Faculty of Electrical Engineering

HIGH ACCURACY WALKING MOTION TRAJECTORY GENERATION PROFILE BASED ON 6-5-6-PSPB POLYNOMIAL SEGMENT WITH POLYNOMIAL BLEND

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DECLARATION

I declare that this thesis entitled “High Accuracy Walking Motion Trajectory Generation Profile Based on 6-5-6-PSPB Polynomial Segment with Polynomial Blend” 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 the candidature of any other degree.

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APPROVAL

I hereby declare that I have read this thesis and in my opinion, this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechatronic Engineering.

Signature	:	………………………………………
Supervisor Name	:	Assoc. Prof. Ts. Dr. Muhammad Fahmi Bin Miskon
Date	:	…………………………………………

DEDICATION

To my beloved Mother (Wahbah), Father (Qaid), and Brother (Mohammed)

ABSTRACT

Many robots, such as humanoid robot, biped robot, and robotic exoskeleton, need human guide. Particularly, there is a strong need for devices to assist individuals who lost limb function due to illnesses or injuries. Thus, several methods of generating walking motion have been implemented in order to generate walking motion according to natural human behaviour for the exoskeleton robot system. Polynomial blend technique has implemented to generate the walking motion trajectory, where the polynomial blend refers to the combination of more than one polynomial. However, three constraints (angular position, velocity, and acceleration) have been imposed by the polynomial blend techniques where the constraint of angular jerk was neglected because involving the jerk constrain will be caused problem of the non-ideal match of kinematic constraints at via point. Based on the aforementioned problem, there are three objectives to be achieved in this project. The first objective is to investigate the trajectory profile for various kinematic constraints of walking motion condition when using polynomial equation. The second objective is to modify a technique for improving a trajectory generation method to solve the problem of non-ideal match of the kinematic constraints through via points that connects between successive segments of the human walking motion. The last objective is to validate the trajectory generation method by testing the trajectory generation methods based on simulation using SimMechanics as well as to ensure that the coefficients values of the polynomial equations are correctly obtained. In this project, 5^{th} polynomial segment with the 6^{th} polynomial blend (6-5-6 PSPB) trajectory is proposed that aims to reduce the error that increases because of non-ideal match between kinematic constraints at the via points of successive segments. The trajectory planning of the 6-5-6 PSPB is generated based on the stance and swing phases. Each phase is presented by one full of the 6-5-6 PSPB trajectory. In order to validate the 6-5-6 PSPB trajectory, simulation using SimMechanics is conducted to ensure that the coefficients values of the polynomial equations are correctly obtained. The result shows that the error was improved almost 0.1445 degree based on the proposed 6-5-6 PSPB compared with the 4-3-4 PSPB and 5-4-5 PSPB. Thus, the 6^{th} -5^{th} -6^{th} Polynomial blend leads to impose the angular jerk kinematic constraint beside the angular position, velocity, and acceleration kinematic constraints during the whole walking motion trajectory. Minimizing the maximum jerk in joint space has a beneficial effect in terms of reducing the actuator and mechanical strain and joint wear and to limit excessive wear on the robot and the excitation of resonances so that the robot life-span is expanded.

ABSTRAK

Kebanyakan robot, seperti robot 'humanoid', robot berkaki, dan 'exoskeleton' robot, memerlukan panduan dari manusia. Terutamanya, terdapat keperluan yang kuat untuk peranti yang dapat membantu individu yang kehilangan fungsi anggota badan akibat dari penyakit atau pun kecederaan. Oleh itu, beberapa kaedah penjanaan pergerakan berjalan telah dilaksanakan bagi menghasilkan pergerakan berjalan seperti manusia secara semula jadi untuk sistem robot 'exoskeleton'. Teknik gabungan Polinomial telah dilaksanakan untuk penjanaan trajektori pergerakan, di mana campuran polinomial merujuk kepada gabungan lebih dari satu polinomial. Walau bagaimanapun, tiga kekangan (kedudukan sudut, halaju, dan pecutan) telah dalam teknik campuran polinomial dikenakan di mana kekangan sudut bergetar sentakan diabaikan kerana melibatkan kekangan getaran akan menyebabkan masalah ketidakseragaman kinematik di titik via. Berdasarkan masalah yang disebutkan di atas, terdapat tiga objektif yang perlu dicapai dalam projek ini. Objektif pertama adalah untuk menyiasat profil trajektori untuk pelbagai kekangan kinematik dalam keadaan bergerak semasa menggunakan persamaan polinomial. Objektif kedua adalah pengubahsuaian teknik bagi memperbaiki kaedah penjanaan trajektori bagi menyelesaikan masalah ketidakseragaman kinematik menerusi titik-titik yang pertemuan (via-point) antara segmen pergerakan berjalan manusia yang berturut-turut. Objektif terakhir adalah untuk mengesahkan kaedah penjanaan trajektori dengan menguji kaedah penjanaan trajektori secara simulasi menggunakan SimMechanics serta untuk memastikan nilai pekali persamaan polinomial diperolehi dengan betul. Dalam projek ini, segmen polinomial ke-5 dengan campuran polinomial ke-6 (6-5-6 PSPB) dicadangkan bertujuan untuk mengurangkan kesilapan yang meningkat kerana ketidakseragaman kinematik di titik pertemuan segmen yang berturut-turut. Penjanaan trajektori 6-5-6 PSPB dihasilkan berdasarkan kepada fasa berdiri dan berayun. Setiap fasa diwakili oleh satu set lengkap trajektori 6-5-6 PSPB. Untuk mengesahkan trajektori 6-5-6 PSPB, simulasi menggunakan SimMechanics dijalankan bagi memastikan nilai pekali persamaan polinomial yang diperolehi adalah betul. Hasil keputusan menunjukkan bahawa ralat telah diperbaiki hampir 0.1445 darjah menggunakan 6-5-6 PSPB berbanding dengan 4-3-4 PSPB dan 5-4-5 PSPB. Oleh itu, campuran Polynomial ke-6 ke-5 membawa kepada menekan kekangan kinematik sudut bergetar selain dari kedudukan sudut, halaju, dan pecutan kinematik semasa keseluruhan pergerakan trajektori berjalan. Mengurangkan getaran maksimum di ruang kerja memberikan kesan yang baik dari segi mengurangkan ketegangan penggerak dan mekanikal dan pemakaian sendi dan untuk menghadkan pemakaian berlebihan dan pengujaan resonans supaya jangka hayat robot dipanjangkan.

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4-3-4 PSPB	-	3^{rd} order Polynomial Segment with 4^{th} order Polynomial Blend
5-4-5 PSPB	-	4^{th} order Polynomial Segment with 5^{th} order Polynomial Blend
6-5-6 PSPB	-	5^{th} order Polynomial Segment with 6^{th} order Polynomial Blend
PSPB	-	Polynomial Segment with Polynomial Blend
LSPB	-	Linear Segment with Parabolic Blend
LSCB	-	Linear Segment with Cubic Blend
LSQB	-	Linear Segment with Quintic Blend
ADE	-	Average Difference Error
RMSE	-	Root Mean Square Error
DE	-	Deference Error
SDE	-	Standard Deviation Error
DS-stance	-	Double Support Stance Phase
SS-stance	-	Single Support Stance Phase
2-phases	-	Motion trajectory is divided into two phases.
4-phases	-	Motion trajectory is divided into four phases.
7-phases	-	Motion trajectory is divided into seven phases.
PD Controller	-	Proportional Derivative Controller
TCP	-	Tool-Centre Point
EMG	-	Electromyography
TGM	-	Trajectory Generation Method

LIST OF SYMBOLS

P_0	-	Initial Position
P_f	-	Final Position
P_m	-	Intermediate Position
t_0	-	Initial Time
t_f	-	Final Time
t_b	-	Blend time of the first segment
t_g	-	Blend time of the last segment
θ	-	Angular position
$\dot{\theta}$	-	Angular velocity
$\ddot{\theta}$	-	Angular acceleration
$\dddot{\theta}$	-	Angular Jerk
V	-	Velocity
A	-	Acceleration
T_{Ref}	-	Reference Trajectory
T_{Gen}	-	Generated Trajectory
$\mu_{T_{Gen}}$	-	The Mean of the Generated Trajectory
$\mu_{T_{Ref}}$	-	The Mean of the Reference Trajectory
σ	-	The Standard Deviation
a_n	-	Coefficient of Polynomial Equation

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M. Q. Mohammed and M. F. Miskon. (2018). High Accuracy Motion Trajectory Generation Profile Based on 6-5-6 PSPB For Human Walking. *Int. J. Mech. Mechatronics Eng.*, vol. 18, no. 3, pp. 43–51, 2018. **[Indexed by SCOPUS]**

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CHAPTER 1

INTRODUCTION

The human body consists of more than six hundred muscles, producing movements which are inseparably connected to its life. That does not necessarily refer to the vital functions of the body, like breathing or the heartbeat. It refers to movement in general, which is very important for all living creatures. Mobility is one of the most important things in life. Already the common daily activities are very important for the quality of life such as Getting up from bed in the morning and walking to the bathroom, the breakfast table, or the refrigerator. Or during work, whether inside an office or while carrying heavy parts in a factory. Furthermore, lack of mobility often results in lack of participation in social life, which in turn leads to an undesired reduction of communication. It is also important for the body health to move around to activate the circulation system of the body and the muscles. Exoskeleton-type walking assistive devices have been developed for this reason and can achieve patients' dream of walking, whereas wheelchairs only help them to move (Huo et al., 2016).

The trajectory generation is a complex part of the robot designing either exoskeleton, biped, or manipulator robots because a proper trajectory profile will provide health, comfort, as well as safety for the user (Miskon and Yusof, 2014). Besides that, a suitable trajectory profile helps to perform the target task successfully. The performance of a desired walking motion for Exoskeleton robot can be generated based on the trajectory that is involving in several dimensions through the space, whereas the trajectory generates based on the four kinematic constrains named angular position, velocity, acceleration, and jerk with taking a consideration to the time of every single degree of freedom (Craig,2004).

Nowadays, trajectory planning of human walking is considered as the most concerned by researchers. Achieving an appropriate trajectory with consideration to the most effective kinematic constraints which are (angular position, velocity, acceleration, and jerk), a complex trajectory planning is needed. According to that, the polynomial equations are the technique that has been implemented in generating the walking motion trajectory because of its simplicity and ability to cover more kinematic constraints. Whereas the polynomials are represented mathematical formula that is comprising the sum of the powers in one variable or more with multiplying the coefficients (Jazar, 2010). Furthermore, the polynomial blend is a combination of different polynomial equations which aims to generate interpolation spline curve (Wiltsche, 2005). At the same time, polynomial blend aims to generate the trajectory motion profile with high accuracy where the accuracy refers to the closeness of a measured value to an actual value. Different kinematic constraints affect the trajectory generation

Increasing to higher order polynomial (e.g. 7^{th} ,9^{th} , and so on) addressed the problem of producing high acceleration and jerk during the trajectory generation (Ezair et al., 2014) (Boryga and Graboś, 2009). This higher order polynomial leads to generate undesirable trajectory (Jazar, 2010) (Biagiotti and Melchiorri., 2008). At the same time, higher order polynomial addressed problem of producing Runge's phenomenon, where the Runge phenomenon illustrates that equidistant polynomial interpolation of the Runge function will cause wild oscillation near the endpoints of the interpolation interval since the order of the interpolation polynomial increases as illustrated in Figure 1.1 (Fornberg and Zuev, 2007) (Chen et al., 2014) (Boyd, 2010) (Boyd, 1992).