TRAJECTORY PLANNING OF HIP POWERED ORTHOTIC DEVICE USING CUBIC POLYNOMIAL EQUATION WITH VIA POINT

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in fulfillment of the requirements for the degree of
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DECLARATION

I declare that this thesis entitled "TRAJECTORY PLANNING OF HIP POWERED ORTHOTIC DEVICE USING CUBIC POLYNOMIAL EQUATION WITH VIA POINT is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have checked this report entitled "TRAJECTORY PLANNING OF HIP POWERED ORTHOTIC DEVICE USING CUBIC POLYNOMIAL EQUATION WITH VIA POINT" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Mechatronics Engineering with Honours

Signature	:	....
Supervisor Name	:	....
Date	:	....

DEDICATIONS

To my beloved mother

SURIANI BINTI MOHD SAID

and father

MEOR AFFENDI BIN SHAARI

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ABSTRACT

Many robotic applications has been develop in this recent years and some of them encounters with human nature. Example of robotic application that associated with human nature is orthotic device, exoskeleton robots, humanoids, robotic arms and others. The development of orthotic device has the biggest impact among the lower extremity and disabilities patients. The purpose of this study was to develop a trajectory planning of human hips walking motion for the orthotic device in order to reduce the amount of jerk that occur during the walking motion. The objectives of this project is to design a trajectory planning using the cubic polynomial with via point and to evaluate the performance of motion in terms of angular position, velocity, acceleration and jerk in order to produce smooth motion. The scope of this project is to analyse the performance of jerk in human hips walking cycle based on the reference data of biomechanical human gaits with the method of cubic polynomial. In addition, the method used for developing the trajectory is cubic polynomial with via point. The via point is an intermediate point between the initial and final position path. This method is used to combine the initial and final position of the path to passing though the point in a smooth motion. The simulation of this project is based on the cubic polynomial with via point which generated by Matlab. Moreover, the evaluation of this experiment is based on the comparison graph by the experimental graph with the real-time human's hip walking motion graph. There are three type of profile generated in this project for 7-phase, 4 phase and 2 phase which is the angular position, velocity and acceleration. The results shows in implementing the cubic polynomial method is able to match the trajectory planning of a real-time human's hip walking motion for each profile. Other than that, in terms of error and accuracy show that position profile produce lower errors with 0.005028673 rad/s which provide higher accuracy in matching the reference graph of human hips motion. In addition, 7-phases provide a better performance in accuracy and error compares to 4-phase and 2-phases as shown in the result. Thus, by using the 7-phase profile is better in comparing the method of cubic polynomial with the reference human hips motion. Meanwhile, in terms of reducing the jerk to the smallest amount is not possible in this project due the amount of jerk that presented during terminal swing at 0.87s is higher with the value of 167.1771093 rad/s^3 .

ABSTRAK

Kebanyakan aplikasi robot telah berkembang untuk bertahun-tahun sejak kebelakangan ini dan kebanyakan robot aplikasi ini mempunyai kaitan dengan tubuh badan manusia. Contoh-contoh aplikasi robot yang mempunyai kaitan dengan sifat manusia adalah, peranti orthotic, robot exoskeleton, humanoids robot, robot yang berbentuk tangan dan lain-lain. Selain itu, perkembangan alat peranti orthotic ini mempunyai impak yang besar dan positif terhadap pesakit-pesakit kurang berupaya. Tujuan kajian ini adalah untuk membangunkan perancangan trajektori terhadap pergerakkan pinggul manusia semasa menggunakan peranti orthotic, supaya dapat menggurangkan jumlah pergerakan yang berlaku secara tiba-tiba atau dikenali sebagai “jerk” semasa pergerakkan berlaku. Objektif kajian ini adalah untuk mereka bentuk perancangan trajektori menggunakan polynomial kubik pada sebuah titik dan untuk menilai prestasi gerakan dari sudut sesuatu tempat, halaju, pecutan dan “jerk” yang terhasil supaya dapat menghasilkan gerakan yang lancar. Manakala, skop untuk projek ini adalah untuk menganalisis prestasi “ jerk “ terhadap pergerakan pinggul manusia berdasarkan rujukan data dari biomekanikal gaits manusia dengan kaedah yang digunakan. Di samping itu, kaedah yang digunakan untuk mencipta trajektori adalah dengan menggunakan polynomial kubik melalui sebuah titik. Titik yang dibincangkan di dalam projek ini merupakan sebuah titik diantara kedudukan laluan pertama dan terakhir. Kaedah ini digunakan untuk menggabungkan kedudukan awal, akhir dan kedudukan halalaju untuk memastikan pergerakkan tersebut adalah lancar. Simulasi yang digunakan untuk projek ini adalah berpandukan kaedah polynomial kubik dan dihasilkan menerusi perisian Matlab. Di samping itu, penilaian eksperimen ini adalah berpandukan graf melalui perbandingan diantara eksperimen graf dengan graf pergerakan pinggul manusia yang telah dikaji. Terdapat tiga jenis profil graf yang dinilai di dalam fasa 7, fasa 4 dan fasa 2 untuk projek ini iaitu graf kedudukan sudut, halaju dan pecutan. Keputusan menunjukkan dalam melaksanakan kaedahpolynomial kubik dapat mengikuti pergerakan asal trajektori pinggul manusia untuk setiap jenis profil. Selain itu, dari segi ketepatan dan ralat menunjukkan bahawa kedudukan profil menghasilkan ralat-ralat lebih rendah dengan 0.005028673 rad/s yang memberikan ketepatan yang lebih tinggi terhadap pergerakan asal pinggul manusia. Di samping itu, 7-fasa menyediakan prestasi yang lebih baik dalam ketepatan dan ralat berbanding fasa 4 dan fasa 2 seperti yang ditunjukkan dalam hasil keputusan. Oleh itu, dengan menggunakan profil fasa 7 adalah lebih baik dalam membandingkan kaedah polinomial kubik dengan rujukan asal pergerakan pinggul manusia. Sementara itu, dari segi mengurangkan “ jerk “ dengan jumlah yang paling kecil adalah mustahil dalam projek ini kerana jumlah “ jerk “ yang terhasil adalah tinggi pada 0.87 saat semasa fasa terminal swing dengan jumlah sebanyak 167.1771093 rad/s3.

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LIST OF SYMBOLS AND ABBREVIATIONS

SCI	-	Spinal Cord Injury
Rad		Radians
$\vec{j}(t)$	-	Jerk
$\vec{a}$	-	Derivative of Acceleration
$\vec{r}$	-	Derivative of Position
$\vec{v}$	-	Derivative of Velocity
t	-	Time (s)
$\theta(t)$	-	Position Profile (s)
$\dot{\theta}(t)$	-	Velocity Profile (rad/s)
$\ddot{\theta}(t)$	-	Acceleration Profile (rad/s^2)
$\dddot{\theta}(t)$	-	Jerk Profile (rad/s^3)
t_0	-	Initial time (s)
t_f	-	Final time (s)
θ_0	-	Initial Angle (degree)
θ_f	-	Final Angle (degree)
v_0	-	Initial Velocity (degree/s)
v_f	-	Final Velocity (degree/s)
RMSE	-	Root Mean Square (rad)
AD	-	Average Difference (rad)
n	-	Number of Trial
T_{Ref}	-	Reference Trajectory
T_{Gen}	-	Generated Trajectory

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CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter gives a brief explanation about the research project on the trajectory planning in minimizing the amount of jerk that produce in orthotic device. The project consists of motivation, problem statement, objectives, thesis contribution and scope of work. Lastly, the description of the content for each chapter is presented.

1.2 Motivation

Many disease causes gait disorder or movement disorder which carries to imbalance walking pattern, falling, disability and others. For example, stroke, spinal injury, cardiac illness, cerebellar disease, accidents or others condition which can cause disabilities. A rehabilitation device is introduce in this modern world for people that have a walking disabilities. The orthotic device are known with their capability to support and help a lower limb extremities patient for their rehabilitation phase. In addition, the device is essential to move symmetrically to human walking cycle and able to duplicate the movement efficiently. The development of orthotic device also can help the lower extremities patient to regain their walking abilities again.

In Malaysia, based on the World Health statistics report by World Health Organization's (WHO) in 2013 stated that about 8% percent of Malaysian community are above 60 years old is in a good health condition. Meanwhile, in 2011 of annual report by the Malaysian Ministry of Health's reported that children aged between 0 to 18 years old are detected with physical and cerebral palsy disabilities are about 11% and 7.2% percent [1]. As the percentage above-mentioned, the gait disorder also can affects the range of age between those groups and it is not a common thing amongst them [1]. In this advance technology, the development of powered orthotics devices became a feasible solution to regain walking ability which could improve their walking capability during the rehabilitation phase and by planning a trajectory for the orthotic device are able to create a smooth motion towards the device.

1.3 Problem Statement

The orthotic device is an equipment that applied to the human body to support, correct deformities or improve the movement of joints or limbs on human bodies. Meanwhile, the movement of the device must be imitating the human walking cycle in real-life. Therefore, by implementing trajectory planning allows motion of the device to move in a stable phase from its starting configuration until the final configuration, in order to achieve the required goals. However, undesired motion or a sudden movement are known as the jerk is occur during the motion cycle of the device and may affect the stability of the device. A method or technique are needed to be defined for trajectory planning to minimize the amount of jerk occurs on the device for efficient walking gaits.

On top of that, the accuracy of stability during the walking motion with varies of speed also need to be considered that may be affected by the jerk .Thus, the parameter need to be study is the angular position, angular velocity, angular acceleration and jerk. The amount of rotation that required to change the orientation from one to another about a specified axis are expressed from the angular position of a body orientation with respect to a specified reference position. The changing on the angular position may influence the orientation of the device where the increases amount of orientation provide a smooth walking which proportional to the human walking gaits.

In planning a continuous path, the angular velocity of the joint is required when assigning a constraint on the path planning. The value of angular velocities is essential in order to connect between two consecutive points with the intermediate point. Therefore, when controlling the robot motion between two paths points it must be in continuous state for velocity and positions. Furthermore, the initial and final position of joint angles must matched with the given angles. Thus, the velocity values in planning a trajectory must not equal to zero in order to create a smooth trajectories. The purpose of velocity is useful in providing a continuity on the acceleration of the path point.

Therefore by implementing the method of cubic polynomial with via point able to solved the problem of reducing jerk because jerk can be limited by smooth acceleration and deceleration. A research question is developed to determine the technique or method of walking motion that can provide a higher stability and minimum jerk to the orthotic device with varies speed.

1.4 Objectives

The objective of the project is:

1. To design and develop a trajectory planning using the cubic polynomial with via point in order to reduce jerk motion.
2. To evaluate the performance of the motion in terms of angular position, angular velocity, angular acceleration and jerk towards the orthotic device.
3. To validate the accuracy of the proposed method in reducing a jerk motion by comparing the experimental data with the real-time data of normal human walking gaits.

1.5 Scope

The scope for this project is to design the trajectory planning of hips motion on the orthotic device and the method used for designing the trajectory is the cubic polynomial with via point. Moreover, the purpose of designing the trajectory planning on the orthotic device is to reduce the amount of jerk produce during the motion. A few variables need to be consider while planning the trajectory which is the angular position, angular velocity, angular acceleration and jerk during the motion. The tools used to examine this project is by using the MATLAB software in order to generate the graph for the result. This project is based on the comparison graph between the experimental methods with the real data of hips of human walking gaits. The real data is derive from the research of multi-task gait analysis which develop by Bovi G, Rabuffetti M, Mazzoleni P and Ferrarin M [23]. It contain a research of human walking cycle staring from the ankle, knee to hips. The main part of analysing the motion of human body is too focused only on the movement of the hips.

CHAPTER 2

LITERATURE REVIEW

2.1 Background Theory

Nowadays, robotics has the bigger impact on humanity where it can be implemented in the human or industrial environment. Therefore, a lot of effort are presented in robotics in order to help patients with lower extremity injuries for physical rehabilitation that caused by a different type of paresis such as the spinal cord injury (SCI), stroke and unilateral lower limb disorder [2]. In the area of robot-assisted rehabilitation, various exoskeleton, and orthotic device have been presented each year for the upper and lower extremities for people that have a permanent injury due to stroke or accidents in their therapy to regain walking ability. The existence of this robotic system is to solve problem of damage parts at the lower limb of a human's body, such as knee, hips or ankle. The exoskeleton device is an efficient device that can conduct a training rehabilitation and physical therapist for the lower extremity patients [3]. Thus, it is a good way to help these patients to recover and regain mobility.

A few years ago, rehabilitation therapy are widely used due to the increasing number of disability patients which made the medical centres enthusiastic to develop an efficient and reliable method to treat the patients rather than used a traditional methods [4]. The weakness of using the traditional method is the therapy treatment may require two or more therapist to assistance one patient in moving the effected part of the patient manually for example the leg. Moreover, the treatment are done at least twice a week and the cost charged for the treatment are much higher. Therefore, by using the robotic system device could reduce the amount of therapist in assisting on one patient [5][6][7]. The understanding of human walking gaits is an easy task but implementing the gaits on the machine are more complex and challengeable [8]. The movement of the device must be imitating the walking pattern of a human limb, therefore, the device must be lifelike with a minimum jerk so the machine could adapt the walking gaits efficiently. Jerk is known as the rate of change of acceleration with respected with time or in other word it is an abruptly motion that occur during the movement. In the studies of robotics, to produce a motion that matched to real-life human and less jerk are by planning a trajectory on the device. The next subchapter will describe more on the topics that encounter in this project.

2.2 Overview of human walking cycle in robotics application

For the past years, many researcher has been paid more attention to studying human walking. There are an increasing enthusiasm among the researcher to research the human walking cycle due to predictive abilities and potential applications in the areas of clinical biomechanics, rehabilitations engineering, neurosciences and robotics [8][9]. The importance of human walking cycle in robotic application is the stabilities and efficiency of the device. Thus, in normal walking gaits, the motion must depend on continual interchange between mobility and stability [8].

The understanding of human walking cycle is desired in any application of robotics that associated with human like characteristic. Nowadays, many invention of application in robotics has already associated with human physique. An example of robotic applications that associate with human characteristic is the exoskeleton device, orthotic device, humanoid robots, robotics arm and others. The human walking cycle is a repeated pattern of a human movement which involve steps and strides. A steps describe as a single step, while a complete gait cycle is called as a stride. The step time is define as time period between a heel strike on one leg and the contra-lateral legs [10]. The human walking gaits are well described in the research of biomechanics.

Humans walking motion generally tend to move their body in forward position towards a desired location and speed for moving forward. Then, in the walking principle, by using a least amount of energy it is possible to achieve the initial goals and humans body tend to move in a straight line while moving in forward position. Besides that, the most efficient energy of movement is when the body figure moves up and down with a small energy used. In addition, our brain usually generates information to the feet to act as a shock absorber while implement a less pressure in walking for excluding the force that exert on the body as it landed. Meanwhile, the feet of the body must form a rigid lever towards the end phase when the foot touches the ground for providing a motion to propel the body to move forward.

2.3 Types of Motion

Trajectory planning of a lower limbs can be generate based on a different phases. The phases of one gait cycle can be categorized into three types which is the two phases or known as the stance and swing phase, four phases (Double stance, Single stance and Swing) and seven phases (Heel strike, full foot, Mid-stance, Heel off, posterior swing, Mid-swing and Anterior swing) as illustrated in Figure 2.1 [11][12]

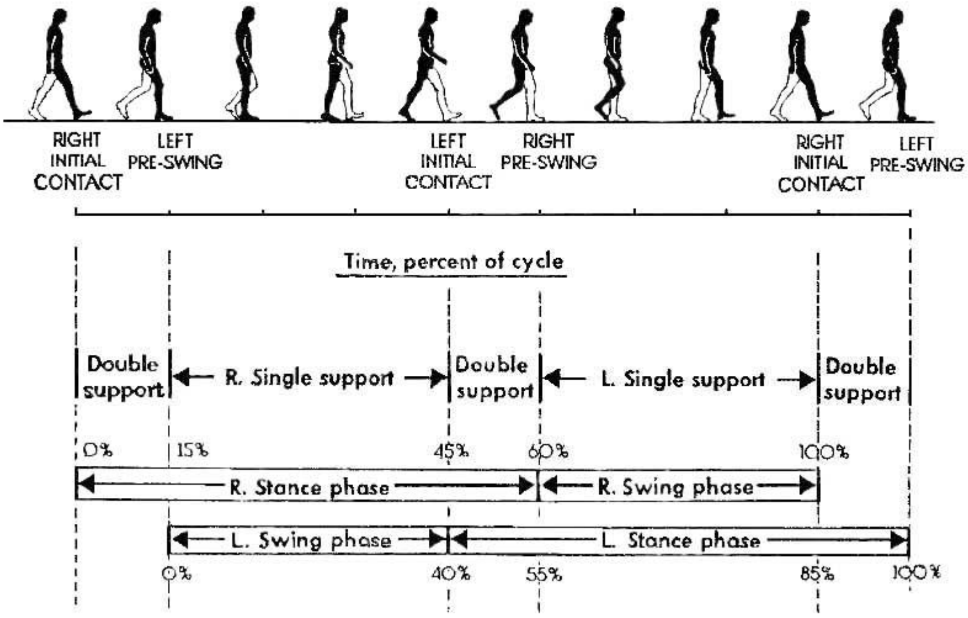

Figure 2.1: Walking Gait Cycle based on different Phases [13]

The figure shown above contains all three categories of walking gaits which develop from the reference of biomechanical analysis in human gait motion. In addition, the sequence of motion is initiate from the initial contact of heel on the ground however the toe are not yet touch and the motion is continuous with interchange from both leg until it reach the final contact or position. The advantages of using the phases of gait motion is to facilitate the planning of trajectory while avoiding the error that occur during the implementation of trajectory. It is due to the requirement of sequence of motion for hip, knee and ankle joint [12]. In this project, the implementation hips motion of seven phases profile will used as a reference data for developing the trajectory planning in the experimental part.

2.3.1 2 Phase (swing and stance phases)

There are two phases of a human walking process which is the stance phase and swing phase in human cycle. Stance is describe as the period of gait cycle during the interaction of foot with the ground while swing is the vice versa from the stance. The stance phase engage the gait cycle about 60% percent while the swing phase initiate only about 40% percent of human walking gaits and the motion involve is a combination of open and close chain activities [14]. The motion of swing phases produce shortest time period about 40% in full trajectory compared to the stance phases [12]. Based on the Figure 2.2 a single support position is occur along the whole trajectory of swing phases. Stance phase is the phase where the initial contact of the motion is occur, when the heel begin to touch the ground but except the toes [14]. Then, the walking motion continues until the mid-stance phase before changing to other phases.

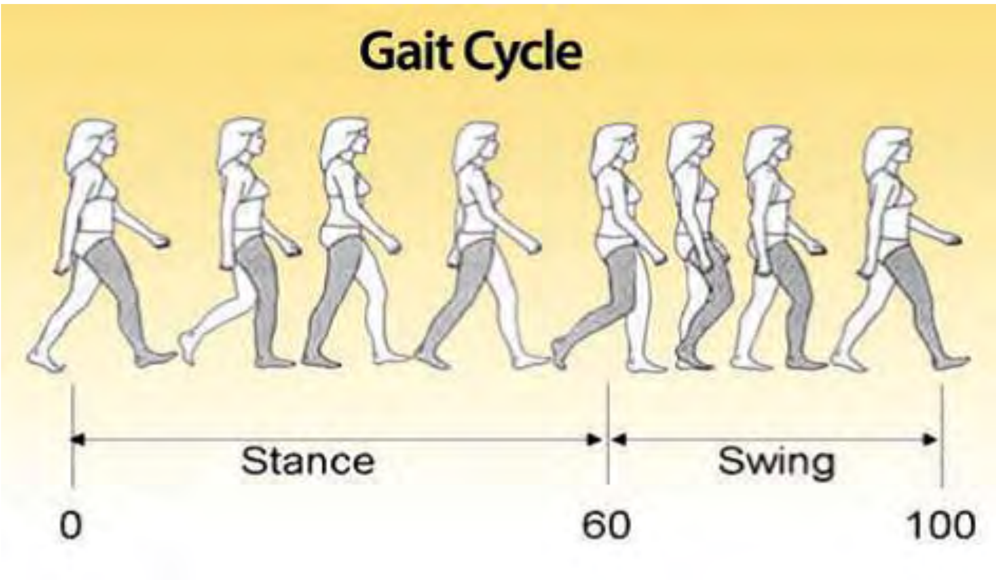

Figure 2.2: The phases of stance and swing cycle

2.3.2 4 Phase (Single and Double Support Phase)

Double support phase contain the gait cycles about 30 % percent of the human walking gaits that occur only on the stance phases. The double support phase is initiate when both feet is contacted with the ground. It is occur when one limb is at the finale stance phases and the contralateral limb is begin at the stance phase. In addition, if the gaits move in a faster state, the double support time will be lessen and it is vice versa with a slower gait motion. Meanwhile, in single support phase contains about 12 % to 50 % percent of the gait cycle. The motion are begins when only one of the foot is contacted with the ground. In other terms, it begins with opposite toe off and ends with an opposite foot strike. There are two period which associate with the single support phase which is the right stance and the left stance.

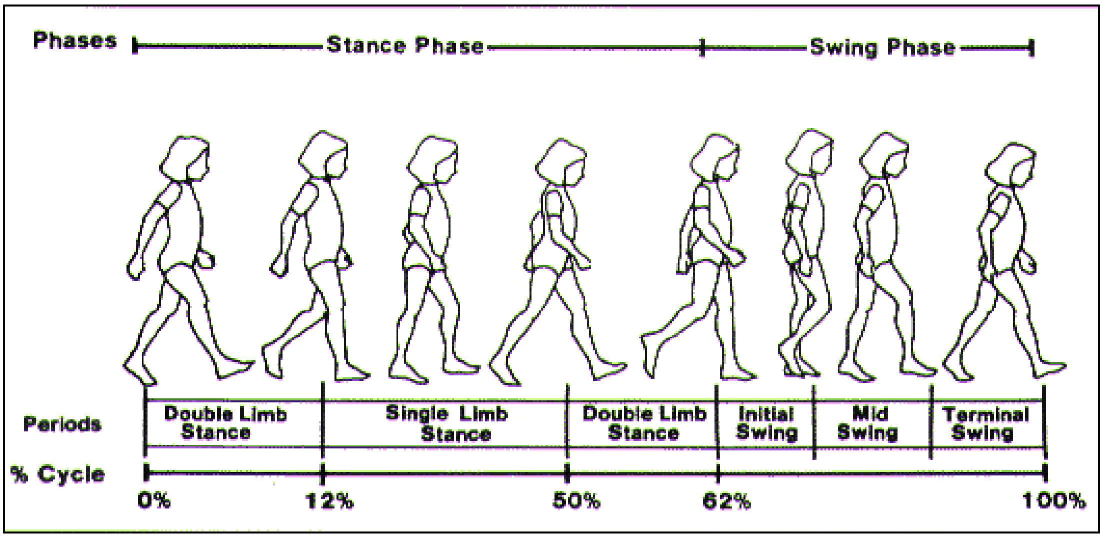

Figure 2.3: The single and double support phase during the stance phase

2.3.3 7 Sub Phases

From the two phases of human gait in Figure 2.2, the gait is separated by eight types of human walking motion which is the initial contact, loading response, mid-stance, terminal stance, pre-swing, initial swing, mid-swing and finally the terminal swing as shown in the Figure 2.3 [11]. The heel strike or known as an initial contact of foot to hit the ground. Initial contact is a phase for shock absorbing, provide limb stability and contain forward progression. The second phase is describe as the loading response which act as a shock absorber from the ground reaction during the knee flexion phase. Mid-stance phase is initiate after the process of second phases. Mid stance starts during the opposite reference foot is raised from the floor and end with a vertical position of contralateral tibia. Moreover, the purpose of terminal stance is to initiate the body in order to passing through the supporting foot. The fifth phase of human gaits is the pre-swing phase. The goal in this gaits is to position the limb for a swing motion or in other words is the weight release. The beginning of initial swing is when the ipsilateral foot is raised from the ground and ends during the swinging foot is opposite to stance foot. Meanwhile, mid swing phase produce once the swing foot crosses the stance foot and ends when the tibia of swing limb achieve at vertical position. The last phase of the human cycle is the terminal swing. The purpose of the last phase is to complete the motion of the limb movement and to prepare for the next phase. Figure 2.4 shows the flow of human walking motion in one gait cycle.

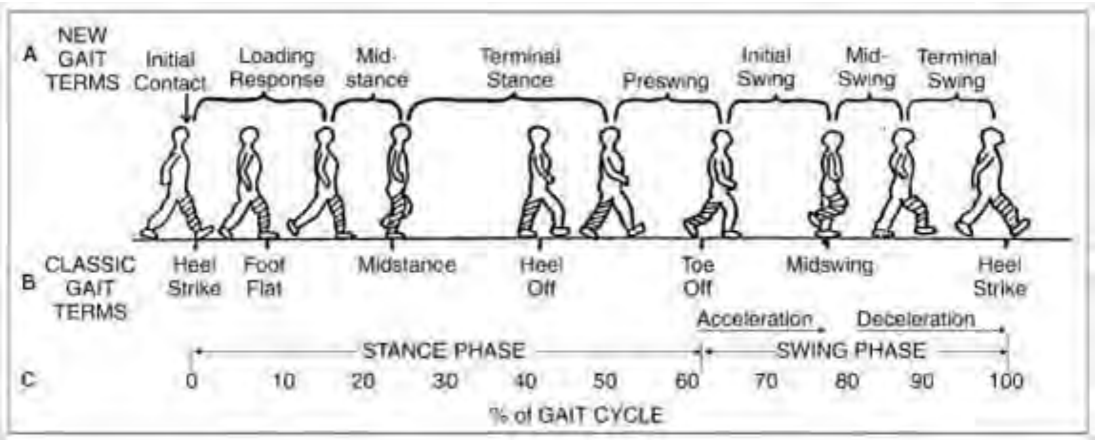

Figure 2.4: Seven sub-phases of one stride length

2.4 Trajectory Planning

Trajectory planning is a motion planning for the movement of the robot to travel from the starting position to the desired position. The purpose of planning a trajectory is to generate the reference input of the control system for the manipulator, in order to execute the motion [12]. The input is describe as the geometric path, dynamic and kinematic constraint while the trajectory joint or the end effector is known as the output. Basic of executing any trajectory planning algorithm is the same in motion law [12].Moreover, trajectory planning is one of the important role in robotics world which used to design a path for manipulator or electrical motor in order to move to its desired point [13]. The development on the trajectory must be in the area of space joint, after the inversion of kinematic of the given geometric path as stated by other researcher in their studies [14][15]. Meanwhile trajectory is also refer as a time history of position, acceleration and velocity for each degree of freedom. One of the most important part in robotics is the reduction of jerk on the manipulators for creating a smooth motion without any vibrational phenomena. It is a fundamental issue in robotics application that are widely used in the modern applications.

The benefits of generating on the trajectory profile in joint space is it would not require a calculation of inverse kinematic compares to Cartesian space and able to exclude the problems that arise in kinematic singularities and manipulator redundancy [12][16]. Major advantages of trajectory planning in the joint space area, especially for the control system to act on the manipulator rather than on the end effector. It is easier to alter the trajectories according to their design requirement if it's employed in the joint space area.

Based on the previous studies, most of basic development on trajectory planning is due to a problem such as minimum execution time, minimum energy on the actuator, minimum jerk or some other parameters [13]. Minimum time algorithm is the primarily trajectory planning technique that proposed in the research world which associate with the industrial sector in order to increase productivity. A few technique has been proposed in solving the problem, however the outcomes produce is a non-continuous torques which lead the motion on the joint to be delayed from the reference trajectory with a tracking errors that increase from the disturbance or modelling errors [12]. Therefore to overcome the problem the method of spline function is use to generate a smooth trajectories. The second problem that encountered with the basic of trajectory planning is the minimum energy. Minimum energy are not required for all robotic applications, only for a certain manipulators that have a limited capacity of energy source such as submarine exploration robots or spatial robot. Besides that, the robot trajectory can be planning with an energetic criteria able to reduce stresses of the actuator to the manipulator easily which lead to smooth trajectories [12] [13].