	0.71	0.24	0.06
	HP	6.61	5.12	66.68	58.41	8.01	369.53	22.36
KΘ-KP	KΘ	3.02	1.56	0.46	0.86	0.26	0.37	245.60
	KP	3.92	4.78	2.22	9.76	11.55	1.91	0.26
HΘ-AP	HΘ	0.08	0.07	0.28	1.14	0.19	0.04	0.09
	AP	0.34	1.12	1.25	0.61	0.90	3.50	15.53
KΘ-AP	KΘ	2.53	1.03	1.82	0.53	0.00	0.31	63.78
	AP	5.06	2.48	2.96	0.47	11.84	50.09	135.72
AΘ-HP	AΘ	1.80	0.46	0.46	0.52	1.17	3.35	4.20
	HP	0.98	1.22	3.09	30.83	6.96	90.19	2.19
KΘ-HP	KΘ	0.70	0.38	0.14	0.44	0.12	0.27	12.85
	HP	0.02	0.96	26.93	16.07	1.72	5.57	0.12
AΘ-KP	AΘ	1.84	0.76	0.72	1.19	2.47	3.04	2.70
	KP	5.59	5.49	2.92	3.31	13.57	2.58	2.67
HΘ-KP	HΘ	0.14	0.06	0.60	1.38	0.06	0.04	0.16
	KP	10.63	7.65	4.61	14.98	6.80	3.62	1.84
AM-AP	AM	1.12	0.98	0.98	0.96	2.06	1.87	5.29
	AP	0.89	0.83	0.71	0.80	0.92	0.64	0.45
HM-HP	HM	0.93	0.82	1.39	1.50	3.14	0.22	1.19
	HP	0.43	1.39	32.88	22.51	2.75	5.34	1.43
KM-KP	KM	1.04	1.04	1.03	0.50	0.12	0.41	1.07
	KP	1.89	0.98	0.87	9.49	2.63	0.99	0.14
HM-AP	HM	0.99	0.97	0.40	1.06	1.16	0.39	0.82
	AP	1.16	0.84	0.75	0.77	0.85	1.26	8.13
KM-AP	KM	1.25	1.22	1.27	0.56	0.02	7.21	1.23
	AP	1.91	0.48	0.33	0.75	0.55	2.42	5.87
AM-HP	AM	0.68	0.78	0.51	2.32	36.37	0.51	94.25
	HP	0.43	2.44	129.18	140.47	20.42	113.69	8.34
KM-HP	KM	0.96	0.96	0.90	0.50	0.37	2.58	0.56
	HP	0.52	1.59	37.78	15.01	1.49	17.19	0.57
AM-KP	AM	0.62	0.99	0.98	1.03	8.79	4.62	5.20
	KP	1.06	0.72	0.65	9.48	2.47	0.45	0.10
HM-KP	HM	0.79	0.68	3.43	1.39	1.02	0.50	0.61
	KP	5.75	5.14	2.79	7.64	4.72	0.35	0.57

TT3:

Relationship	Variables	Normalized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
HΘ-AΘ	HΘ	0.86	5.67	13.89	1.99	0.88	0.74	0.68
	AΘ	36.59	8.28	5.68	2.82	74.60	54.06	129.69
AΘ-KΘ	AΘ	42.79	8.99	5.98	2.29	91.31	64.82	152.18
	KΘ	5.67	3.60	4.58	0.03	0.62	1.13	142.06
HΘ-KΘ	HΘ	1.25	9.15	22.82	4.52	1.26	1.06	1.05
	KΘ	7.12	7.11	6.48	0.77	0.55	1.05	367.52
HM-AM	HM	0.84	0.81	1.34	1.60	1.24	0.51	0.84
	AM	1.75	1.05	1.02	0.45	1.31	5.06	23.38
AM-KM	AM	1.16	1.00	1.01	0.34	0.99	0.23	25.75
	KM	0.99	1.02	1.07	0.80	5.54	1.53	1.05
HM-KM	HM	0.58	0.62	1.82	1.75	1.18	0.55	0.98
	KM	1.24	1.13	1.14	0.72	0.54	1.05	0.92
HP-AP	HP	1.03	3.34	8.48	0.01	5.06	5.24	0.86
	AP	0.79	1.57	0.66	0.03	10.42	10.17	6.82
AP-KP	AP	1.36	1.61	0.93	0.83	2.66	5.51	10.56
	KP	0.38	1.20	1.05	0.62	0.92	0.86	0.87
HP-KP	HP	0.87	3.20	5.43	0.21	4.00	4.17	1.37
	KP	0.54	1.39	1.29	0.21	0.24	0.64	0.86
AΘ-AM	AΘ	45.46	9.65	6.06	2.79	94.79	68.10	162.09
	AM	4.06	0.98	0.72	15.18	0.04	5.31	16.54
HΘ-HM	HΘ	0.62	4.97	13.74	2.77	0.45	0.42	0.49
	HM	10.52	13.00	122.53	23.10	3.23	31.72	15.67
KΘ-KM	KΘ	2.32	4.75	4.96	0.61	0.33	0.54	96.57
	KM	1.02	1.02	1.24	0.45	18.09	2.45	0.63
HΘ-AM	HΘ	1.04	7.35	18.52	3.42	0.94	0.82	0.88
	AM	4.09	0.54	0.58	5.03	5.74	12.02	87.95
KΘ-AM	KΘ	7.66	6.64	4.83	0.31	0.16	0.97	597.47
	AM	23.20	2.76	1.72	28.12	4.93	90.82	706.88
AΘ-HM	AΘ	51.69	12.46	8.91	5.84	98.04	71.95	180.25
	HM	1.67	1.61	30.15	9.25	0.37	5.29	2.27
KΘ-HM	KΘ	1.85	4.50	4.60	0.45	0.43	0.73	143.76
	HM	0.55	0.30	8.31	2.24	0.79	0.69	0.09
AΘ-KM	AΘ	38.35	8.86	5.91	2.07	81.01	58.56	139.04
	KM	1.14	0.97	1.13	2.64	13.36	2.89	1.57
HΘ-KM	HΘ	0.97	6.91	17.11	3.16	0.84	0.73	0.79
	KM	3.24	2.29	0.70	1.93	39.23	8.44	4.94

Relationship	Variables	Normalized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
AΘ-AP	AΘ	41.07	9.99	6.17	2.95	85.73	61.95	147.61
	AP	4.33	1.02	0.71	8.56	19.37	26.05	59.36
HΘ-HP	HΘ	1.31	8.13	20.52	4.56	1.20	1.04	1.08
	HP	6.79	7.21	156.78	6.68	139.30	265.32	16.84
KΘ-KP	KΘ	2.24	4.29	4.73	0.53	0.32	0.46	99.25
	KP	3.48	2.48	1.45	3.07	3.78	0.53	0.24
HΘ-AP	HΘ	0.99	7.60	18.48	3.56	0.97	0.81	0.84
	AP	0.56	1.56	1.21	1.27	0.01	6.60	27.89
KΘ-AP	KΘ	9.46	9.14	7.62	0.52	0.55	1.30	580.70
	AP	6.11	4.52	3.55	0.49	53.41	135.93	317.52
AΘ-HP	AΘ	28.12	6.10	4.55	1.57	58.51	42.64	101.69
	HP	7.69	2.15	129.65	7.01	223.30	367.81	17.71
KΘ-HP	KΘ	4.87	5.15	5.12	0.63	0.54	0.92	262.94
	HP	0.10	2.51	11.59	0.87	36.96	69.23	2.06
AΘ-KP	AΘ	37.21	8.27	5.75	2.38	77.85	55.87	132.60
	KP	42.03	50.31	29.17	38.67	2.00	1.65	11.60
HΘ-KP	HΘ	0.98	7.21	18.23	3.53	0.93	0.79	0.81
	KP	8.83	7.62	3.77	3.37	3.57	0.64	0.94
AM-AP	AM	1.03	1.10	1.03	1.19	1.70	2.86	5.09
	AP	1.01	1.58	1.11	1.03	0.47	0.47	1.38
HM-HP	HM	0.86	0.85	1.16	1.81	1.13	0.64	0.87
	HP	0.75	3.64	6.15	0.63	2.58	1.93	0.56
KM-KP	KM	1.04	1.05	1.08	0.71	4.66	1.57	1.10
	KP	0.66	0.86	1.21	0.10	0.89	0.80	0.98
HM-AP	HM	0.98	0.99	0.39	1.07	0.99	0.92	0.91
	AP	1.24	1.11	0.80	0.94	4.12	10.96	12.36
KM-AP	KM	1.22	0.60	0.68	1.41	5.94	0.36	0.97
	AP	2.48	1.45	1.03	1.45	6.39	6.84	6.42
AM-HP	AM	1.59	0.23	0.72	2.27	6.34	12.57	48.88
	HP	0.84	11.67	21.54	7.94	6.16	11.89	0.40
KM-HP	KM	1.02	0.89	0.82	1.23	2.34	0.47	0.87
	HP	1.02	4.06	3.73	0.82	3.32	2.56	0.85
AM-KP	AM	0.68	0.97	1.00	1.29	1.43	0.57	4.43
	KP	0.39	0.16	1.26	0.06	0.81	0.74	1.08
HM-KP	HM	0.70	0.74	0.62	1.04	0.72	0.62	0.43
	KP	7.49	4.61	2.73	1.54	1.64	0.30	0.55

TT4:

Relationship	Variables	Normalized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
HΘ-AΘ	HΘ	0.35	0.95	2.21	2.69	0.70	0.39	0.34
	AΘ	0.08	0.61	0.66	0.76	2.30	1.94	2.92
AΘ-KΘ	AΘ	0.10	0.66	0.69	0.75	2.11	2.19	3.71
	KΘ	1.90	0.18	0.02	0.36	0.20	0.52	5.98
HΘ-KΘ	HΘ	0.44	1.15	2.24	2.76	0.92	0.54	0.45
	KΘ	4.19	0.59	1.37	0.05	0.15	0.53	110.68
HM-AM	HM	0.81	0.87	0.60	1.51	2.12	0.08	0.84
	AM	2.42	1.05	1.02	1.89	0.50	1.21	22.90
AM-KM	AM	1.14	0.98	0.97	2.83	2.17	4.71	28.27
	KM	0.97	1.00	0.98	1.10	1.30	0.77	0.98
HM-KM	HM	0.53	0.72	1.64	1.76	1.96	0.25	0.96
	KM	1.21	1.12	1.08	1.02	0.85	0.74	0.92
HP-AP	HP	0.76	0.15	5.32	6.55	1.25	5.09	0.20
	AP	1.06	1.38	0.14	0.35	0.83	2.24	7.10
AP-KP	AP	0.88	0.48	0.83	0.90	1.12	1.87	5.46
	KP	0.52	2.83	1.53	4.72	0.19	0.42	0.28
HP-KP	HP	0.43	0.14	5.26	14.68	1.36	15.70	0.04
	KP	0.34	1.58	1.60	3.43	0.42	0.39	0.25
AΘ-AM	AΘ	0.58	0.47	0.50	0.80	1.23	0.99	0.96
	AM	7.09	1.20	1.09	0.21	0.78	3.60	33.30
HΘ-HM	HΘ	0.87	2.29	4.15	4.95	1.36	0.82	0.87
	HM	7.99	6.65	104.56	31.87	50.44	63.51	11.42
KΘ-KM	KΘ	6.13	1.41	0.65	0.56	0.01	0.21	83.25
	KM	0.82	0.88	0.98	0.74	0.43	2.65	0.73
HΘ-AM	HΘ	0.54	1.45	2.87	3.44	0.94	0.54	0.52
	AM	5.63	1.04	0.87	0.41	0.90	2.17	22.59
KΘ-AM	KΘ	3.16	0.48	0.99	0.16	0.16	0.65	124.16
	AM	5.69	0.87	1.07	11.16	13.24	1.43	104.68
AΘ-HM	AΘ	0.69	0.43	0.49	0.70	1.73	1.41	0.54
	HM	0.37	0.64	3.19	2.44	3.38	1.89	0.60
KΘ-HM	KΘ	6.33	1.29	0.77	0.51	0.04	0.26	100.75
	HM	0.41	0.58	4.70	2.24	2.67	2.24	0.18
AΘ-KM	AΘ	0.97	0.56	0.54	0.83	0.69	0.70	0.56
	KM	0.80	0.90	0.91	1.10	1.23	0.85	1.07
HΘ-KM	HΘ	0.60	1.63	3.25	3.84	1.00	0.60	0.59
	KM	0.60	1.63	3.25	3.84	1.00	0.60	0.59

Relationship	Variables	Normalized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
AΘ-AP	AΘ	1.29	0.62	0.37	0.86	0.80	0.23	0.69
	AP	4.62	0.10	0.27	1.25	6.66	17.40	39.30
HΘ-HP	HΘ	0.30	0.72	2.15	1.88	0.67	0.33	0.31
	HP	8.27	4.51	75.67	64.19	15.15	455.88	17.33
KΘ-KP	KΘ	6.40	1.09	1.06	0.33	0.02	0.26	54.77
	KP	5.44	4.55	4.30	2.48	4.25	1.69	0.38
HΘ-AP	HΘ	0.55	1.55	3.17	3.29	0.95	0.57	0.55
	AP	0.08	0.91	1.00	0.67	2.17	7.04	16.23
KΘ-AP	KΘ	8.33	1.34	1.48	0.11	0.21	0.65	191.65
	AP	13.89	2.73	2.73	0.55	21.89	68.64	159.26
AΘ-HP	AΘ	1.19	0.67	0.44	0.87	0.19	0.03	0.82
	HP	1.47	1.84	4.44	0.94	0.49	7.83	0.22
KΘ-HP	KΘ	0.13	0.24	0.22	0.16	0.13	0.43	39.94
	HP	0.25	0.36	2.31	13.56	0.26	35.41	1.32
AΘ-KP	AΘ	0.70	0.59	0.50	0.57	0.95	0.34	0.24
	KP	8.17	5.18	6.99	2.95	2.20	1.13	0.06
HΘ-KP	HΘ	0.61	1.62	3.44	3.55	1.01	0.63	0.60
	KP	6.61	7.07	4.72	4.39	1.52	1.68	1.05
AM-AP	AM	1.18	0.94	0.99	0.64	1.14	0.98	4.98
	AP	0.66	0.70	0.82	0.69	1.08	1.65	1.08
HM-HP	HM	0.86	0.82	1.06	1.49	1.52	0.34	0.96
	HP	0.34	0.16	4.91	15.96	0.93	18.73	0.20
KM-KP	KM	1.04	1.03	1.07	1.20	0.94	1.75	0.97
	KP	0.16	2.21	1.85	3.41	0.50	0.43	0.40
HM-AP	HM	0.94	0.96	0.84	1.14	1.66	0.33	0.88
	AP	1.14	0.80	0.85	0.92	0.03	2.73	8.27
KM-AP	KM	1.32	1.24	1.23	0.73	1.19	2.46	1.03
	AP	3.51	0.30	0.66	0.68	2.13	5.21	11.14
AM-HP	AM	4.05	1.92	0.68	1.84	4.16	5.12	34.07
	HP	0.65	4.13	29.40	41.60	2.67	36.59	1.52
KM-HP	KM	1.04	1.16	0.91	1.17	1.34	1.26	0.81
	HP	0.60	0.04	8.45	15.66	1.11	14.16	0.39
AM-KP	AM	0.76	0.98	1.03	1.62	1.20	1.81	19.35
	KP	0.47	1.81	1.60	4.67	0.55	0.33	0.42
HM-KP	HM	0.61	0.74	3.80	0.41	3.02	0.95	0.50
	KP	8.76	5.20	2.76	6.97	0.48	0.18	0.16

TT5:

Relationship	Variables	Normalized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
HΘ-AΘ	HΘ	0.20	1.99	5.09	0.28	1.20	1.36	1.38
	AΘ	1.52	0.47	0.41	0.06	24.16	15.47	25.39
AΘ-KΘ	AΘ	0.51	0.42	0.40	0.00	14.74	5.25	7.48
	KΘ	7.63	1.36	0.17	0.14	0.99	1.51	251.24
HΘ-KΘ	HΘ	0.23	1.65	4.07	0.15	0.72	0.91	0.97
	KΘ	5.49	0.42	0.66	0.14	0.98	1.87	455.88
HM-AM	HM	0.84	0.84	0.45	1.39	0.56	0.84	0.84
	AM	1.89	1.05	1.04	0.28	0.98	1.49	28.15
AM-KM	AM	1.19	1.00	0.98	1.62	3.12	10.21	34.19
	KM	1.01	1.01	1.00	1.03	2.90	0.82	0.99
HM-KM	HM	0.57	0.64	1.52	1.55	1.69	1.00	0.97
	KM	1.24	1.13	1.09	0.96	2.49	0.78	0.93
HP-AP	HP	0.94	2.67	18.65	0.78	0.51	0.93	0.90
	AP	0.21	0.62	0.70	1.28	1.93	6.53	2.23
AP-KP	AP	1.12	0.74	0.52	0.82	7.80	32.99	45.07
	KP	0.61	0.73	3.66	2.17	0.24	0.05	0.36
HP-KP	HP	0.80	3.04	9.85	2.42	18.17	3.17	1.48
	KP	0.54	1.52	3.40	3.13	0.91	0.63	0.59
AΘ-AM	AΘ	1.26	0.25	0.20	0.99	1.20	1.57	1.48
	AM	4.88	1.17	1.10	0.91	1.61	3.88	19.99
HΘ-HM	HΘ	0.60	1.87	4.91	0.70	0.36	0.10	0.15
	HM	6.01	8.45	106.14	49.71	105.27	35.22	21.24
KΘ-KM	KΘ	11.16	2.59	0.84	0.18	0.67	1.32	170.42
	KM	0.63	0.69	0.95	2.28	42.69	6.66	3.96
HΘ-AM	HΘ	0.31	0.45	0.98	0.44	0.46	0.67	0.69
	AM	0.28	0.91	0.87	0.34	11.71	21.40	119.18
KΘ-AM	KΘ	6.39	0.52	0.45	0.23	1.34	2.07	257.08
	AM	5.85	0.79	1.01	4.15	71.47	194.67	921.14
AΘ-HM	AΘ	1.35	0.10	0.06	0.89	5.96	5.89	4.50
	HM	0.47	0.61	1.53	2.13	2.08	0.06	0.57
KΘ-HM	KΘ	10.50	2.32	0.86	0.14	0.48	0.73	30.53
	HM	0.58	0.53	4.07	1.37	1.28	0.76	0.51
AΘ-KM	AΘ	1.39	0.33	0.29	1.04	0.12	0.68	0.71
	KM	0.85	0.92	0.92	1.05	0.88	0.87	0.96
HΘ-KM	HΘ	0.39	0.19	0.30	0.60	0.45	0.67	0.69
	KM	3.84	2.76	2.65	14.52	237.86	8.86	4.75

Relationship	Variables	Normalized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
AΘ-AP	AΘ	1.70	0.06	0.13	1.16	0.88	0.83	0.54
	AP	2.60	0.39	0.38	0.97	14.11	37.69	50.54
HΘ-HP	HΘ	0.11	1.54	2.93	0.31	1.15	1.37	1.41
	HP	5.95	6.09	34.22	10.14	1181.79	151.26	29.58
KΘ-KP	KΘ	9.86	2.45	0.33	0.02	0.56	0.84	11.67
	KP	4.92	2.64	1.48	7.30	0.12	0.21	0.10
HΘ-AP	HΘ	0.32	0.34	0.74	0.34	0.46	0.69	0.73
	AP	0.73	1.06	0.99	4.33	21.23	31.39	34.10
KΘ-AP	KΘ	4.76	0.01	1.12	0.28	1.53	2.56	584.06
	AP	4.68	2.44	1.88	28.49	185.57	294.89	344.40
AΘ-HP	AΘ	1.38	0.16	0.19	0.68	2.34	0.81	0.93
	HP	1.46	1.25	43.59	0.33	4.92	0.39	0.82
KΘ-HP	KΘ	7.44	1.15	0.17	0.14	0.99	1.27	166.36
	HP	0.08	2.16	7.04	2.31	83.04	6.11	0.16
AΘ-KP	AΘ	1.20	0.43	0.27	1.01	1.78	2.24	3.15
	KP	4.83	6.36	1.28	5.64	2.20	0.83	1.91
HΘ-KP	HΘ	0.38	0.54	1.37	0.46	0.46	0.69	0.71
	KP	6.17	3.12	5.47	7.92	1.73	0.08	0.28
AM-AP	AM	1.19	0.99	0.99	0.99	1.04	0.20	7.91
	AP	0.79	0.87	0.75	0.82	1.34	3.53	0.41
HM-HP	HM	0.82	0.74	2.02	1.36	0.64	0.77	0.88
	HP	0.53	2.84	19.43	1.74	15.04	1.34	0.75
KM-KP	KM	1.05	1.05	0.89	0.78	2.54	0.73	1.00
	KP	0.09	1.36	3.15	3.72	1.16	0.77	0.93
HM-AP	HM	0.99	0.97	0.42	1.14	0.24	0.84	0.89
	AP	1.05	0.90	0.84	1.00	3.51	4.21	10.80
KM-AP	KM	1.22	1.18	1.11	0.74	3.93	1.14	1.04
	AP	2.11	0.58	0.50	0.58	3.32	16.79	11.51
AM-HP	AM	0.31	0.41	0.65	6.27	4.93	12.99	72.21
	HP	0.17	8.48	114.92	7.33	7.25	3.91	0.74
KM-HP	KM	1.06	0.95	0.67	0.42	4.07	0.99	0.90
	HP	0.85	3.36	5.77	2.25	2.90	0.23	1.05
AM-KP	AM	0.46	0.99	0.96	0.66	0.34	3.92	34.48
	KP	0.43	1.89	3.03	3.79	0.91	0.60	0.97
HM-KP	HM	0.65	0.60	2.31	1.67	3.35	0.65	0.27
	KP	7.66	1.92	3.56	5.49	0.28	0.79	0.85

TT6:

Relationship	Variables	Normalized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
HΘ-AΘ	HΘ	0.72	3.22	7.03	0.56	0.07	0.48	1.09
	AΘ	3.74	0.80	0.20	0.35	1.90	2.38	3.06
AΘ-KΘ	AΘ	1.75	0.28	0.13	0.60	2.08	0.73	0.89
	KΘ	5.78	2.31	0.86	0.03	0.02	0.34	155.76
HΘ-KΘ	HΘ	0.67	1.66	2.15	0.27	0.28	0.77	1.21
	KΘ	4.24	1.79	0.07	0.08	0.04	0.80	320.65
HM-AM	HM	0.85	0.85	0.34	0.64	1.24	0.63	0.82
	AM	1.66	1.05	1.04	0.49	0.34	0.75	20.82
AM-KM	AM	1.14	1.02	1.00	1.37	1.64	5.12	28.01
	KM	1.01	1.06	1.03	1.06	0.81	0.97	0.97
HM-KM	HM	0.61	0.68	0.32	0.50	2.07	0.81	0.96
	KM	1.22	1.10	1.10	0.96	0.15	0.95	0.99
HP-AP	HP	0.92	3.79	30.33	27.67	5.57	0.23	1.10
	AP	0.54	0.49	0.79	0.05	0.38	0.49	3.92
AP-KP	AP	4.95	0.72	0.17	1.07	0.19	4.18	8.43
	KP	4.69	1.52	2.24	3.97	0.02	1.04	0.95
HP-KP	HP	1.07	4.02	19.11	2.30	1.16	7.77	1.72
	KP	0.97	1.02	1.72	3.19	0.13	1.08	1.07
AΘ-AM	AΘ	2.54	0.24	0.14	0.59	0.08	1.14	2.42
	AM	3.90	1.17	1.11	0.10	0.83	2.88	27.75
HΘ-HM	HΘ	0.97	2.59	6.03	2.71	0.44	1.16	0.95
	HM	4.13	0.96	15.25	1.83	49.93	23.69	5.90
KΘ-KM	KΘ	7.58	3.80	1.99	0.55	0.16	0.52	105.33
	KM	0.05	0.55	0.58	2.07	15.77	4.39	1.37
HΘ-AM	HΘ	0.73	2.63	5.98	1.41	0.27	0.73	1.05
	AM	1.13	0.67	0.67	0.19	6.96	35.66	165.51
KΘ-AM	KΘ	3.85	3.49	1.22	0.16	0.32	0.59	281.99
	AM	6.67	0.19	0.60	7.98	57.88	116.01	114.78
AΘ-HM	AΘ	2.86	0.50	0.34	0.50	0.40	1.38	2.83
	HM	0.57	0.66	0.06	0.73	0.39	0.06	0.57
KΘ-HM	KΘ	6.60	3.42	1.75	0.39	0.10	0.41	70.54
	HM	0.60	0.47	1.50	1.24	0.22	1.68	0.04
AΘ-KM	AΘ	2.56	0.02	0.03	0.72	0.05	0.90	1.83
	KM	0.82	0.97	0.97	1.18	0.15	0.80	1.02
HΘ-KM	HΘ	0.83	3.53	8.77	1.93	0.37	0.67	0.99
	KM	4.34	0.63	0.01	7.93	63.51	19.33	1.58

Relationship	Variables	Normalized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
HΘ-AΘ	HΘ	3.00	0.50	0.32	0.68	0.63	0.49	0.77
	AΘ	1.96	0.63	1.32	1.34	5.93	23.70	43.78
AΘ-KΘ	AΘ	0.64	3.83	9.80	0.36	0.23	0.59	1.17
	KΘ	4.53	1.41	30.22	33.33	85.94	207.19	6.78
HΘ-KΘ	HΘ	2.90	3.51	2.62	0.33	0.01	0.55	112.53
	KΘ	7.12	1.90	7.60	4.27	0.64	0.42	0.67
HM-AM	HM	0.76	3.06	7.89	1.65	0.33	0.79	1.06
	AM	0.60	0.82	0.36	0.66	1.87	19.61	11.89
AM-KM	AM	4.31	2.21	0.24	0.27	0.17	0.02	365.22
	KM	1.36	1.69	3.31	1.98	46.89	120.08	31.00
HM-KM	HM	2.29	0.95	0.08	0.80	1.40	0.11	0.04
	KM	1.33	0.05	13.92	36.98	7.33	16.65	1.35
HP-AP	HP	5.12	2.64	2.25	0.18	0.06	0.05	207.08
	AP	0.13	3.75	23.11	5.87	19.85	48.59	0.38
AP-KP	AP	2.47	0.27	0.12	0.74	0.08	0.92	1.74
	KP	8.91	5.40	9.80	9.53	1.73	0.17	0.32
HP-KP	HP	0.82	3.04	6.98	1.68	0.37	0.74	1.04
	KP	10.70	0.77	3.25	8.33	2.23	0.80	0.52
AΘ-AM	AΘ	0.92	1.01	0.99	0.86	0.84	1.28	4.80
	AM	0.95	0.88	0.03	0.96	1.47	1.90	1.93
HΘ-HM	HΘ	0.82	1.08	2.19	2.14	0.53	0.89	0.83
	HM	0.62	4.59	26.66	11.35	4.69	4.40	0.65
KΘ-KM	KΘ	0.87	1.07	1.14	1.52	0.49	1.13	1.07
	KM	2.90	2.07	1.51	4.31	0.38	1.13	1.13
HΘ-AM	HΘ	0.99	0.98	0.77	1.09	1.15	0.77	0.88
	AM	1.11	1.00	0.19	0.93	1.92	2.70	6.20
KΘ-AM	KΘ	1.22	1.17	1.26	1.00	3.29	1.08	1.00
	AM	2.09	0.59	0.99	1.37	0.49	3.77	13.87
AΘ-HM	AΘ	0.39	0.08	0.37	4.45	1.73	11.07	58.72
	HM	0.35	14.42	76.40	8.89	5.46	31.14	0.62
KΘ-HM	KΘ	1.04	0.79	0.80	0.88	1.60	0.77	0.91
	HM	0.84	5.17	27.59	5.41	1.81	2.35	0.97
AΘ-KM	AΘ	2.35	0.96	1.08	2.54	2.61	1.94	7.47
	KM	0.84	2.69	2.34	3.11	1.07	1.21	1.28
HΘ-KM	HΘ	0.73	0.54	0.92	0.60	0.52	0.17	0.43
	KM	1.69	1.62	6.57	0.36	1.30	0.77	0.87

TT7:

Relationship	Variables	Normalized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
HΘ-AΘ	HΘ	0.50	2.28	5.34	1.72	0.69	0.50	0.40
	AΘ	0.04	1.20	0.60	1.23	1.26	1.55	2.18
AΘ-KΘ	AΘ	0.96	1.44	0.67	1.07	3.72	2.77	4.97
	KΘ	0.91	0.90	1.47	0.43	0.15	0.05	40.73
HΘ-KΘ	HΘ	0.44	1.76	4.22	1.55	0.60	0.40	0.34
	KΘ	0.72	1.82	2.29	0.58	0.14	0.06	46.27
HM-AM	HM	0.85	0.84	0.24	1.32	2.24	0.29	0.83
	AM	1.66	1.05	1.02	0.15	0.21	0.94	22.88
AM-KM	AM	1.14	1.01	0.97	1.57	2.38	5.66	28.25
	KM	1.01	1.01	0.97	1.00	1.04	2.46	0.98
HM-KM	HM	0.61	0.61	1.56	1.52	2.43	0.42	0.97
	KM	1.22	1.13	1.11	0.86	0.73	2.47	0.92
HP-AP	HP	1.00	1.36	24.24	0.63	0.48	6.68	0.27
	AP	0.95	1.04	0.74	1.45	7.98	3.92	8.85
AP-KP	AP	1.07	0.61	0.74	0.39	0.61	1.63	5.44
	KP	0.07	1.10	1.76	6.25	0.24	0.44	1.31
HP-KP	HP	0.85	1.55	41.34	1.32	1.06	0.61	0.31
	KP	0.04	0.10	0.66	7.29	0.32	0.68	1.39
AΘ-AM	AΘ	0.16	0.91	0.44	1.15	1.45	1.45	1.22
	AM	3.87	1.16	1.10	1.09	0.77	3.69	32.01
HΘ-HM	HΘ	0.13	2.14	4.08	0.31	0.10	0.04	0.15
	HM	8.85	11.59	108.29	24.01	85.01	86.06	13.15
KΘ-KM	KΘ	3.24	0.55	0.68	0.26	0.06	0.32	143.90
	KM	0.91	0.84	0.77	1.92	1.19	5.31	1.33
HΘ-AM	HΘ	0.30	0.70	1.82	0.94	0.50	0.32	0.22
	AM	0.64	0.79	0.78	5.35	3.52	3.30	24.01
KΘ-AM	KΘ	2.13	1.86	2.38	0.43	0.15	0.37	65.30
	AM	8.81	1.27	1.21	26.04	14.72	15.24	255.87
AΘ-HM	AΘ	0.06	1.62	0.42	1.16	1.33	1.41	0.91
	HM	0.47	0.45	2.17	1.82	4.21	2.29	0.61
KΘ-HM	KΘ	3.15	0.42	0.69	0.31	0.00	0.27	170.48
	HM	0.55	0.46	4.01	2.06	2.06	0.11	0.43
AΘ-KM	AΘ	0.52	0.83	0.48	1.17	1.02	0.93	0.75
	KM	0.85	0.93	0.90	1.05	1.25	0.93	1.04
HΘ-KM	HΘ	0.21	0.14	0.77	0.69	0.42	0.27	0.15
	KM	4.46	3.09	2.94	0.69	13.35	73.77	5.63

Relationship	Variables	Normalized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
AΘ-AP	AΘ	0.75	0.39	0.16	0.88	0.06	0.63	0.48
	AP	1.90	0.17	0.27	1.45	10.53	24.68	39.34
HΘ-HP	HΘ	0.55	2.37	4.98	1.66	0.76	0.53	0.46
	HP	5.82	6.75	156.96	5.69	13.44	360.35	16.87
KΘ-KP	KΘ	2.55	0.60	0.86	0.68	0.03	0.33	108.38
	KP	4.65	4.07	1.69	1.41	3.98	0.67	1.54
HΘ-AP	HΘ	0.27	0.15	0.57	0.74	0.52	0.31	0.20
	AP	0.44	1.13	0.95	0.23	5.27	10.96	21.84
KΘ-AP	KΘ	3.42	2.83	2.77	0.45	0.19	0.36	149.76
	AP	5.31	2.75	1.99	1.36	40.50	112.54	245.10
AΘ-HP	AΘ	0.52	1.09	0.36	0.73	1.39	0.64	0.09
	HP	1.35	2.38	2.46	0.68	3.01	17.47	1.53
KΘ-HP	KΘ	0.05	0.76	1.32	0.52	0.14	0.03	30.27
	HP	0.16	0.20	21.36	0.92	3.50	60.99	1.31
AΘ-KP	AΘ	0.22	1.03	0.51	1.18	1.30	0.93	0.29
	KP	5.03	6.61	3.48	0.76	2.27	0.62	0.70
HΘ-KP	HΘ	0.23	0.37	1.29	0.85	0.47	0.27	0.17
	KP	8.27	6.03	3.54	12.45	3.69	1.20	2.90
AM-AP	AM	1.10	1.01	0.97	0.38	1.08	1.59	5.04
	AP	0.91	0.75	0.69	0.27	0.84	0.16	0.68
HM-HP	HM	0.82	0.53	2.29	1.09	3.36	1.04	0.77
	HP	0.72	0.95	37.74	1.09	2.47	26.39	0.47
KM-KP	KM	1.05	1.05	0.97	1.24	0.90	0.21	0.97
	KP	0.27	0.41	1.04	7.37	0.18	0.49	1.16
HM-AP	HM	0.99	0.95	0.50	1.06	1.72	0.14	0.88
	AP	1.11	0.82	0.74	0.86	2.12	0.27	8.46
KM-AP	KM	1.20	1.24	1.41	1.44	0.11	7.32	1.03
	AP	1.79	0.49	0.48	0.64	3.21	4.46	10.96
AM-HP	AM	1.46	1.11	0.64	7.06	1.98	2.66	8.76
	HP	0.41	0.28	154.10	6.30	12.72	96.32	5.31
KM-HP	KM	1.03	1.07	0.92	1.01	0.88	1.31	0.84
	HP	0.93	1.34	46.62	1.40	2.52	18.65	0.72
AM-KP	AM	0.76	0.99	0.97	0.69	0.59	0.74	3.34
	KP	0.10	0.02	0.86	7.97	0.42	0.74	1.57
HM-KP	HM	0.70	0.64	1.97	1.51	4.35	1.71	0.54
	KP	6.58	4.19	1.84	6.11	1.78	0.87	1.75

TT8:

Relationship	Variables	Normlized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
HΘ-AΘ	HΘ	1.19	5.33	10.02	0.01	0.76	0.83	0.95
	AΘ	2.59	0.15	0.12	1.20	5.19	4.71	11.81
AΘ-KΘ	AΘ	3.34	0.12	0.17	0.98	4.53	4.10	11.14
	KΘ	6.44	1.53	0.84	0.58	0.81	1.06	208.89
HΘ-KΘ	HΘ	0.95	4.44	9.57	0.61	0.83	0.77	0.74
	KΘ	5.70	3.27	2.61	0.81	0.91	1.23	204.86
HM-AM	HM	0.85	0.84	1.08	1.38	2.07	0.36	0.80
	AM	1.76	1.05	1.03	0.34	0.12	1.61	18.95
AM-KM	AM	1.17	1.00	0.95	1.62	2.06	3.37	23.06
	KM	1.01	1.00	0.92	1.04	1.40	3.38	0.92
HM-KM	HM	0.60	0.61	3.39	1.64	2.55	1.14	0.89
	KM	1.23	1.14	1.13	0.92	0.64	3.79	1.02
HP-AP	HP	1.17	2.13	11.98	0.24	0.68	2.09	0.79
	AP	0.30	0.33	0.38	0.44	1.08	2.18	5.65
AP-KP	AP	1.03	0.84	0.78	1.08	4.46	0.54	11.79
	KP	0.85	0.87	1.52	0.13	0.17	0.38	0.81
HP-KP	HP	0.98	2.15	3.19	1.67	1.74	12.96	1.00
	KP	1.77	2.94	1.39	0.79	1.77	0.61	0.90
AΘ-AM	AΘ	4.39	0.25	0.21	1.16	5.98	5.82	16.68
	AM	5.36	1.10	1.08	0.09	0.81	5.15	55.14
HΘ-HM	HΘ	0.22	0.24	2.57	0.81	0.22	0.21	0.08
	HM	13.37	14.67	73.98	10.24	70.32	108.92	20.65
KΘ-KM	KΘ	1.50	0.84	0.91	0.45	0.59	0.83	75.79
	KM	0.94	0.83	1.39	1.79	6.94	32.95	0.84
HΘ-AM	HΘ	0.82	3.28	6.75	0.33	0.56	0.60	0.63
	AM	0.30	0.82	0.69	5.43	4.21	5.12	17.97
KΘ-AM	KΘ	4.10	3.69	1.61	0.26	1.34	1.68	136.95
	AM	6.95	1.45	0.92	4.39	13.19	26.17	122.31
AΘ-HM	AΘ	4.41	0.53	0.33	1.17	7.27	7.40	22.86
	HM	0.59	0.68	1.59	1.51	2.26	0.49	1.02
KΘ-HM	KΘ	0.91	0.86	0.65	0.39	0.66	0.86	39.26
	HM	0.43	0.41	7.60	2.37	4.03	4.09	0.02
AΘ-KM	AΘ	4.15	0.35	0.16	1.18	6.23	5.33	14.08
	KM	0.82	0.81	0.83	1.24	1.94	2.03	1.26
HΘ-KM	HΘ	0.75	2.91	5.74	0.03	0.51	0.56	0.58
	KM	6.45	4.17	0.32	0.47	6.80	77.23	9.10

Relationship	Variables	Normlized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
AΘ-AP	AΘ	4.66	0.05	0.27	1.14	6.80	6.36	16.80
	AP	1.01	0.46	0.15	1.73	7.95	15.77	10.72
HΘ-HP	HΘ	1.09	4.07	8.67	0.49	0.82	0.81	0.90
	HP	7.64	9.27	42.83	1.95	16.14	523.18	26.38
KΘ-KP	KΘ	1.61	1.03	0.81	0.31	0.72	0.90	70.52
	KP	2.93	2.49	2.20	3.98	2.34	0.36	0.22
HΘ-AP	HΘ	0.77	3.04	6.51	0.41	0.54	0.57	0.59
	AP	0.32	1.34	1.16	0.90	4.35	14.08	38.82
KΘ-AP	KΘ	6.46	4.05	2.33	0.53	1.22	1.57	224.12
	AP	4.23	2.78	2.13	1.56	73.85	119.80	171.46
AΘ-HP	AΘ	3.57	1.11	0.13	1.12	5.93	4.63	11.10
	HP	0.55	1.85	27.21	2.20	1.85	58.07	4.84
KΘ-HP	KΘ	2.54	2.81	0.88	0.30	1.00	1.27	116.10
	HP	0.66	2.59	9.75	2.97	3.40	74.75	1.74
AΘ-KP	AΘ	3.49	0.24	0.03	1.16	7.41	6.02	12.63
	KP	12.67	5.08	5.36	0.37	2.41	3.33	2.29
HΘ-KP	HΘ	0.77	3.05	6.40	0.30	0.48	0.54	0.58
	KP	10.54	7.65	3.63	0.57	3.52	1.74	1.18
AM-AP	AM	1.11	0.96	1.01	1.93	1.37	1.44	6.42
	AP	0.76	1.00	0.86	0.96	1.57	0.84	0.56
HM-HP	HM	0.89	1.61	0.37	1.59	2.57	0.34	0.79
	HP	1.12	3.38	19.75	3.89	0.32	20.31	0.20
KM-KP	KM	1.04	1.03	1.01	0.97	1.35	0.33	1.10
	KP	0.92	0.67	1.30	0.17	1.42	0.87	0.95
HM-AP	HM	0.99	0.98	0.89	1.13	1.75	0.18	0.86
	AP	1.17	1.04	0.89	0.93	1.73	0.14	1.57
KM-AP	KM	1.24	1.11	1.16	0.79	0.31	1.34	1.09
	AP	2.04	0.80	0.90	1.07	2.38	2.83	7.46
AM-HP	AM	0.49	0.04	0.72	0.59	0.82	6.21	31.66
	HP	1.26	15.46	32.21	5.34	2.63	23.11	0.49
KM-HP	KM	0.90	0.65	1.01	0.93	0.99	1.30	0.91
	HP	1.31	3.49	11.92	3.63	0.21	6.37	0.18
AM-KP	AM	0.64	0.99	1.01	1.29	0.81	1.02	6.84
	KP	0.79	0.42	1.25	0.49	2.99	1.32	1.10
HM-KP	HM	0.66	0.69	1.80	1.97	3.25	2.60	0.43
	KP	9.15	3.94	2.09	4.35	6.91	2.48	0.68

TT9:

Relationship	Variables	Normlized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
HΘ-AΘ	HΘ	0.88	1.91	3.11	2.09	0.95	0.74	0.63
	AΘ	3.23	0.67	0.18	1.14	3.31	11.91	13.10
AΘ-KΘ	AΘ	3.55	0.50	0.17	1.09	3.09	9.66	8.49
	KΘ	0.50	0.12	0.29	0.13	0.33	0.56	22.93
HΘ-KΘ	HΘ	0.96	2.15	3.37	2.19	0.87	0.63	0.43
	KΘ	1.41	1.55	1.83	0.39	0.32	0.60	91.05
HM-AM	HM	0.86	0.84	0.64	1.34	1.58	0.16	0.80
	AM	1.65	1.04	1.02	1.21	0.78	0.53	17.00
AM-KM	AM	1.14	0.99	0.98	0.86	2.16	2.28	20.85
	KM	1.01	1.00	1.00	1.00	0.90	3.52	1.07
HM-KM	HM	0.62	0.65	1.06	1.56	1.66	0.51	1.01
	KM	1.21	1.13	1.11	0.94	0.74	3.35	1.00
HP-AP	HP	1.29	1.23	4.63	1.99	0.97	13.92	1.22
	AP	0.79	0.38	0.40	0.35	1.23	0.69	32.49
AP-KP	AP	1.21	0.60	0.25	0.63	0.55	1.73	8.31
	KP	0.17	1.50	1.26	0.19	0.60	0.48	0.66
HP-KP	HP	1.11	1.70	15.03	0.38	1.11	23.80	0.71
	KP	0.99	0.28	1.41	0.70	0.71	0.42	0.66
AΘ-AM	AΘ	4.68	0.88	0.42	1.17	3.89	15.43	12.51
	AM	3.89	1.15	1.09	1.55	3.51	1.68	22.40
HΘ-HM	HΘ	0.42	0.17	0.75	0.56	0.16	0.10	0.44
	HM	4.63	6.78	75.46	19.62	39.38	57.73	26.65
KΘ-KM	KΘ	1.60	0.78	0.16	0.12	0.13	0.35	18.15
	KM	0.98	0.80	0.90	1.62	3.35	10.01	1.13
HΘ-AM	HΘ	0.69	1.29	1.46	0.74	0.66	0.55	0.47
	AM	0.62	0.73	0.78	0.05	9.78	4.45	23.41
KΘ-AM	KΘ	1.07	1.41	1.31	0.26	0.25	0.41	103.61
	AM	5.00	1.05	1.02	2.78	38.17	8.36	94.16
AΘ-HM	AΘ	4.79	1.16	0.60	1.22	4.34	20.66	14.10
	HM	0.64	0.74	0.17	1.46	1.69	0.74	0.88
KΘ-HM	KΘ	2.04	0.70	0.21	0.09	0.20	0.41	56.66
	HM	0.54	0.49	3.97	1.97	2.34	1.52	0.16
AΘ-KM	AΘ	4.29	0.69	0.24	1.16	3.52	11.97	10.16
	KM	0.83	0.87	0.87	1.03	1.20	0.29	1.01
HΘ-KM	HΘ	0.61	1.01	1.01	0.41	0.52	0.48	0.37
	KM	1.97	0.68	1.48	0.58	2.40	47.53	7.79

Relationship	Variables	Normlized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
AΘ-AP	AΘ	4.90	1.22	0.60	1.10	3.95	14.65	12.47
	AP	2.12	0.31	0.10	1.12	3.52	11.33	26.42
HΘ-HP	HΘ	1.08	2.17	2.92	2.02	1.00	0.85	0.88
	HP	5.05	8.15	136.23	5.77	9.77	509.18	18.19
KΘ-KP	KΘ	1.49	0.51	0.10	0.01	0.19	0.38	11.66
	KP	3.47	3.10	1.70	1.92	2.34	1.56	0.46
HΘ-AP	HΘ	0.68	1.07	1.18	1.22	0.67	0.56	0.47
	AP	1.72	0.85	0.86	0.78	2.57	5.45	17.51
KΘ-AP	KΘ	3.23	2.06	1.93	0.37	0.33	0.64	186.91
	AP	3.97	2.32	1.64	0.32	10.26	45.49	150.87
AΘ-HP	AΘ	3.97	0.92	0.22	1.05	3.20	11.40	9.22
	HP	0.99	0.82	9.09	1.12	0.56	51.37	0.59
KΘ-HP	KΘ	0.68	0.89	1.44	0.20	0.32	0.54	36.95
	HP	0.61	1.36	20.00	0.30	0.07	19.10	0.65
AΘ-KP	AΘ	4.07	0.62	0.18	1.15	3.37	10.92	9.70
	KP	7.93	4.17	2.85	5.31	3.02	1.51	0.01
HΘ-KP	HΘ	0.69	1.21	1.52	0.83	0.61	0.50	0.42
	KP	3.28	4.79	3.11	4.84	2.47	1.70	1.91
AM-AP	AM	1.12	0.96	0.98	1.04	1.24	1.38	3.71
	AP	0.94	0.74	0.46	0.76	0.65	1.14	2.57
HM-HP	HM	0.80	0.96	4.21	1.88	1.30	0.79	0.92
	HP	1.08	1.75	26.45	0.47	0.74	15.57	0.77
KM-KP	KM	1.05	1.04	1.05	1.06	0.80	4.16	1.09
	KP	0.62	1.03	0.69	0.79	0.68	0.40	0.72
HM-AP	HM	0.99	0.97	0.20	1.10	1.20	0.73	0.90
	AP	1.15	0.83	0.73	0.87	0.95	3.34	9.23
KM-AP	KM	1.22	1.24	1.32	1.00	0.91	0.55	0.95
	AP	1.83	0.43	0.12	0.80	0.43	0.39	6.58
AM-HP	AM	6.18	0.68	0.65	1.52	3.65	10.44	59.23
	HP	2.62	5.76	74.29	6.54	2.03	84.65	1.99
KM-HP	KM	0.93	0.88	0.85	0.97	1.39	4.42	0.88
	HP	1.16	2.06	35.62	0.05	0.71	20.40	1.08
AM-KP	AM	0.74	0.98	0.98	0.84	2.12	1.54	14.02
	KP	0.43	0.83	0.59	0.68	0.87	0.63	0.89
HM-KP	HM	0.71	0.70	2.09	1.56	2.35	0.04	0.46
	KP	7.47	4.73	2.13	2.49	0.64	0.09	0.44

TT10:

Relationship	Variables	Normlized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
HΘ-AΘ	HΘ	0.60	2.70	5.85	1.08	0.45	0.49	0.55
	AΘ	1.26	0.41	0.31	1.78	2.39	1.01	2.54
AΘ-KΘ	AΘ	1.03	0.33	0.56	1.52	1.46	1.25	1.10
	KΘ	1.92	0.31	0.08	0.09	0.15	0.33	134.87
HΘ-KΘ	HΘ	0.55	2.35	5.26	0.90	0.52	0.51	0.53
	KΘ	4.85	2.19	1.86	0.16	0.13	0.27	188.30
HM-AM	HM	0.84	0.83	0.37	1.33	2.23	1.08	0.77
	AM	1.75	1.04	1.04	0.20	0.32	2.13	20.11
AM-KM	AM	1.14	0.98	0.95	1.89	2.20	3.68	24.33
	KM	0.99	0.98	0.92	1.09	1.11	4.50	1.04
HM-KM	HM	0.59	0.59	1.92	1.56	2.74	1.56	0.87
	KM	1.23	1.13	1.11	0.85	0.68	5.94	0.99
HP-AP	HP	0.74	1.72	11.46	0.13	1.03	3.91	0.21
	AP	1.38	0.94	0.23	0.68	4.55	6.70	26.14
AP-KP	AP	0.71	0.60	0.59	0.02	2.48	6.29	11.70
	KP	0.73	1.72	2.46	0.37	0.44	0.02	0.80
HP-KP	HP	0.60	1.94	7.67	0.86	1.50	7.60	0.85
	KP	0.24	0.96	2.00	1.68	0.85	0.15	0.69
AΘ-AM	AΘ	1.77	0.27	0.44	1.71	3.70	1.96	5.82
	AM	4.67	1.12	1.05	1.73	1.41	3.25	29.10
HΘ-HM	HΘ	0.06	1.10	2.17	0.46	0.15	0.06	0.07
	HM	7.48	9.45	90.92	6.52	53.15	87.96	14.49
KΘ-KM	KΘ	0.07	0.23	0.37	0.06	0.16	0.20	42.55
	KM	0.80	1.05	1.47	0.62	5.27	26.89	0.91
HΘ-AM	HΘ	0.39	1.12	2.60	0.64	0.31	0.26	0.31
	AM	1.50	0.77	0.74	7.92	4.17	1.42	15.14
KΘ-AM	KΘ	2.75	2.19	1.06	0.38	0.37	0.75	148.49
	AM	5.24	1.32	1.04	22.24	6.03	27.05	303.00
AΘ-HM	AΘ	1.87	0.20	0.66	1.80	4.04	4.33	8.36
	HM	0.50	0.56	1.51	1.44	3.43	0.24	0.87
KΘ-HM	KΘ	0.29	0.37	0.15	0.09	0.06	0.05	8.23
	HM	0.46	0.48	3.88	1.89	1.25	0.73	0.38
AΘ-KM	AΘ	1.89	0.21	0.43	1.60	3.41	1.83	5.31
	KM	0.86	0.86	0.72	1.06	1.51	0.60	1.00
HΘ-KM	HΘ	0.32	0.81	1.68	0.32	0.26	0.22	0.25
	KM	3.97	2.51	1.31	7.32	5.24	92.47	7.21

Relationship	Variables	Normlized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
AΘ-AP	AΘ	2.33	0.11	1.04	1.39	4.65	2.53	6.79
	AP	2.01	0.11	0.17	1.76	12.90	21.08	38.85
HΘ-HP	HΘ	0.61	2.51	4.89	0.91	0.49	0.45	0.55
	HP	4.99	6.80	125.66	0.91	13.03	404.98	17.64
KΘ-KP	KΘ	0.08	0.16	0.53	0.07	0.07	0.01	6.34
	KP	2.57	3.51	1.45	7.66	1.89	0.39	1.90
HΘ-AP	HΘ	0.37	0.72	1.35	0.68	0.34	0.29	0.32
	AP	0.61	0.93	0.66	0.95	2.63	8.71	22.69
KΘ-AP	KΘ	4.61	2.08	2.21	0.12	0.27	0.76	232.53
	AP	3.78	2.19	1.33	0.13	69.57	164.26	349.92
AΘ-HP	AΘ	1.35	0.28	0.54	0.83	3.78	2.12	4.25
	HP	1.51	1.89	27.86	1.40	2.04	10.94	1.19
KΘ-HP	KΘ	2.17	0.63	0.69	0.21	0.21	0.53	93.52
	HP	0.04	1.07	20.32	0.15	2.65	124.24	4.46
AΘ-KP	AΘ	1.44	0.18	0.46	1.45	3.33	1.81	5.25
	KP	9.43	4.50	2.96	9.08	1.84	1.18	2.10
HΘ-KP	HΘ	0.35	0.99	2.24	0.65	0.29	0.24	0.29
	KP	8.22	7.00	4.06	5.08	2.57	1.67	2.58
AM-AP	AM	0.91	0.94	0.99	1.07	1.27	2.01	5.66
	AP	0.85	0.69	0.52	0.75	0.69	0.69	1.35
HM-HP	HM	0.77	0.52	3.60	2.00	2.77	0.32	0.67
	HP	0.38	1.60	23.33	1.03	0.02	2.38	0.88
KM-KP	KM	1.02	1.03	0.94	0.75	1.12	2.25	1.11
	KP	0.33	1.00	1.50	2.50	0.61	0.05	0.51
HM-AP	HM	0.98	0.97	0.68	1.17	1.70	0.06	0.84
	AP	1.23	0.75	0.66	1.13	2.49	0.85	4.28
KM-AP	KM	1.30	1.31	1.62	0.89	0.15	2.73	1.07
	AP	2.37	0.25	0.25	0.85	4.45	1.26	3.55
AM-HP	AM	0.73	1.18	0.75	7.09	1.26	6.41	2.42
	HP	1.51	1.63	120.37	8.98	1.98	29.14	6.92
KM-HP	KM	1.11	1.07	0.74	0.25	1.07	5.24	0.83
	HP	0.68	2.01	24.82	0.94	0.70	8.40	1.36
AM-KP	AM	0.76	0.99	1.01	0.28	1.19	1.45	7.84
	KP	0.05	0.84	1.37	3.21	1.21	0.49	0.66
HM-KP	HM	0.72	0.69	1.51	1.90	3.96	0.30	0.76
	KP	5.74	4.50	1.69	8.61	1.29	1.12	0.67

TF1:

Relationship	Variables	Normlized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
HΘ-AΘ	HΘ	1.21	5.21	14.35	2.59	1.63	1.28	1.18
	AΘ	1.67	0.76	0.59	1.07	1.70	1.81	3.77
AΘ-KΘ	AΘ	0.88	0.99	0.73	0.80	5.72	3.30	5.25
	KΘ	3.96	2.89	2.30	1.44	1.18	1.32	229.84
HΘ-KΘ	HΘ	1.28	5.61	14.46	2.44	1.67	1.30	1.20
	KΘ	7.01	4.54	3.88	1.74	1.10	1.33	402.20
HM-AM	HM	0.85	0.86	1.67	1.51	1.36	0.44	0.83
	AM	1.79	1.08	1.03	0.36	0.54	1.46	21.01
AM-KM	AM	1.16	1.02	0.98	1.39	2.33	4.00	27.30
	KM	1.02	1.03	1.00	0.94	1.01	0.92	1.03
HM-KM	HM	0.60	0.62	4.50	2.04	1.31	0.63	1.00
	KM	1.21	1.11	1.09	0.89	1.45	1.26	0.96
HP-AP	HP	1.11	1.14	22.88	10.22	1.17	10.47	1.07
	AP	0.68	0.60	1.46	0.52	5.74	3.86	1.22
AP-KP	AP	1.05	0.83	0.13	0.89	3.72	2.09	6.00
	KP	0.17	0.70	1.72	1.73	1.03	0.85	0.83
HP-KP	HP	0.96	1.45	6.84	3.07	1.62	22.38	1.56
	KP	0.39	1.12	0.57	1.50	1.10	0.88	0.82
AΘ-AM	AΘ	0.81	0.76	0.74	1.19	0.91	0.31	1.63
	AM	1.58	1.10	1.00	1.84	2.36	3.98	33.93
HΘ-HM	HΘ	0.80	2.20	3.69	0.18	1.12	0.92	0.81
	HM	7.61	9.50	225.66	42.46	16.08	31.85	10.16
KΘ-KM	KΘ	2.32	2.20	1.94	1.17	0.78	0.65	119.47
	KM	0.93	0.87	0.71	1.02	6.51	1.38	0.31
HΘ-AM	HΘ	1.08	4.33	10.81	1.73	1.37	1.08	0.96
	AM	5.21	0.53	0.68	6.04	8.02	19.03	129.78
KΘ-AM	KΘ	6.17	3.68	3.67	1.98	1.37	1.66	310.98
	AM	16.11	1.55	1.23	24.39	28.17	18.70	92.24
AΘ-HM	AΘ	1.37	1.62	0.73	1.29	2.32	0.05	0.64
	HM	0.77	0.37	8.38	2.30	1.16	0.19	0.56
KΘ-HM	KΘ	1.56	1.99	1.87	1.12	0.80	0.77	94.19
	HM	0.46	0.33	11.19	2.99	1.24	1.14	0.06
AΘ-KM	AΘ	1.32	0.53	0.55	1.05	0.59	0.17	1.33
	KM	0.75	0.84	0.75	0.75	1.19	1.04	1.12
HΘ-KM	HΘ	0.98	3.57	9.02	1.40	1.31	1.01	0.88
	KM	1.73	1.41	2.05	2.38	7.62	2.32	0.04

Relationship	Variables	Normlized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
AΘ-AP	AΘ	1.38	1.08	0.07	0.98	2.04	0.66	2.42
	AP	4.92	0.13	2.19	1.70	6.28	19.04	39.40
HΘ-HP	HΘ	1.25	5.18	13.83	2.42	1.69	1.32	1.20
	HP	5.15	5.51	75.61	43.74	41.14	525.05	17.32
KΘ-KP	KΘ	1.91	2.37	2.17	1.20	0.75	0.71	142.51
	KP	4.22	4.28	2.52	1.68	4.27	1.19	0.44
HΘ-AP	HΘ	1.05	3.89	9.02	1.49	1.42	1.10	0.98
	AP	0.30	0.96	1.22	0.35	6.10	7.42	9.33
KΘ-AP	KΘ	8.50	3.96	5.99	2.16	1.49	1.70	375.48
	AP	5.71	2.04	4.61	6.74	127.43	165.91	236.75
AΘ-HP	AΘ	1.45	0.40	0.56	1.11	0.23	0.07	2.08
	HP	0.74	1.19	46.13	16.90	0.21	7.30	0.14
KΘ-HP	KΘ	3.85	3.09	2.80	1.45	1.11	1.31	237.98
	HP	0.38	0.76	10.63	5.30	8.65	109.68	1.01
AΘ-KP	AΘ	1.22	0.77	0.57	1.05	0.27	0.44	0.39
	KP	7.70	9.16	5.53	2.89	1.02	0.46	2.84
HΘ-KP	HΘ	1.03	4.02	10.01	1.59	1.36	1.05	0.92
	KP	8.12	7.02	3.94	1.47	2.40	0.36	0.69
AM-AP	AM	1.11	0.94	1.05	1.00	1.03	1.18	3.88
	AP	0.86	0.84	0.28	0.94	1.21	1.45	2.29
HM-HP	HM	0.87	0.81	3.40	1.81	1.32	0.33	0.97
	HP	0.95	1.41	0.80	0.03	0.10	4.32	1.17
KM-KP	KM	1.05	1.04	1.02	0.92	1.65	1.16	1.08
	KP	0.45	0.92	0.65	1.22	0.98	0.96	0.98
HM-AP	HM	0.99	1.01	1.93	1.49	1.15	0.72	0.89
	AP	1.15	0.97	0.04	1.04	0.26	2.29	11.18
KM-AP	KM	1.23	1.20	1.33	1.04	2.36	1.06	1.08
	AP	1.97	0.42	0.38	1.14	2.21	3.76	7.96
AM-HP	AM	2.48	0.65	1.08	2.84	2.66	8.49	75.21
	HP	1.63	4.42	62.52	25.78	6.92	48.41	2.30
KM-HP	KM	0.97	0.94	0.98	1.11	0.40	0.77	0.81
	HP	1.16	1.65	5.78	2.70	1.07	8.48	1.38
AM-KP	AM	0.57	1.00	0.99	1.27	1.29	1.39	4.24
	KP	0.01	0.56	0.35	1.44	0.95	1.00	1.12
HM-KP	HM	0.67	0.58	5.16	2.18	1.08	0.64	0.37
	KP	7.54	4.89	1.46	0.55	1.20	0.35	0.46

TF2:

Relationship	Variables	Normlized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
HΘ-AΘ	HΘ	0.31	0.14	2.89	2.98	0.09	0.20	0.22
	AΘ	1.57	1.42	1.32	1.13	1.91	3.12	10.85
AΘ-KΘ	AΘ	2.04	1.49	1.40	0.90	4.16	4.27	9.07
	KΘ	7.22	4.78	4.54	1.87	1.34	1.56	277.42
HΘ-KΘ	HΘ	0.26	0.09	2.86	3.06	0.18	0.10	0.19
	KΘ	10.96	6.72	6.44	2.22	1.43	1.78	499.66
HM-AM	HM	0.86	0.90	0.05	1.48	1.89	0.56	0.84
	AM	1.76	1.03	1.00	0.68	0.31	0.79	18.50
AM-KM	AM	1.17	1.00	0.98	1.03	2.12	3.77	24.39
	KM	1.01	0.98	0.95	1.00	1.09	0.23	0.92
HM-KM	HM	0.61	0.74	0.90	1.76	2.03	0.26	0.98
	KM	1.23	1.10	1.05	0.96	0.75	5.91	0.94
HP-AP	HP	1.44	1.45	0.67	0.57	0.98	0.78	1.45
	AP	0.28	0.95	1.08	0.86	0.81	2.16	9.67
AP-KP	AP	1.15	1.00	0.94	0.98	1.00	3.20	6.54
	KP	0.28	0.52	1.07	1.05	0.97	1.01	0.93
HP-KP	HP	1.31	1.38	0.95	0.24	1.25	16.37	1.98
	KP	0.35	0.11	0.75	1.15	1.31	1.02	1.04
AΘ-AM	AΘ	1.24	1.38	1.21	0.93	2.97	3.19	6.64
	AM	4.08	1.20	1.09	0.37	0.94	3.11	23.26
HΘ-HM	HΘ	0.39	1.68	6.03	6.37	1.10	0.48	0.25
	HM	9.54	8.33	132.96	39.73	87.00	133.66	12.70
KΘ-KM	KΘ	5.70	4.39	4.22	1.73	1.29	1.45	242.81
	KM	0.86	0.91	0.80	0.92	1.15	1.40	0.99
HΘ-AM	HΘ	0.08	0.50	3.67	4.11	0.30	0.02	0.02
	AM	0.80	0.87	0.86	0.09	0.50	4.94	62.80
KΘ-AM	KΘ	10.54	7.09	6.98	2.27	1.51	1.74	388.10
	AM	15.17	1.86	1.50	7.49	12.67	28.89	223.18
AΘ-HM	AΘ	1.77	1.10	1.46	0.90	3.32	3.40	9.66
	HM	0.35	0.35	8.48	2.84	4.13	3.54	0.25
KΘ-HM	KΘ	5.09	3.92	3.76	1.66	1.25	1.39	201.74
	HM	0.38	0.44	6.85	3.68	5.78	7.16	0.09
AΘ-KM	AΘ	0.76	1.25	1.14	0.94	2.49	2.68	5.19
	KM	0.87	0.96	0.96	1.02	1.16	0.10	0.95
HΘ-KM	HΘ	0.02	0.75	4.33	4.43	0.41	0.12	0.12
	KM	6.84	3.45	3.34	5.85	39.44	257.52	6.67

Relationship	Variables	Normlized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
AΘ-AP	AΘ	0.61	1.14	1.11	0.97	2.20	2.47	4.97
	AP	2.89	0.65	0.57	1.47	5.25	21.12	58.04
HΘ-HP	HΘ	0.28	0.11	2.63	3.01	0.22	0.12	0.21
	HP	6.34	5.30	64.53	51.44	11.55	570.20	27.61
KΘ-KP	KΘ	6.08	4.46	4.35	1.80	1.29	1.45	244.69
	KP	1.80	1.07	0.89	0.90	0.84	0.96	0.96
HΘ-AP	HΘ	0.07	0.54	4.37	4.02	0.33	0.03	0.00
	AP	0.05	1.29	1.32	0.68	7.45	17.33	28.93
KΘ-AP	KΘ	13.08	7.78	7.35	2.48	1.60	1.94	475.80
	AP	6.32	3.19	3.68	1.21	29.34	82.40	189.02
AΘ-HP	AΘ	0.52	0.99	1.07	1.05	1.48	1.38	3.33
	HP	1.18	1.02	5.24	5.59	1.24	26.92	3.42
KΘ-HP	KΘ	8.47	5.14	5.07	2.03	1.39	1.62	317.39
	HP	0.63	0.95	11.77	11.62	1.04	70.57	1.65
AΘ-KP	AΘ	0.99	1.24	1.18	0.95	2.72	2.93	6.02
	KP	4.07	1.01	2.96	0.32	1.30	1.52	1.29
HΘ-KP	HΘ	0.02	0.63	4.23	4.15	0.36	0.10	0.10
	KP	11.69	7.18	4.83	2.28	4.63	2.09	1.41
AM-AP	AM	1.09	1.03	1.01	0.73	1.03	1.42	3.49
	AP	0.90	1.06	1.08	0.97	1.03	1.12	1.10
HM-HP	HM	0.90	0.92	0.97	1.48	1.41	0.12	0.74
	HP	1.33	1.34	7.73	5.31	0.49	17.91	0.08
KM-KP	KM	1.04	1.00	0.98	1.01	0.86	3.12	1.02
	KP	0.51	0.52	0.78	1.09	1.10	0.96	1.09
HM-AP	HM	1.00	0.99	0.47	1.17	1.45	0.05	0.86
	AP	1.21	0.96	0.99	1.00	1.62	1.66	4.82
KM-AP	KM	1.25	1.10	1.06	0.87	0.37	10.14	1.15
	AP	1.95	0.86	1.01	1.14	0.39	1.31	10.32
AM-HP	AM	3.76	0.53	0.94	3.83	4.16	4.81	24.05
	HP	4.14	3.21	14.26	15.19	2.67	30.21	2.70
KM-HP	KM	0.90	0.94	1.08	1.17	1.30	2.41	0.98
	HP	1.48	1.61	1.75	2.50	0.89	5.33	1.04
AM-KP	AM	0.71	0.95	0.96	1.17	1.07	0.73	7.04
	KP	0.02	0.20	0.64	1.34	1.48	1.31	1.28
HM-KP	HM	0.67	0.55	7.05	2.45	3.66	2.24	0.30
	KP	7.08	4.66	2.66	0.05	0.29	1.01	0.99

TF3:

Relationship	Variables	Normlized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
HΘ-AΘ	HΘ	0.83	2.57	5.67	0.45	0.18	0.15	0.23
	AΘ	0.79	1.99	0.82	0.58	5.24	3.65	5.82
AΘ-KΘ	AΘ	0.26	0.69	0.53	0.28	7.02	4.74	6.86
	KΘ	2.11	4.86	3.61	0.24	0.57	1.44	323.58
HΘ-KΘ	HΘ	0.25	1.21	4.03	0.56	0.31	0.08	0.20
	KΘ	3.45	6.55	4.76	0.39	0.55	1.64	489.07
HM-AM	HM	0.88	0.79	1.76	1.49	1.26	0.65	0.86
	AM	1.43	1.02	1.04	0.57	0.51	1.45	21.57
AM-KM	AM	1.08	1.00	0.99	1.77	2.41	5.02	29.79
	KM	1.00	1.00	1.06	1.00	1.54	0.71	0.93
HM-KM	HM	0.67	0.55	2.74	1.83	1.84	0.81	1.00
	KM	1.19	1.15	1.10	0.97	1.05	0.70	0.87
HP-AP	HP	0.29	0.31	70.78	37.07	2.09	13.01	1.03
	AP	0.39	0.76	1.31	1.03	0.88	3.38	9.76
AP-KP	AP	0.62	0.82	0.53	1.35	3.12	0.74	2.73
	KP	1.07	0.52	1.46	2.13	0.39	0.04	0.80
HP-KP	HP	0.75	1.19	26.99	21.04	1.25	5.45	0.80
	KP	2.97	1.56	3.81	0.80	0.07	0.01	0.67
AΘ-AM	AΘ	0.46	0.43	0.33	0.31	4.58	3.35	4.30
	AM	3.07	1.09	1.06	0.38	0.40	3.46	35.27
HΘ-HM	HΘ	0.37	0.90	2.88	2.34	0.76	0.31	0.23
	HM	13.46	24.22	277.48	35.75	14.37	36.85	11.25
KΘ-KM	KΘ	1.45	4.85	3.24	0.25	0.38	1.32	268.48
	KM	0.80	1.02	0.26	0.48	41.42	11.44	1.36
HΘ-AM	HΘ	0.24	0.82	1.46	0.60	0.30	0.01	0.04
	AM	0.15	1.08	0.92	1.93	1.43	2.11	21.92
KΘ-AM	KΘ	3.10	7.69	4.82	0.81	0.58	1.67	472.32
	AM	10.07	2.04	1.17	10.98	28.32	107.13	433.84
AΘ-HM	AΘ	1.93	0.44	0.18	0.05	7.57	4.36	5.32
	HM	0.46	0.39	6.20	2.75	1.58	1.01	0.49
KΘ-HM	KΘ	1.44	4.42	3.20	0.11	0.30	1.07	233.27
	HM	0.50	0.09	17.31	3.82	0.97	0.27	0.12
AΘ-KM	AΘ	0.94	0.52	0.47	0.43	4.04	2.76	3.11
	KM	0.91	0.95	1.00	1.13	0.12	0.82	1.02
HΘ-KM	HΘ	0.23	1.02	1.16	0.94	0.38	0.05	0.02
	KM	9.53	7.07	4.14	2.18	46.82	16.54	4.41

Relationship	Variables	Normlized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
AΘ-AP	AΘ	0.78	0.04	0.28	0.36	3.83	2.41	2.16
	AP	0.75	0.01	0.15	1.43	4.38	12.87	34.58
HΘ-HP	HΘ	0.73	1.84	4.40	0.18	0.08	0.22	0.24
	HP	12.14	26.83	400.53	143.48	30.26	525.00	14.95
KΘ-KP	KΘ	1.83	4.36	4.54	0.85	0.14	1.03	278.72
	KP	4.18	2.25	1.24	1.66	6.17	0.77	0.56
HΘ-AP	HΘ	0.11	0.49	0.69	0.83	0.33	0.01	0.01
	AP	0.85	1.69	1.70	0.75	5.28	11.49	21.09
KΘ-AP	KΘ	3.12	10.70	5.79	0.31	0.74	1.99	486.84
	AP	1.22	3.86	4.15	0.65	70.98	159.76	248.95
AΘ-HP	AΘ	0.42	0.73	0.43	0.48	2.92	1.80	1.03
	HP	1.30	3.62	134.69	48.66	3.24	34.78	2.07
KΘ-HP	KΘ	1.95	6.58	6.93	0.99	0.38	1.26	376.26
	HP	0.17	0.07	27.85	20.68	1.11	42.88	0.48
AΘ-KP	AΘ	0.62	0.36	0.46	0.39	3.27	2.43	3.09
	KP	20.67	0.71	1.51	2.64	2.26	2.37	1.43
HΘ-KP	HΘ	0.06	0.56	1.33	0.47	0.38	0.04	0.02
	KP	7.18	2.00	1.82	4.38	3.79	1.11	0.58
AM-AP	AM	1.19	1.04	1.00	0.87	0.81	0.75	5.37
	AP	0.64	0.86	0.90	0.98	1.67	2.75	4.02
HM-HP	HM	0.67	1.09	28.15	0.75	1.31	0.42	0.93
	HP	0.28	1.30	4.55	12.63	0.21	21.58	0.59
KM-KP	KM	1.04	1.06	0.95	0.95	0.52	0.71	1.00
	KP	2.20	0.88	0.97	1.72	0.42	0.04	0.78
HM-AP	HM	0.97	0.88	0.71	1.09	1.04	0.71	0.90
	AP	0.65	0.72	0.97	0.89	1.58	5.11	9.28
KM-AP	KM	1.21	1.15	1.13	0.85	0.53	1.31	1.08
	AP	1.01	0.76	0.86	1.08	2.51	6.32	16.95
AM-HP	AM	0.81	0.94	0.89	1.63	3.48	7.52	46.07
	HP	2.74	2.79	15.26	37.60	1.51	24.26	0.19
KM-HP	KM	1.28	1.02	0.62	0.83	2.27	0.99	0.83
	HP	0.75	2.04	2.62	13.24	0.88	6.28	0.76
AM-KP	AM	0.81	0.99	0.97	1.01	1.48	2.51	6.18
	KP	1.29	0.60	1.23	2.51	0.11	0.17	0.87
HM-KP	HM	0.74	0.60	8.51	2.43	0.48	1.23	0.22
	KP	9.92	3.83	1.87	3.59	0.96	1.11	0.21

TF4:

Relationship	Variables	Normlized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
HΘ-AΘ	HΘ	0.68	1.96	5.48	1.87	0.77	0.55	0.49
	AΘ	2.57	1.61	1.06	0.74	3.57	3.70	8.84
AΘ-KΘ	AΘ	3.12	1.93	1.21	0.71	3.34	3.36	8.40
	KΘ	4.73	4.02	3.56	0.92	0.12	0.21	273.83
HΘ-KΘ	HΘ	0.68	2.18	6.12	1.79	0.59	0.48	0.46
	KΘ	8.85	5.86	5.17	1.19	0.13	0.42	439.17
HM-AM	HM	0.85	0.84	2.41	1.56	1.42	0.51	0.83
	AM	1.75	1.04	1.04	0.91	0.23	2.60	22.87
AM-KM	AM	1.16	1.01	0.98	1.57	1.42	1.69	28.27
	KM	1.01	1.01	1.00	0.67	2.52	1.04	0.98
HM-KM	HM	0.60	0.64	5.60	1.87	2.10	0.65	0.96
	KM	1.22	1.15	1.10	0.68	2.34	1.05	0.92
HP-AP	HP	0.01	1.19	47.09	21.17	0.03	1.06	2.47
	AP	0.57	1.24	0.19	0.63	1.78	4.62	1.55
AP-KP	AP	0.91	0.98	1.06	0.82	0.09	3.13	6.25
	KP	2.69	0.36	0.11	1.74	1.40	0.14	0.03
HP-KP	HP	0.21	1.23	44.97	16.44	1.90	5.03	2.03
	KP	1.52	0.22	0.18	2.78	1.34	0.19	0.32
AΘ-AM	AΘ	2.72	1.52	1.07	0.85	3.15	3.63	8.44
	AM	4.30	1.16	1.09	0.73	0.80	4.03	30.02
HΘ-HM	HΘ	0.14	1.32	4.62	0.86	0.02	0.07	0.02
	HM	8.63	9.71	194.62	42.93	22.58	37.62	12.43
KΘ-KM	KΘ	3.55	3.60	3.16	0.67	0.10	0.02	232.18
	KM	0.69	0.84	0.91	0.20	27.00	8.20	0.35
HΘ-AM	HΘ	0.49	0.84	1.90	0.95	0.47	0.39	0.31
	AM	1.20	0.77	0.79	2.95	3.25	5.40	31.71
KΘ-AM	KΘ	8.33	5.45	4.89	0.97	0.01	0.30	422.86
	AM	12.71	1.73	1.47	7.06	28.82	71.68	137.98
AΘ-HM	AΘ	2.94	2.07	1.02	0.96	0.95	3.20	8.74
	HM	0.33	0.39	4.57	2.49	0.98	0.56	0.46
KΘ-HM	KΘ	3.17	3.36	2.93	0.57	0.01	0.20	189.02
	HM	0.38	0.29	12.02	2.53	1.37	1.91	0.11
AΘ-KM	AΘ	2.01	1.47	1.02	0.81	3.21	3.19	6.85
	KM	0.89	0.95	0.94	0.94	2.10	1.12	1.06
HΘ-KM	HΘ	0.42	0.38	0.51	0.55	0.39	0.33	0.25
	KM	3.53	2.05	1.82	0.83	33.77	12.23	4.76

Relationship	Variables	Normlized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
AΘ-AP	AΘ	1.81	1.54	1.00	0.92	2.45	2.63	5.95
	AP	2.27	0.61	0.37	1.16	4.27	18.53	44.50
HΘ-HP	HΘ	0.80	2.24	5.14	2.11	0.84	0.60	0.55
	HP	5.90	6.91	121.66	66.88	32.95	520.47	17.25
KΘ-KP	KΘ	3.63	3.57	3.15	0.70	0.02	0.41	263.47
	KP	2.05	1.36	1.06	4.42	2.04	0.43	0.59
HΘ-AP	HΘ	0.47	0.70	1.67	0.83	0.47	0.37	0.30
	AP	0.10	1.18	1.24	0.71	3.60	10.06	20.08
KΘ-AP	KΘ	10.05	6.68	5.74	1.36	0.06	0.27	502.44
	AP	5.34	2.96	3.86	1.37	3.06	3.95	49.90
AΘ-HP	AΘ	1.80	1.25	0.60	0.67	1.87	1.92	3.15
	HP	1.93	1.24	13.06	3.43	2.19	15.14	1.55
KΘ-HP	KΘ	6.05	4.72	3.71	0.88	0.13	0.35	290.68
	HP	0.80	0.40	32.41	10.50	1.59	24.01	0.80
AΘ-KP	AΘ	1.94	1.61	1.06	0.85	3.26	2.93	5.77
	KP	0.05	1.03	2.23	1.04	1.16	0.27	0.04
HΘ-KP	HΘ	0.44	0.58	1.33	0.84	0.42	0.35	0.26
	KP	9.84	5.31	2.74	5.29	1.57	0.80	1.92
AM-AP	AM	1.02	1.00	1.01	1.15	1.35	1.56	4.65
	AP	0.76	1.03	1.01	0.84	0.67	0.21	0.74
HM-HP	HM	0.89	0.92	3.64	1.69	1.21	0.69	0.66
	HP	0.33	1.13	51.80	19.35	0.16	10.08	2.17
KM-KP	KM	1.01	1.04	1.05	0.64	1.72	0.93	1.01
	KP	2.54	0.50	0.20	2.68	1.56	0.49	0.15
HM-AP	HM	0.99	0.98	0.33	1.14	1.42	0.75	0.88
	AP	0.94	0.96	0.84	0.83	2.44	2.43	5.75
KM-AP	KM	1.24	1.11	1.05	0.89	1.95	1.14	1.04
	AP	1.78	0.77	0.52	0.94	1.33	1.85	7.70
AM-HP	AM	2.72	1.04	0.27	0.47	3.33	9.34	99.22
	HP	3.09	2.77	230.08	87.39	1.37	19.05	6.57
KM-HP	KM	1.06	0.98	0.74	1.03	0.57	0.51	0.61
	HP	0.27	1.35	52.39	18.33	0.78	1.54	1.52
AM-KP	AM	0.85	0.99	0.98	1.29	1.05	0.15	14.53
	KP	2.30	0.10	0.16	2.58	1.90	0.32	0.13
HM-KP	HM	0.70	0.64	3.48	2.01	0.48	0.77	0.65
	KP	8.12	3.61	2.17	4.04	0.78	0.37	0.13

TF5:

Relationship	Variables	Normlized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
HΘ-AΘ	HΘ	0.27	1.01	1.84	1.41	0.09	0.08	0.14
	AΘ	2.14	1.39	0.81	0.00	1.18	2.22	1.22
AΘ-KΘ	AΘ	1.10	1.18	0.57	0.55	1.25	2.56	0.26
	KΘ	6.98	3.28	5.41	1.28	0.08	0.60	207.39
HΘ-KΘ	HΘ	0.30	2.58	4.15	1.72	0.70	0.01	0.11
	KΘ	10.63	4.17	5.60	1.74	0.06	0.72	331.51
HM-AM	HM	0.84	0.86	0.53	0.46	1.51	0.48	0.84
	AM	1.89	1.03	1.05	1.06	0.74	1.25	18.81
AM-KM	AM	1.19	1.01	1.02	0.99	1.08	3.12	22.48
	KM	1.01	1.01	1.06	1.05	0.80	0.51	0.98
HM-KM	HM	0.57	0.69	0.06	2.63	1.67	0.88	0.98
	KM	1.24	1.12	1.14	1.26	0.50	0.49	0.95
HP-AP	HP	0.48	0.23	1.74	18.66	0.74	1.49	0.74
	AP	0.30	1.05	1.00	0.83	1.12	1.99	0.75
AP-KP	AP	0.54	0.36	0.46	1.14	1.52	5.41	2.12
	KP	0.29	3.85	0.14	1.47	2.13	0.28	0.59
HP-KP	HP	0.12	0.52	0.39	14.88	0.56	8.55	1.65
	KP	1.08	1.83	2.88	0.78	1.91	0.53	0.51
AΘ-AM	AΘ	1.94	0.80	0.03	0.18	1.36	1.54	2.03
	AM	4.70	1.19	0.93	1.07	1.45	2.77	26.09
HΘ-HM	HΘ	0.13	2.52	3.93	5.14	3.22	0.33	0.30
	HM	6.77	0.41	1.80	10.78	38.50	35.39	11.29
KΘ-KM	KΘ	4.80	2.50	3.88	0.80	0.28	0.50	168.43
	KM	0.68	0.44	0.49	0.93	3.02	24.48	0.65
HΘ-AM	HΘ	0.15	2.26	3.27	0.51	1.16	0.02	0.01
	AM	0.64	0.17	0.20	0.62	0.06	3.00	17.13
KΘ-AM	KΘ	11.90	4.45	4.61	1.53	0.17	0.48	339.39
	AM	15.52	1.10	1.19	1.06	37.27	38.54	123.07
AΘ-HM	AΘ	2.20	0.95	0.79	0.33	1.72	5.06	2.46
	HM	0.47	0.53	0.16	0.46	1.98	0.37	0.56
KΘ-HM	KΘ	4.47	2.67	3.96	0.75	0.20	0.57	133.66
	HM	0.38	0.35	1.31	5.08	2.11	2.96	0.09
AΘ-KM	AΘ	2.06	0.98	0.08	0.27	1.34	0.80	1.97
	KM	0.84	0.91	0.73	0.68	1.16	0.01	1.03
HΘ-KM	HΘ	0.07	1.84	2.65	1.61	1.46	0.10	0.06
	KM	3.33	1.46	0.22	8.65	18.78	70.19	5.95

Relationship	Variables	Normlized error for each phase, X_{norm}						
		LR	MSt	TSt	PSw	ISw	MSw	TSw
AΘ-AP	AΘ	2.21	0.40	0.02	0.17	1.61	3.07	3.29
	AP	3.48	0.24	1.47	0.83	1.14	11.13	34.06
HΘ-HP	HΘ	0.44	1.16	2.95	3.28	0.04	0.13	0.17
	HP	6.22	0.94	9.45	133.40	8.06	329.21	20.75
KΘ-KP	KΘ	4.53	2.82	4.41	1.32	0.16	0.68	146.58
	KP	3.35	4.17	0.59	0.07	3.34	1.21	0.63
HΘ-AP	HΘ	0.13	1.92	3.26	0.70	1.23	0.05	0.01
	AP	0.68	1.03	0.84	0.84	1.80	6.28	19.07
KΘ-AP	KΘ	14.96	5.49	9.07	2.75	0.10	0.55	432.54
	AP	9.10	2.33	4.19	0.27	7.95	20.10	108.78
AΘ-HP	AΘ	1.03	0.95	1.02	1.09	1.55	2.69	2.27
	HP	2.30	2.27	2.89	23.15	0.86	26.04	1.12
KΘ-HP	KΘ	8.42	3.94	4.92	1.65	0.01	0.54	274.00
	HP	0.90	0.69	9.37	85.66	0.50	7.51	0.73
AΘ-KP	AΘ	1.78	1.05	0.78	0.53	1.39	1.81	1.82
	KP	7.55	6.71	12.92	1.25	2.40	2.26	0.85
HΘ-KP	HΘ	0.09	2.05	2.93	0.88	1.32	0.10	0.06
	KP	5.90	7.98	4.87	3.63	9.00	2.67	0.88
AM-AP	AM	1.32	0.95	1.02	1.03	1.60	1.33	1.73
	AP	0.85	0.75	0.56	0.90	1.05	1.43	2.90
HM-HP	HM	0.59	0.44	0.82	7.87	1.11	0.77	0.94
	HP	0.39	0.25	3.45	52.17	0.54	11.60	0.16
KM-KP	KM	1.04	1.03	1.09	0.80	0.87	1.68	1.02
	KP	0.12	1.37	0.00	1.32	1.96	0.71	0.67
HM-AP	HM	0.99	0.96	0.62	0.59	1.17	0.15	0.90
	AP	1.61	0.94	0.32	0.95	1.16	4.47	7.08
KM-AP	KM	1.21	1.20	1.05	1.21	0.64	9.43	0.93
	AP	2.53	0.54	0.18	0.92	0.95	0.97	12.20
AM-HP	AM	2.29	2.00	0.95	1.27	3.79	6.85	63.07
	HP	4.87	5.21	3.16	57.93	0.08	12.11	2.40
KM-HP	KM	1.16	1.16	0.81	0.78	1.39	1.60	0.87
	HP	0.22	0.14	8.64	89.88	0.58	12.50	0.76
AM-KP	AM	1.10	1.03	0.95	0.91	0.86	0.40	12.92
	KP	0.36	1.51	0.35	1.21	1.71	0.40	0.82
HM-KP	HM	0.64	0.65	0.39	0.73	1.86	0.13	0.42
	KP	8.17	5.37	3.15	1.41	2.73	0.32	0.84

APPENDIX F: RAW RESULT OF PHASE 3

LOADING RESPONSE:

SUB.	PAIR	VAR.	LR	MSt	TSt	PSw	ISw	MSw	TSw
TF1	KΘ-AM	KΘ	6.17	3.68	3.67	1.98	1.37	1.66	310.98
		AM	16.08	1.55	1.23	24.39	28.17	18.70	92.24
	KΘ-AM	KΘ	6.15	3.68	3.67	1.98	1.37	1.66	310.98
		AM	9.56	1.55	1.23	24.39	28.17	18.70	92.24
TF2	KΘ-AM	KΘ	10.55	7.09	6.98	2.27	1.51	1.74	388.10
		AM	15.14	1.86	1.50	7.49	12.67	28.89	223.18
	KΘ-AM	KΘ	6.14	7.09	6.98	2.27	1.51	1.74	388.10
		AM	9.57	1.86	1.50	7.49	12.67	28.89	223.18
TF3	HΘ-HM	HΘ	0.37	0.90	2.88	2.34	0.76	0.31	0.23
		HM	13.19	23.78	276.91	37.63	16.51	35.91	10.58
	HΘ-HM	HΘ	0.29	0.90	2.88	2.34	0.76	0.31	0.23
		HM	9.00	23.78	276.91	37.63	16.51	35.91	10.58
TF4	KΘ-AM	KΘ	8.34	5.45	4.89	0.97	0.01	0.30	422.86
		AM	12.67	1.73	1.47	7.06	28.82	71.68	137.98
	KΘ-AM	KΘ	6.15	5.45	4.89	0.97	0.01	0.30	422.86
		AM	9.56	1.73	1.47	7.06	28.82	71.68	137.98
TF5	KΘ-AM	KΘ	11.90	4.45	4.61	1.53	0.17	0.48	339.39
		AM	15.51	1.10	1.19	1.06	37.27	38.54	123.07
	KΘ-AM	KΘ	7.82	4.34	4.61	1.53	0.17	0.48	339.39
		AM	11.15	1.09	1.19	1.06	37.27	38.54	123.07

SUB.	PAIR	VAR.	LR	MSt	TSt	PSw	ISw	MSw	TSw
TT1	KΘ-AM	KΘ	3.45	0.54	1.79	0.45	0.13	0.62	201.10
		AM	17.72	1.11	1.18	15.74	31.54	83.10	430.12
	KΘ-AM	KΘ	7.82	0.69	1.79	0.45	0.13	0.62	201.10
		AM	11.15	1.13	1.18	15.74	31.54	83.10	430.12
TT2	HΘ-KP	HΘ	0.14	0.06	0.60	1.38	0.06	0.04	0.16
		KP	7.46	7.65	4.61	14.98	6.80	3.62	1.84
	HΘ-KP	HΘ	0.02	0.06	0.60	1.38	0.06	0.04	0.16
		KP	8.83	7.65	4.61	14.98	6.80	3.62	1.84
TT3	AΘ-HM	AΘ	51.69	12.46	8.91	5.84	98.04	71.95	180.25
		HM	1.67	1.61	30.15	9.25	0.37	5.29	2.27
	AΘ-HM	AΘ	0.75	12.46	8.91	5.84	98.04	71.95	180.25
		HM	0.41	1.61	30.15	9.25	0.37	5.29	2.27
TT4	KΘ-AP	KΘ	8.38	1.23	1.48	0.11	0.21	0.65	191.65
		AP	14.86	2.55	2.73	0.55	21.89	68.64	159.26
	KΘ-AP	KΘ	19.70	1.88	1.48	0.11	0.21	0.65	191.65
		AP	15.79	2.84	2.73	0.55	21.89	68.64	159.26
TT5	KΘ-KM	KΘ	11.16	2.59	0.84	0.18	0.67	1.32	170.42
		KM	0.63	0.69	0.95	2.28	42.69	6.66	3.96
	KΘ-KM	KΘ	1.89	2.36	0.84	0.18	0.67	1.32	170.42
		KM	0.81	0.71	0.95	2.28	42.69	6.66	3.96
TT6	HΘ-KP	HΘ	0.83	3.04	6.98	1.68	0.37	0.74	1.04
		KP	5.57	0.77	3.25	8.33	2.23	0.80	0.52
	HΘ-KP	HΘ	0.11	3.04	6.98	1.68	0.37	0.74	1.04
		KP	10.70	0.77	3.25	8.33	2.23	0.80	0.52
TT7	HΘ-HM	HΘ	0.13	2.14	4.08	0.31	0.10	0.04	0.15
		HM	8.86	11.59	108.29	24.01	85.01	86.06	13.15
	HΘ-HM	HΘ	0.26	2.14	4.08	0.31	0.10	0.04	0.15
		HM	7.38	11.59	108.29	24.01	85.01	86.06	13.15
TT8	HΘ-HM	HΘ	0.22	0.24	2.57	0.81	0.22	0.21	0.08
		HM	13.37	14.67	73.98	10.24	70.32	108.92	20.65
	HΘ-HM	HΘ	0.26	0.24	2.57	0.81	0.22	0.21	0.08
		HM	7.53	14.67	73.98	10.24	70.32	108.92	20.65
TT9	AΘ-KP	AΘ	4.01	0.62	0.18	1.15	3.37	10.92	9.70
		KP	7.58	4.17	2.85	5.31	3.02	1.51	0.01
	AΘ-KP	AΘ	0.58	0.62	0.18	1.15	3.37	10.92	9.70
		KP	5.18	4.17	2.85	5.31	3.02	1.51	0.01
TT10	AΘ-KP	AΘ	1.41	0.18	0.46	1.45	3.33	1.81	5.25
		KP	9.41	4.50	2.96	9.08	1.84	1.18	2.10
	AΘ-KP	AΘ	0.34	0.18	0.46	1.45	3.33	1.81	5.25
		KP	4.51	4.50	2.96	9.08	1.84	1.18	2.10

MID-STANCE:

SUB.	PAIR	VAR.	LR	MSt	TSt	PSw	ISw	MSw	TSw
TF1	HΘ-HM	HΘ	0.80	2.20	3.69	0.18	1.12	0.92	0.81
		HM	7.61	9.50	225.66	42.46	16.08	31.85	10.16
	HΘ-HM	HΘ	0.80	0.93	3.69	0.18	1.12	0.92	0.81
		HM	7.61	9.83	225.66	42.46	16.08	31.85	10.16
TF2	HΘ-HM	HΘ	0.39	1.68	6.03	6.37	1.10	0.48	0.25
		HM	9.54	8.34	132.96	39.73	87.00	133.66	12.70
	HΘ-HM	HΘ	0.39	1.26	6.03	6.37	1.10	0.48	0.25
		HM	9.54	7.97	132.96	39.73	87.00	133.66	12.70
TF3	HΘ-HP	HΘ	0.73	1.84	4.40	0.18	0.08	0.22	0.24
		HP	12.14	26.83	400.53	143.48	30.26	525.00	14.95
	HΘ-HP	HΘ	0.73	1.84	4.40	0.18	0.08	0.22	0.24
		HP	12.14	26.83	400.53	143.48	30.26	525.00	14.95
TF4	HΘ-HM	HΘ	0.14	1.32	4.62	0.86	0.02	0.07	0.02
		HM	8.63	9.71	194.62	42.93	22.58	37.62	12.43
	HΘ-HM	HΘ	0.14	1.60	4.62	0.86	0.02	0.07	0.02
		HM	8.63	9.49	194.62	42.93	22.58	37.62	12.43
TF5	AΘ-KP	AΘ	1.78	1.05	0.78	0.53	1.39	1.81	1.82
		KP	7.55	6.71	12.92	1.25	2.40	2.26	0.85
	AΘ-KP	AΘ	1.78	1.05	0.78	0.53	1.39	1.81	1.82
		KP	7.55	6.71	12.92	1.25	2.40	2.26	0.85

SUB.	PAIR	VAR.	LR	MSt	TSt	PSw	ISw	MSw	TSw
TT1	HΘ-HM	HΘ	0.23	0.77	0.49	0.24	0.27	0.27	0.25
		HM	9.77	10.88	115.16	30.43	23.90	42.00	11.63
	HΘ-HM	HΘ	0.23	0.79	0.49	0.24	0.27	0.27	0.25
		HM	9.77	9.69	115.16	30.43	23.90	42.00	11.63
TT2	HΘ-HM	HΘ	0.49	0.92	1.24	0.96	0.05	0.20	0.40
		HM	9.09	9.08	141.10	43.45	29.02	32.62	11.91
	HΘ-HM	HΘ	0.49	0.71	1.24	0.96	0.05	0.20	0.40
		HM	9.09	7.71	141.10	43.45	29.02	32.62	11.91
TT3	HΘ-HP	HΘ	37.21	8.30	5.75	2.38	77.85	55.87	132.60
		HP	42.03	50.35	29.17	38.67	2.00	1.65	11.60
	HΘ-HP	HΘ	37.21	2.61	5.75	2.38	77.85	55.87	132.60
		HP	42.03	9.58	29.17	38.67	2.00	1.65	11.60
TT4	HΘ-HM	HΘ	0.87	2.29	4.15	4.95	1.36	0.82	0.87
		HM	7.99	6.65	104.56	31.87	50.44	63.51	11.42
	HΘ-HM	HΘ	0.87	1.08	4.15	4.95	1.36	0.82	0.87
		HM	7.99	6.97	104.56	31.87	50.44	63.51	11.42
TT5	AM-HP	AM	0.31	1.20	0.65	6.27	4.93	12.99	72.21
		HP	0.17	2.16	114.92	7.33	7.25	3.91	0.74
	AM-HP	AM	0.31	0.41	0.65	6.27	4.93	12.99	72.21
		HP	0.17	8.49	114.92	7.33	7.25	3.91	0.74
TT6	AM-HP	AM	0.24	1.01	0.37	4.45	1.73	11.07	58.72
		HP	0.27	6.38	76.40	8.89	5.46	31.14	0.62
	AM-HP	AM	0.39	0.07	0.37	4.45	1.73	11.07	58.72
		HP	0.36	14.43	76.40	8.89	5.46	31.14	0.62
TT7	HΘ-HM	HΘ	0.13	2.14	4.08	0.31	0.10	0.04	0.15
		HM	8.85	11.60	108.29	24.01	85.01	86.06	13.15
	HΘ-HM	HΘ	0.15	2.08	4.08	0.31	0.10	0.04	0.15
		HM	8.67	10.63	108.29	24.01	85.01	86.06	13.15
TT8	AM-HP	AM	0.49	1.09	0.72	0.59	0.82	6.21	31.66
		HP	1.26	7.34	32.21	5.34	2.63	23.11	0.49
	AM-HP	AM	0.49	0.03	0.72	0.59	0.82	6.21	31.66
		HP	1.26	15.47	32.21	5.34	2.63	23.11	0.49
TT9	HΘ-HP	HΘ	1.07	2.16	2.92	2.02	1.00	0.85	0.88
		HP	4.64	5.95	136.23	5.77	9.77	509.18	18.19
	HΘ-HP	HΘ	0.98	1.67	2.92	2.02	1.00	0.85	0.88
		HP	5.20	9.07	136.23	5.77	9.77	509.18	18.19
TT10	HΘ-HM	HΘ	0.06	1.10	2.17	0.46	0.15	0.06	0.07
		HM	7.48	9.45	90.92	6.52	53.15	87.96	14.49
	HΘ-HM	HΘ	0.06	1.36	2.17	0.46	0.15	0.06	0.07
		HM	7.48	9.58	90.92	6.52	53.15	87.96	14.49

TERMINAL-STANCE:

SUB.	PAIR	VAR.	LR	MSt	TSt	PSw	ISw	MSw	TSw
TF1	HΘ-HM	HΘ	0.80	2.20	3.69	0.18	1.12	0.92	0.81
		HM	7.61	9.50	225.65	42.46	16.08	31.85	10.16
	HΘ-HM	HΘ	0.80	0.34	5.13	0.02	1.12	0.92	0.81
		HM	7.61	9.21	195.98	40.70	16.08	31.85	10.16
TF2	HΘ-HM	HΘ	0.39	1.68	6.03	6.37	1.10	0.48	0.25
		HM	9.54	8.33	133.00	39.73	87.00	133.66	12.70
	HΘ-HM	HΘ	0.39	1.20	1.34	5.92	1.10	0.48	0.25
		HM	9.54	8.44	145.17	40.71	87.00	133.66	12.70
TF3	HΘ-HP	HΘ	0.73	1.89	4.08	0.17	0.08	0.22	0.24
		HP	12.14	17.01	115.83	62.71	30.26	525.00	14.95
	HΘ-HP	HΘ	0.73	1.36	3.30	0.20	0.08	0.22	0.24
		HP	12.14	22.32	384.44	145.63	30.26	525.00	14.95
TF4	AM-HP	AM	2.72	1.15	0.92	0.52	3.33	9.34	99.22
		HP	3.09	1.59	2.14	11.66	1.37	19.05	6.57
	AM-HP	AM	2.72	1.04	0.27	0.47	3.33	9.34	99.22
		HP	3.09	2.78	230.59	87.63	1.37	19.05	6.57
TF5	AΘ-KP	AΘ	1.78	1.06	0.79	0.52	1.39	1.81	1.82
		KP	7.55	6.29	13.73	2.28	2.40	2.26	0.85
	AΘ-KP	AΘ	1.78	0.96	0.26	0.41	1.39	1.81	1.82
		KP	7.55	5.71	3.54	0.42	2.40	2.26	0.85

SUB.	PAIR	VAR.	LR	MSt	TSt	PSw	ISw	MSw	TSw
TT1	HΘ-HM	HΘ	0.23	0.78	0.49	0.24	0.27	0.27	0.25
		HM	9.77	10.88	115.23	30.43	23.90	42.00	11.63
	HΘ-HM	HΘ	0.23	1.59	3.90	0.24	0.27	0.27	0.25
		HM	9.77	10.58	112.26	30.43	23.90	42.00	11.63
TT2	HΘ-HM	HΘ	0.49	0.92	1.24	0.96	0.05	0.20	0.40
		HM	9.09	9.08	141.18	43.46	29.02	32.62	11.91
	HΘ-HM	HΘ	0.49	0.92	1.16	0.98	0.05	0.20	0.40
		HM	9.09	8.94	129.40	42.43	29.02	32.62	11.91
TT3	HΘ-HP	HΘ	1.31	8.65	21.29	4.56	1.20	1.04	1.08
		HP	6.79	6.63	101.67	6.68	139.30	265.32	16.84
	HΘ-HP	HΘ	1.31	3.11	4.71	4.56	1.20	1.04	1.08
		HP	6.79	7.31	180.27	6.68	139.30	265.32	16.84
TT4	HΘ-HM	HΘ	0.87	2.29	4.15	4.95	1.36	0.82	0.87
		HM	7.99	6.65	104.73	31.89	50.44	63.51	11.42
	HΘ-HM	HΘ	0.87	1.98	1.22	4.59	1.36	0.82	0.87
		HM	7.99	6.77	128.72	34.40	50.44	63.51	11.42
TT5	AM-HP	AM	0.31	0.56	0.89	6.27	4.93	12.99	72.21
		HP	0.17	3.23	7.60	7.33	7.25	3.91	0.74
	AM-HP	AM	0.31	0.41	0.64	6.27	4.93	12.99	72.21
		HP	0.17	8.49	115.64	7.33	7.25	3.91	0.74
TT6	AM-HP	AM	0.39	0.37	0.91	4.41	1.73	11.07	58.72
		HP	0.35	4.61	0.98	18.54	5.46	31.14	0.62
	AM-HP	AM	0.39	0.07	0.37	4.45	1.73	11.07	58.72
		HP	0.35	14.44	76.67	9.24	5.46	31.14	0.62
TT7	HΘ-HP	HΘ	0.55	2.38	5.19	1.66	0.76	0.53	0.46
		HP	5.82	6.56	129.85	5.69	13.44	360.35	16.87
	HΘ-HP	HΘ	0.55	2.21	4.21	1.66	0.76	0.53	0.46
		HP	5.82	6.48	148.10	5.69	13.44	360.35	16.87
TT8	HΘ-HM	HΘ	0.22	0.24	2.56	0.81	0.22	0.21	0.08
		HM	13.37	14.68	74.24	10.24	70.32	108.92	20.65
	HΘ-HM	HΘ	0.22	1.30	4.64	0.81	0.22	0.21	0.08
		HM	13.37	13.34	141.30	10.24	70.32	108.92	20.65
TT9	HΘ-HP	HΘ	1.08	2.20	3.10	2.02	1.00	0.85	0.88
		HP	5.05	6.02	73.00	5.77	9.77	509.18	18.19
	HΘ-HP	HΘ	1.08	1.89	2.44	2.02	1.00	0.85	0.88
		HP	5.05	8.70	173.44	5.77	9.77	509.18	18.19
TT10	HΘ-HP	HΘ	0.61	2.67	5.57	0.91	0.49	0.45	0.55
		HP	4.99	5.74	95.25	0.91	13.03	404.98	17.64
	HΘ-HP	HΘ	0.61	2.01	3.50	0.91	0.49	0.45	0.55
		HP	4.99	6.87	144.44	0.91	13.03	404.98	17.64

PRE-SWING:

SUB.	PAIR	VAR.	LR	MSt	TSt	PSw	ISw	MSw	TSw
TF1	HΘ-HP	HΘ	1.25	5.18	13.83	2.51	1.69	1.32	1.20
		HP	5.15	5.51	75.61	44.00	41.14	525.05	17.32
	HΘ-HP	HΘ	1.25	5.18	13.83	0.60	1.69	1.32	1.20
		HP	5.15	5.51	75.61	44.49	41.14	525.05	17.32
TF2	HΘ-HP	HΘ	0.28	0.11	2.63	2.82	0.22	0.12	0.21
		HP	6.34	5.30	64.53	50.66	11.55	570.20	27.61
	HΘ-HP	HΘ	0.28	0.11	2.63	3.15	0.22	0.12	0.21
		HP	6.34	5.30	64.53	53.52	11.55	570.20	27.61
TF3	HΘ-HP	HΘ	0.73	1.84	4.40	0.12	0.08	0.22	0.24
		HP	12.14	26.83	400.53	126.95	30.26	525.00	14.95
	HΘ-HP	HΘ	0.73	1.84	4.40	2.98	0.08	0.22	0.24
		HP	12.14	26.83	400.53	147.51	30.26	525.00	14.95
TF4	AM-HP	AM	2.72	1.04	0.27	0.48	3.33	9.34	99.22
		HP	3.09	2.77	230.08	73.86	1.37	19.05	6.57
	AM-HP	AM	2.72	1.04	0.27	0.47	3.33	9.34	99.22
		HP	3.09	2.77	230.08	87.48	1.37	19.05	6.57
TF5	HΘ-HP	HΘ	0.44	1.16	2.95	2.29	0.04	0.13	0.17
		HP	6.22	0.94	9.45	115.73	8.06	329.21	20.75
	HΘ-HP	HΘ	0.44	1.16	2.95	5.04	0.04	0.13	0.17
		HP	6.22	0.94	9.45	140.49	8.06	329.21	20.75

SUB.	PAIR	VAR.	LR	MSt	TSt	PSw	ISw	MSw	TSw
TT1	AΘ-KP	AΘ	2.97	0.47	0.01	1.45	0.13	1.29	7.44
		KP	0.88	0.79	7.68	54.00	4.99	2.89	1.48
	AΘ-KP	AΘ	2.97	0.47	0.02	1.39	0.13	1.29	7.44
		KP	0.88	0.79	9.13	41.23	4.99	2.89	1.48
TT2	AM-HP	AM	0.68	0.78	0.51	2.71	36.37	0.51	94.25
		HP	0.43	2.44	129.18	102.45	20.42	113.69	8.34
	AM-HP	AM	0.68	0.78	0.51	2.32	36.37	0.51	94.25
		HP	0.43	2.44	129.18	140.53	20.42	113.69	8.34
TT3	AΘ-KP	AΘ	37.21	8.27	5.77	2.33	77.85	55.87	132.60
		KP	42.03	50.31	29.28	37.69	2.00	1.65	11.60
	AΘ-KP	AΘ	37.21	8.27	5.01	3.71	77.85	55.87	132.60
		KP	42.03	50.31	25.74	54.90	2.00	1.65	11.60
TT4	HΘ-HP	HΘ	0.30	0.72	2.15	2.52	0.67	0.33	0.31
		HP	8.27	4.51	75.67	61.56	15.15	455.88	17.33
	HΘ-HP	HΘ	0.30	0.72	2.15	4.03	0.67	0.33	0.31
		HP	8.27	4.51	75.67	65.44	15.15	455.88	17.33
TT5	HΘ-HM	HΘ	0.60	1.87	4.91	0.70	0.36	0.10	0.15
		HM	6.01	8.45	106.13	49.71	105.27	35.22	21.24
	HΘ-HM	HΘ	0.60	1.87	4.82	0.25	0.36	0.10	0.15
		HM	6.01	8.45	104.94	51.72	105.27	35.22	21.24
TT6	AΘ-HP	AΘ	2.29	0.95	0.08	0.60	1.40	0.11	0.04
		HP	1.33	0.05	13.92	27.85	7.33	16.65	1.35
	AΘ-HP	AΘ	2.29	0.95	0.08	0.88	1.40	0.11	0.04
		HP	1.33	0.05	13.92	37.10	7.33	16.65	1.35
TT7	KΘ-AM	KΘ	2.13	1.86	2.38	0.43	0.15	0.37	65.30
		AM	8.81	1.27	1.21	26.04	14.72	15.24	255.87
	KΘ-AM	KΘ	2.13	1.86	2.24	0.34	0.15	0.37	65.30
		AM	8.81	1.27	1.21	26.22	14.72	15.24	255.87
TT8	HΘ-HM	HΘ	0.22	0.24	2.57	0.81	0.22	0.21	0.08
		HM	13.37	14.67	73.98	10.26	70.32	108.92	20.65
	HΘ-HM	HΘ	0.22	0.24	2.57	2.17	0.22	0.21	0.08
		HM	13.37	14.67	73.98	24.64	70.32	108.92	20.65
TT9	HΘ-HM	HΘ	0.42	0.17	0.75	0.56	0.16	0.10	0.44
		HM	4.63	6.78	75.46	19.62	39.38	57.73	26.65
	HΘ-HM	HΘ	0.42	0.17	0.87	2.29	0.16	0.10	0.44
		HM	4.63	6.78	72.95	25.29	39.38	57.73	26.65
TT10	KΘ-AM	KΘ	2.75	2.19	1.06	0.38	0.37	0.75	148.49
		AM	5.24	1.32	1.04	22.24	6.03	27.05	303.00
	KΘ-AM	KΘ	2.75	2.19	1.42	0.03	0.37	0.75	148.49
		AM	5.24	1.32	1.16	22.65	6.03	27.05	303.00

INITIAL-SWING:

SUB.	PAIR	VAR.	LR	MSt	TSt	PSw	ISw	MSw	TSw
TF1	KΘ-AP	KΘ	8.50	3.96	5.99	2.18	1.49	1.70	375.48
		AP	5.71	2.04	4.61	7.16	126.53	165.91	236.75
	KΘ-AP	KΘ	8.50	3.96	5.99	1.52	0.99	1.70	375.48
		AP	5.71	2.04	4.61	2.16	98.72	165.91	236.75
TF2	HΘ-HM	HΘ	0.39	1.68	6.03	6.37	1.10	0.48	0.25
		HM	9.54	8.33	132.96	39.72	87.00	133.66	12.70
	HΘ-HM	HΘ	0.39	1.68	6.03	8.87	0.47	0.48	0.25
		HM	9.54	8.33	132.96	38.71	80.04	133.66	12.70
TF3	KΘ-AP	KΘ	3.12	10.70	5.79	0.32	0.74	1.99	486.84
		AP	1.22	3.86	4.15	0.23	70.34	159.76	248.95
	KΘ-AP	KΘ	3.12	10.70	5.79	0.49	0.62	1.99	486.84
		AP	1.22	3.86	4.15	0.29	58.41	159.76	248.95
TF4	HΘ-KM	HΘ	0.42	0.38	0.51	0.55	0.39	0.33	0.25
		KM	3.53	2.05	1.82	0.83	33.77	12.23	4.76
	HΘ-KM	HΘ	0.42	0.38	0.51	0.97	0.16	0.33	0.25
		KM	3.53	2.05	1.82	1.27	33.59	12.23	4.76
TF5	HΘ-HM	HΘ	0.13	2.52	3.93	5.14	3.22	0.33	0.30
		HM	6.77	0.41	1.80	10.78	38.49	35.39	11.29
	HΘ-HM	HΘ	0.13	2.52	3.93	5.14	1.01	0.33	0.30
		HM	6.77	0.41	1.80	10.78	32.36	35.39	11.29

SUB.	PAIR	VAR.	LR	MSt	TSt	PSw	ISw	MSw	TSw
TT1	HΘ-HP	HΘ	0.47	2.42	6.49	2.93	0.72	0.39	0.29
		HP	6.16	3.32	110.76	13.09	51.29	579.25	14.54
	HΘ-HP	HΘ	0.47	2.42	6.49	3.52	0.57	0.39	0.29
		HP	6.16	3.32	110.76	15.76	55.19	579.25	14.54
TT2	AM-HP	AM	0.68	0.78	0.51	2.32	36.37	0.51	94.25
		HP	0.43	2.44	129.18	140.47	20.42	113.69	8.34
	AM-HP	AM	0.68	0.78	0.51	2.32	36.37	0.51	94.25
		HP	0.43	2.44	129.18	140.47	20.42	113.69	8.34
TT3	AΘ-HP	AΘ	28.12	6.10	4.55	1.65	58.45	42.64	101.69
		HP	7.69	2.15	129.65	7.33	223.15	367.81	17.71
	AΘ-HP	AΘ	28.12	6.10	4.55	1.38	63.37	42.64	101.69
		HP	7.69	2.15	129.65	5.85	220.79	367.81	17.71
TT4	HΘ-HM	HΘ	0.87	2.29	4.15	4.95	1.36	0.82	0.87
		HM	7.99	6.65	104.56	31.88	50.43	63.51	11.42
	HΘ-HM	HΘ	0.87	2.29	4.15	7.13	0.58	0.82	0.87
		HM	7.99	6.65	104.56	33.71	54.71	63.51	11.42
TT5	HΘ-HP	HΘ	0.11	1.54	2.93	0.28	1.15	1.37	1.41
		HP	5.95	6.09	34.22	10.38	1181.79	151.26	29.58
	HΘ-HP	HΘ	0.11	1.54	2.93	1.08	1.15	1.37	1.41
		HP	5.95	6.09	34.22	7.93	1181.79	151.26	29.58
TT6	HΘ-HP	HΘ	0.64	3.83	9.80	0.28	0.21	0.59	1.17
		HP	4.53	1.41	30.22	32.85	85.82	207.19	6.78
	HΘ-HP	HΘ	0.64	3.83	9.80	1.45	0.17	0.59	1.17
		HP	4.53	1.41	30.22	34.26	86.56	207.19	6.78
TT7	HΘ-HM	HΘ	0.13	2.14	4.08	0.31	0.10	0.04	0.15
		HM	8.85	11.59	108.29	24.01	85.01	86.06	13.15
	HΘ-HM	HΘ	0.13	2.14	4.08	0.84	0.13	0.04	0.15
		HM	8.85	11.59	108.29	25.09	85.05	86.06	13.15
TT8	KΘ-AP	KΘ	6.46	4.05	2.33	0.55	1.22	1.57	224.12
		AP	4.23	2.78	2.13	2.08	73.31	119.80	171.46
	KΘ-AP	KΘ	6.46	4.05	2.33	0.29	0.67	1.57	224.12
		AP	4.23	2.78	2.13	0.24	55.77	119.80	171.46
TT9	HΘ-HM	HΘ	0.42	0.17	0.75	0.56	0.16	0.10	0.44
		HM	4.63	6.78	75.46	19.62	39.37	57.73	26.65
	HΘ-HM	HΘ	0.42	0.17	0.75	0.15	0.32	0.10	0.44
		HM	4.63	6.78	75.46	21.50	39.53	57.73	26.65
TT10	KΘ-AP	KΘ	4.61	2.08	2.21	0.10	0.27	0.76	232.53
		AP	3.78	2.19	1.33	0.76	69.25	164.26	349.92
	KΘ-AP	KΘ	4.61	2.08	2.21	0.17	0.29	0.76	232.53
		AP	3.78	2.19	1.33	1.93	51.84	164.26	349.92

MID-SWING:

SUB.	PAIR	VAR.	LR	MSt	TSt	PSw	ISw	MSw	TSw
TF1	HΘ-HP	HΘ	1.25	5.18	13.83	2.42	1.69	1.32	1.20
		HP	5.15	5.51	75.61	43.74	41.00	518.83	17.32
	HΘ-HP	HΘ	1.25	5.18	13.83	2.42	0.93	0.77	1.20
		HP	5.15	5.51	75.61	43.74	36.88	473.28	17.32
TF2	HΘ-HP	HΘ	0.28	0.11	2.63	3.01	0.22	0.11	0.21
		HP	6.34	5.30	64.53	51.44	9.83	510.74	27.61
	HΘ-HP	HΘ	0.28	0.11	2.63	3.01	0.12	0.25	0.21
		HP	6.34	5.30	64.53	51.44	14.10	547.32	27.61
TF3	HΘ-HP	HΘ	0.73	1.84	4.40	0.18	0.08	0.22	0.24
		HP	12.14	26.83	400.53	143.48	29.35	520.10	14.95
	HΘ-HP	HΘ	0.73	1.84	4.40	0.18	0.01	0.25	0.24
		HP	12.14	26.83	400.53	143.48	28.09	476.19	14.95
TF4	HΘ-HP	HΘ	0.80	2.24	5.14	2.11	0.84	0.60	0.55
		HP	5.90	6.91	121.66	66.88	31.23	508.51	17.25
	HΘ-HP	HΘ	0.80	2.24	5.14	2.11	0.67	0.42	0.55
		HP	5.90	6.91	121.66	66.88	29.64	478.37	17.25
TF5	HΘ-HP	HΘ	0.44	1.16	2.95	3.28	0.04	0.13	0.17
		HP	6.22	0.94	9.45	133.40	8.14	327.95	20.75
	HΘ-HP	HΘ	0.44	1.16	2.95	3.28	0.07	0.26	0.17
		HP	6.22	0.94	9.45	133.40	8.22	390.15	20.75

SUB.	PAIR	VAR.	LR	MSt	TSt	PSw	ISw	MSw	TSw
TT1	HΘ-HP	HΘ	0.47	2.42	6.49	2.56	0.75	0.37	0.29
		HP	6.16	3.32	110.76	16.27	45.47	562.52	14.54
	HΘ-HP	HΘ	0.47	2.42	6.49	2.56	0.67	0.33	0.29
		HP	6.16	3.32	110.76	16.27	48.88	482.01	14.54
TT2	HΘ-HP	HΘ	0.19	0.75	1.26	1.25	0.69	0.21	0.06
		HP	6.61	5.12	66.68	58.41	9.00	406.32	22.36
	HΘ-HP	HΘ	0.19	0.75	1.26	1.25	0.71	0.28	0.06
		HP	6.61	5.12	66.68	58.41	7.61	354.26	22.36
TT3	AΘ-HP	AΘ	28.12	6.10	4.55	1.57	58.74	42.66	101.69
		HP	7.69	2.15	129.65	7.01	220.26	362.99	17.71
	AΘ-HP	AΘ	28.12	6.10	4.55	1.57	4.27	30.93	101.69
		HP	7.69	2.15	129.65	7.01	7.59	65.07	17.71
TT4	HΘ-HP	HΘ	0.30	0.72	2.15	1.88	0.66	0.34	0.31
		HP	8.27	4.51	75.67	64.19	15.09	446.41	17.33
	HΘ-HP	HΘ	0.30	0.72	2.15	1.88	0.42	0.04	0.31
		HP	8.27	4.51	75.67	64.19	14.31	407.31	17.33
TT5	KΘ-AP	KΘ	4.76	0.01	1.12	0.28	1.53	2.56	584.06
		AP	4.68	2.44	1.88	28.42	185.36	294.89	344.40
	KΘ-AP	KΘ	4.76	0.01	1.12	0.21	0.33	2.56	584.06
		AP	4.68	2.44	1.88	16.78	43.71	294.89	344.40
TT6	HΘ-HP	HΘ	0.64	3.83	9.80	0.36	0.22	0.59	1.17
		HP	4.53	1.41	30.22	33.33	90.53	214.18	6.78
	HΘ-HP	HΘ	0.64	3.83	9.80	0.36	0.06	0.55	1.17
		HP	4.53	1.41	30.22	33.33	138.46	240.82	6.78
TT7	HΘ-HP	HΘ	0.55	2.37	4.98	1.66	0.75	0.52	0.46
		HP	5.82	6.75	156.96	5.69	15.08	377.11	16.87
	HΘ-HP	HΘ	0.55	2.37	4.98	1.66	0.59	0.36	0.46
		HP	5.82	6.75	156.96	5.69	15.37	377.52	16.87
TT8	HΘ-HP	HΘ	1.09	4.07	8.67	0.49	0.82	0.81	0.90
		HP	7.64	9.27	42.83	1.95	15.47	499.42	26.38
	HΘ-HP	HΘ	1.09	4.07	8.67	0.49	0.62	0.40	0.90
		HP	7.64	9.27	42.83	1.95	16.63	510.25	26.38
TT9	HΘ-HP	HΘ	1.08	2.17	2.92	2.02	1.00	0.85	0.88
		HP	5.05	8.15	136.23	5.77	8.99	475.64	18.19
	HΘ-HP	HΘ	1.08	2.17	2.92	2.02	0.91	0.39	0.88
		HP	5.05	8.15	136.23	5.77	9.56	416.73	18.19
TT10	HΘ-HP	HΘ	0.61	2.51	4.89	0.91	0.49	0.46	0.55
		HP	4.99	6.80	125.66	0.91	12.65	441.37	17.64
	HΘ-HP	HΘ	0.61	2.51	4.89	0.91	0.41	0.31	0.55
		HP	4.99	6.80	125.66	0.91	17.31	450.85	17.64

TERMINAL-SWING:

SUB.	PAIR	VAR.	LR	MSt	TSt	PSw	ISw	MSw	TSw
TF1	HΘ-KΘ	HΘ	1.28	5.61	14.46	2.44	1.67	1.29	1.19
		KΘ	7.01	4.54	3.88	1.74	1.10	0.97	340.08
	HΘ-KΘ	HΘ	1.28	5.61	14.46	2.44	1.67	0.76	0.22
		KΘ	7.01	4.54	3.88	1.74	1.10	1.23	322.07
TF2	HΘ-KΘ	HΘ	0.26	0.09	2.86	3.06	0.18	0.09	0.16
		KΘ	10.96	6.72	6.44	2.22	1.43	1.41	310.81
	HΘ-KΘ	HΘ	0.26	0.09	2.86	3.06	0.18	0.12	0.21
		KΘ	10.96	6.72	6.44	2.22	1.43	1.76	396.65
TF3	HΘ-KΘ	HΘ	0.25	1.21	4.03	0.56	0.31	0.08	0.18
		KΘ	3.45	6.55	4.76	0.39	0.55	0.96	281.61
	HΘ-KΘ	HΘ	0.25	1.21	4.03	0.56	0.31	0.11	0.21
		KΘ	3.45	6.55	4.76	0.39	0.55	1.63	467.36
TF4	KΘ-AP	KΘ	10.05	6.68	5.74	1.36	0.06	0.26	513.67
		AP	5.34	2.96	3.86	1.37	3.06	4.18	48.63
	KΘ-AP	KΘ	10.05	6.68	5.74	1.36	0.06	0.37	320.49
		AP	5.34	2.96	3.86	1.37	3.06	36.40	156.88
TF5	KΘ-AP	KΘ	14.96	5.49	9.07	2.75	0.10	0.55	408.35
		AP	9.10	2.33	4.19	0.27	7.95	20.01	103.98
	KΘ-AP	KΘ	14.96	5.49	9.07	2.75	0.10	0.45	289.40
		AP	9.10	2.33	4.19	0.27	7.95	7.34	152.98

SUB.	PAIR	VAR.	LR	MSt	TSt	PSw	ISw	MSw	TSw
TT1	KΘ-AM	KΘ	3.44	0.54	1.79	0.45	0.13	0.62	201.11
		AM	17.72	1.11	1.18	15.74	31.54	83.12	430.20
	KΘ-AM	KΘ	3.44	0.54	1.79	0.45	0.13	0.03	254.60
		AM	17.72	1.11	1.18	15.74	31.54	39.01	65.45
TT2	KΘ-KP	KΘ	3.02	1.56	0.46	0.86	0.26	0.30	73.39
		KP	3.92	4.78	2.22	9.76	11.55	1.54	0.90
	KΘ-KP	KΘ	3.02	1.56	0.46	0.86	0.26	0.37	94.11
		KP	3.92	4.78	2.22	9.76	11.55	1.68	1.32
TT3	KΘ-AM	KΘ	7.66	6.64	4.83	0.31	0.16	0.97	597.47
		AM	23.20	2.76	1.72	28.12	4.93	90.84	707.01
	KΘ-AM	KΘ	7.66	6.64	4.83	0.31	0.16	0.05	254.80
		AM	23.20	2.76	1.72	28.12	4.93	10.20	66.03
TT4	KΘ-AP	KΘ	8.33	1.34	1.48	0.11	0.21	0.65	190.65
		AP	13.89	2.73	2.73	0.55	21.89	68.31	158.15
	KΘ-AP	KΘ	8.33	1.34	1.48	0.11	0.21	0.60	332.73
		AP	13.89	2.73	2.73	0.55	21.89	67.27	156.70
TT5	KΘ-AM	KΘ	6.39	0.52	0.45	0.23	1.34	2.07	257.07
		AM	5.85	0.79	1.01	4.15	71.47	194.68	921.14
	KΘ-AM	KΘ	6.39	0.52	0.45	0.23	1.34	1.19	339.75
		AM	5.85	0.79	1.01	4.15	71.47	2.23	85.94
TT6	KΘ-AP	KΘ	4.31	2.21	0.24	0.27	0.17	0.02	365.49
		AP	1.36	1.69	3.31	1.98	46.89	120.58	31.83
	KΘ-AP	KΘ	4.31	2.21	0.24	0.27	0.17	0.36	331.39
		AP	1.36	1.69	3.31	1.98	46.89	11.37	164.92
TT7	KΘ-AM	KΘ	2.13	1.86	2.38	0.43	0.15	0.37	65.30
		AM	8.81	1.27	1.21	26.04	14.72	15.24	255.86
	KΘ-AM	KΘ	2.13	1.86	2.38	0.43	0.15	0.50	254.59
		AM	8.81	1.27	1.21	26.04	14.72	1.46	66.89
TT8	KΘ-AP	KΘ	6.46	4.05	2.33	0.53	1.22	1.58	226.84
		AP	4.23	2.78	2.13	1.56	73.85	119.80	173.35
	KΘ-AP	KΘ	6.46	4.05	2.33	0.53	1.22	1.29	262.43
		AP	4.23	2.78	2.13	1.56	73.85	107.82	152.68
TT9	KΘ-AP	KΘ	3.23	2.06	1.93	0.37	0.33	0.64	186.97
		AP	3.97	2.32	1.64	0.32	10.26	45.29	149.64
	KΘ-AP	KΘ	3.23	2.06	1.93	0.37	0.33	0.58	265.18
		AP	3.97	2.32	1.64	0.32	10.26	45.11	144.56
TT10	KΘ-AP	KΘ	4.61	2.08	2.21	0.12	0.27	0.75	251.57
		AP	3.78	2.19	1.33	0.13	69.57	163.20	344.56
	KΘ-AP	KΘ	4.61	2.08	2.21	0.12	0.27	0.63	246.27
		AP	3.78	2.19	1.33	0.13	69.57	128.04	137.75