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DESIGN AND DEVELOPMENT OF SIT-TO-STAND TRAJECTORY AND CONTROL OF HUMANOID ROBOT

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DESIGN AND DEVELOPMENT OF SIT-TO-STAND TRAJECTORY AND CONTROL OF HUMANOID ROBOT

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A thesis submitted in fulfilment of the requirements for the award of The degree of Master of Science in Mechatronic Engineering

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DECLARATION

I hereby declare that this thesis entitled "Design and Development of Sit-To-Stand Trajectory and Control of Humanoid Robot" 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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Name	: Mohd Bazli Bin Bahar
Date	: ....

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 :DR. Muhammad Fahmi Miskon

Date : ....

DEDICATION

To my beloved family

ABSTRACT

Sitting position is an important feature in a humanoid robotic system as it is more stable when compared to standing position, resulting in less energy consumption since no actuator is needed to stabilize the robot. Sitting is crucial especially for humanoid robot in security and domestic robotics field where the robots are used for a long period. In order to return to standing position, sit to stand (STS) motion is needed. One of the main challenges in STS is during the lift-off; i.e. the moment when the robot's thigh is lifted from the chair's surface. During lift-off, a sudden change of the position of centre of mass (CoM) causes instability to the STS motion. Furthermore, the limitation of body and joint will exacerbate the problem by limiting the ability to move the CoM to appropriate position. Due to this issue, the first objective of this research is to develop and validate a system that autonomously able to identify a trajectory to transfer the CoM to an appropriate position before lift-off from any chair height. The method works by autonomously calculate the horizontal distance between the CoM and the support polygon. With the estimated distance, flexion of hip and ankle joints is made to bring the CoM into the support polygon. The arrangement of the motion is based on Alexander STS technique. Second objective is to develop and validate a control system to balance the robot from tumbling down during STS motion due to stability issue. The proposed control system employs the IF-THEN rules as the action selector. The rules are set based on CoP position and feedback from body's angular direction in y-axis on sagittal plane. The rules set three variable i.e. HAT (Head-Arm-Torso) direction, HAT velocity, and proportional controller gain. To determine the gain for the proportional controller, the gain identification method implements the partitioning of CoP position into a number of regions. The coefficient at each region is set differently to increase the sensitivity of the controller. To verify the effectiveness of the proposed method, experiments using NAO robot were conducted. The stability of the robot was measured based on the position of Centre of pressure (CoP) within the feet area and the angle y reading. Results show that the robot was able to perform the STS motion when height of chair is varied from 9.95cm to 16.25cm. The CoP position also shows that the pressure point is always within the feet area. However, the system failed to perform the task when the height of chair is lower than 96.60% of the robot's shank length due to the robot's body limitation.

ABSTRAK

Posisi duduk merupakan ciri penting bagi robot humanoid kerana ia lebih stabil berbanding dengan posisi berdiri, dan ini menyebabkan penggunan tenaga yang kurang kerana tiada unit penggerak diperlukan untuk mengekalkan kestabilan. Kriteria ini penting untuk robot yang digunakan bagi tujuan keselamatan dan domestik yang beroperasi dalam jangka masa yang lama.Untuk kembali ke posisi berdiri, pergerakan bangun atau 'sit to stand' (STS) diperlukan. Salah satu cabaran dalam pergerakan ini adalah ketika proses mengangkat iaitu ketika peha robot terangkat dan tidak lagi bersentuh dengan permukaan kerusi. Perubahan mendadak pada kedudukan pusat jisim menyebabkan ketidakstabilan pada pergerakan.Selain itu, had pada tubuh dan sendi robot akan memburukkan lagi masalah dengan menghadkan pergerakan pusat jisim.Oleh sebab itu, objektif pertama kajian ini adalah membangunkan satu sistem yang mampu mengenalpasti pergerakan pusat jisim yang sesuai secara automatik sebelum mengangkat dari sebarang ketinggian kerusi.Sistem ini beroperasi dengan mengira jarak lurus antara pusat jisim dengan kawasan sokongan secara automatik. Hasil dari jarak yang telah dikira, sistem akan menggerakkan pinggang dan pergelangan kaki untuk memindahkan pusat jisim ke dalam kawasan sokongan. Tatacara pergerakan ini berdasarkan dari pergerakan STS Alexander.Objektif kedua adalah membangunkan sistem kawalan yang mampu mengawal kestabilan pergerakan. Sistem kawalan ini menggunakan peraturan JIKA-MAKA sebagai pemilih tindakan.Penetapan peraturan ini berdasarkan bacaan pusat tekanan yang berada di tapak kaki (CoP) dan ralat yang berlaku pada sudut arah badan dalam satah saggital (bacaan sudut y). Peraturan ini mengawal tiga pembolehubah iaitu arah, halaju, dan pekali. Untuk mendapatkan pekali bagi pengawal halaju berkadar, pelaksanaan pembahagian kawasan tapak kaki yang diwakili oleh bacaan CoP kepada beberapa kawasan yang lebih kecil dibuat. Pada setiap kawasan ini, pemalar yang berbeza-beza di tetapkan untuk meningkatkan kepekaan pengawal. Untuk mengesahkan keberkesanan kaedah yang dicadangkan, ujikaji menggunakan robot NAO telah dijalankan.Kestabilan robot diukur derdasarkan kedudukan pusat tekanan yang berada di kawasan tapak kaki dan bacaan sudut y. Keputusan menunjukkan robot mampu bangun pada ketinggian kerusi dari 9.95cm hingga ke 16.25cm. Kedudukan pusat tekanan juga menunjukkan ia sentiasa berada di dalam lingkungan kawasan tapak kaki. Walau bagaimanapun, sistem ini gagal untuk menjalankan tugas apabila ketinggian kerusi lebih rendah daripada96.60% panjang keting robot kerana kekangan pada tubuh robot.

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LIST OF ABBREVIATIONS

AE	Actual environment
ANN	Artificial neural network
AT	Alexander technique
B	Back region
CoM	Centre of mass
CoP	Centre of pressure
F	Front region
FSR	Force sensitive resistor
HAT	Head-arm-torso system
HDI	Horizontal distance identification
JAD	Joint angle determination
M	Middle region
PID	Proportional, integral, and derivative
RMSE	Root mean square error
SE	Simulation environment
SL	Shank length
SP	Support polygon
STS	Sit to stand
ZMP	Zero Moment Point

LIST OF PUBLICATION

Conference paper

1. Mohd Bazli B., M. F. Miskon, Norazhar A. B., Ahmad Zaki S. & Fariz A. 2013. Horizontal Distance Identification Algorithm for Sit to Stand Joint Angle Determination for Various Chair Height Using NAO Robot. In*: The 8th International Conference on Robotic, Vision, Signal Processing & Power Applications*, H. A. Mat Sakim & M. T. Mustaffa, eds. 10-12 November, Pulau Pinang. Springer Science+Business Media Singapore.

Journal

1. Mohd Bazli B., M. F. Miskon, Norazhar A. B., Ahmad Zaki S. & Fariz A. 2014. Path Generation of Sit to Stand Motion using Humanoid Robot. In: *Australian Journal of Basic and Applied Sciences*, Volume (8) issue (2) 2014.

2. Mohd Bazli B., M. F. Miskon, Norazhar A. B., Ahmad Zaki S. & Fariz A. 2014. STS Motion Control using Humanoid Robot. In: *Research Journal of Applied Sciences. Engineering and Technology.*

CHAPTER 1

INTRODUCTION

1.1 Research Background

The purpose of this thesis is to develop a method to perform sit to stand (STS) motion using humanoid robot. STS motion is defined as the standing up motion of human or humanoid robot from a chair (Huanghuan et al., 2007, Banerjee et al., 2010, Mughal and Iqbal, 2008c, Mughal and Iqbal, 2008a) i.e. motion in between the sitting position to standing position where all joints from hip to ankle are parallel to each others. This motion is also called the chair rise motion (Marcello et al., 1994).

The study of sit to stand motion (STS) gives high impact to the robotics field particularly in rehabilitation in order to understand the motion behaviour (Chuy et al., 2006, Guangming et al., 2007, Saint-Bauzel et al., 2009a), exoskeleton (Strausser and Kazerooni, 2011, Dellon and Matsuoka, 2007, Hasegawa et al., 2010, Chu et al., 2005) as well as humanoid robotics in order to implement the STS motion in the exoskeleton and humanoid system. In humanoid robotics field, the STS study has not been given emphasis until year 2010.

Several groups have been identified to study STS using humanoids. They are M. Mistry who studied STS based on vision feedback from the human volunteer (Mistry et al., 2010) with discuss on virtual holonomic constraints in (Mettin et al., 2007), K. Qi analysed the state transition with generalized function set (Kaicheng et al., 2009), S. Pchelkin discussed a constructive procedure for planning human-like motions of humanoid robots on finite-time intervals (Pchelkin et al., 2010), M. Sakai et al, compare the MTBDDs and

MDDs through simulations to acquire robot action rules (Sakai et al., 2010), X.Gu et al. proposed biologically inspired control model with three different ways of motor synergies over multiple motor routines to perform the STS motion (Xue and Ballard, 2006), and P.Faloutsos proposed an explicit model of the "pre-conditions" where it was based from the learning theory by Support Vector Machine (SVM) (Faloutsos et al., 2003).

There are also STS motion research that implemented learning process, such as the research done by K. Kuwayama using HOAP-1 (Kuwayama et al., 2003), and adaptive allocation method of basic functions for reinforcement learning (Iida et al., 2004a). M. Sugisaka studied STS control system using different humanoid robot that were equipped with artificial muscles (Sugisaka, 2007, Sugisaka, 2009). Apart from using simulation of humanoid robot or actual robot, the research was also done by using a 3D biped simulation model, that was develop by these authors (Andani et al., 2007, Mughal and Iqbal, 2006a, Prinz et al., 2007, Konstantin Kondak, 2003, Fu-Cheng et al., 2007, Riener and Fuhr, 1998).

1.1.1 STS Problem.

The main challenge in STS is addressing the robot's lift-off from chair. The lift-off is a state when the hip that touches the chair's surface starts to lift. System's support polygon area becomes smaller since the feet are the only surface that is still in contact with the ground when the robot hips lift from the chair surface. The illustration of the lift-off is shown in Figure 1.1. The top part of the figure described the transition of the support polygon from the top view starting from the robot at sit position to standing. The period between t_1 and t_2 is nearly to zero where fast transition happened. The bottom part of the figure shows image of the robot posture seen from the side view during the lift off.

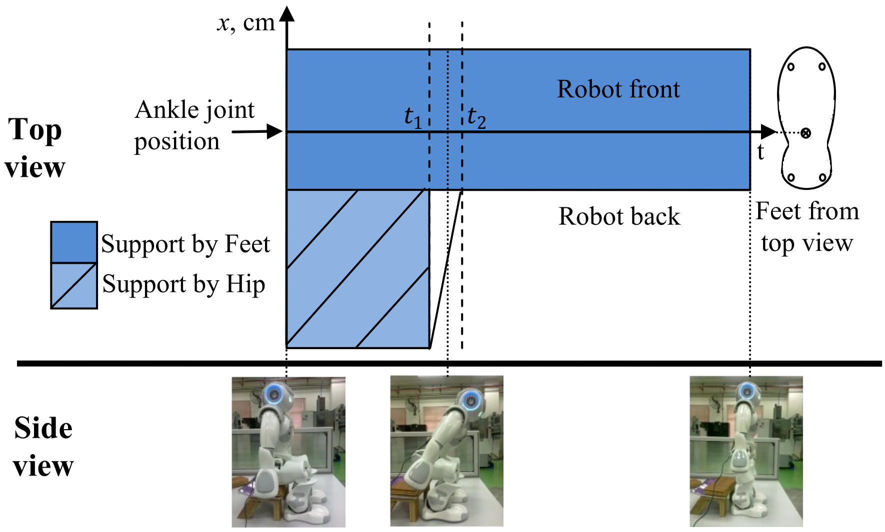

Figure 1.1: Lift-off from chair occur between t_1 and t_2.

In solving the problem, two main components of the humanoid STS motion system were observed; the (1) phase and trajectory planning and (2) control scheme. Both components have to be considered to ensure stable motions which in turn allow the robot to stand successfully.

Phase planning is a proper plan to separate the whole movement into several phases. The phases are usually separated based on the task requirements at the particular time. With a number of phases set, the trajectory planning in each phase can be made with the need of each phase in consideration. During lift-off, the instantaneous change of support polygon, between t_1 and t_2 may cause the subject to collapse if centre of mass (CoM) is not in the support polygon (SP), or in the case of STS motion, the subject will fall back to the sit position or collapse to ground. This case is also known as sitback. Phase planning also reduces the load endured at each joints as the STS motion was claimed to be the most mechanically demanding task (Aissaoui and Dansereau, 1999). A single joint cannot handle all the body force at a time. Phase planning should solve this by synchronizing all the joints so that only a small amount of force acts on each joints (Pchelkin et al., 2010).

The second component is the control scheme which can be divided into two parts, (1) joint control and (2) stability control. The function of joint control is to reduce the error between the trajectory given to the robot and the actual trajectory produced by the robot on each joints. In stability control, the focus of the control scheme is to follow exactly the motion that has been planned while keeping the stability of the robot. A control scheme is also crucial in managing when and how a system should react to keep a stable motion.

The study will benefit many, not only those in the field of humanoid robot advancement but also its immediate applications such as experimental tool for medical STS studies in joint motion analysis, body trajectory, and chair design analysis.

1.2 Problem statement

This section contains a detailed elaboration of the problem by using a NAO robot as the humanoid robot platform in the experiment. The robot is $0.573m$ high and has 25 degree of freedom. Focusing on lower body system, all joints are designed to be aligned to each other and the maximum flexion of each joint as in Table 1.1.

Table 1.1: Lower limb joint maximum flexion.

Joint	Flexion
Hip, θ_h	$27.73°$ until $-101.63°$
Knee, θ_k	$121.04°$ until $-5.29°$
Ankle, θ_a	$52.86°$ until $-68.15°$

In order for any humanoid robot to maintain a stable upright position, its Centre of Mass (CoM) needs to be within an area called the support polygon (SP). Generally a support polygon (SP) is an area where ground in touch with any limb of the robot. However, at sitting position another support is provided by the chair that in touch with the thigh. Figure 1.2 shows the support polygon when the NAO robot is in a sitting position on the left figure and on the right is the view from bottom of the robot. At this position, the SP is an area of foot and thigh that contact with the ground and the chair surface respectively. In the head-arm-torso system (HAT), CoM is located at the centre of the robot's body, where $l_{CoM} = 15.0cm$ as shown in Figure 1.2. $l_{thigh} = 10.0cm$ is the length of the robot's thigh and the shank length represented by $l_{shank} = 10.3cm$.

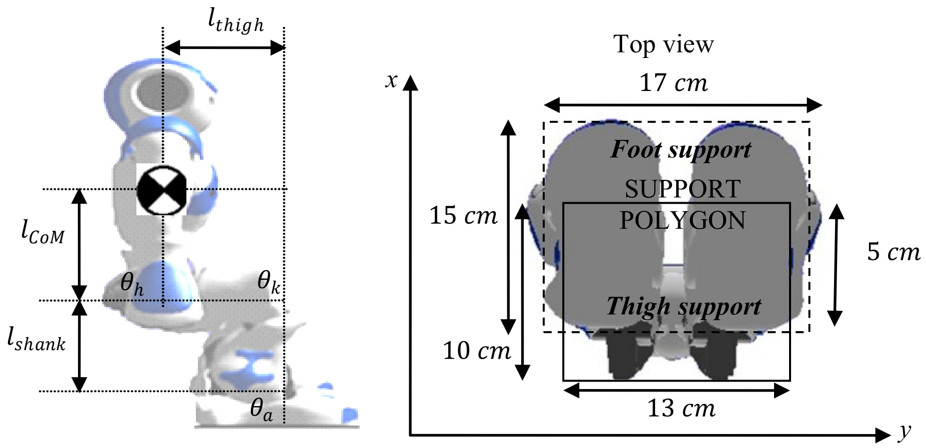

Figure 1.2: Position of Centre of Mass

When the robot thigh start to rise from the chair surface, the remaining SP is only area that support by the foot as mentioned in chapter 1.1.1 and illustrated in Figure 1.1. In order to ensure the HAT CoM always in the SP, proper trajectory planning is needed. The planning should consider on which joint and degree of flexion on each joint that should be controlled to prevent the robot from falling.

Apart from that, the trajectory planning must also able to consider the limitation of each joint flexion as mentioned in Table 1.1 and should operate automatically when the chair height is varied.

Thus, the research question is *how to make a humanoid robot stand from a sitting position with its design limitations taken into consideration, with the assumption that there is no external force acting on the robot*?

Sit to stand motion also needs a control scheme after the lift-off to make sure CoM is always in the support polygon. Three joints (minimum) are needed for the NAO robot to stand but movements from these joints create disturbance that will disrupt the total velocity that is acting on the whole body. This disturbance is contributed by the change of direction in each joint during lift-off and causes imbalance by changing the CoM location from the SP.

The lift-off situation can be explained with an example of all joint being initially at; $\theta_k = 90°$ for the knee joint, $\theta_h = -75.6°$ for the hip joint and $\theta_a = -7°$ for the ankle joint, as shown in Figure 1.2. During lift-off state, the joints changed to $\theta_k = 90°$, $\theta_h = -89°$, and $\theta_a = -10°$. At this state, the body move forward to transfer the CoM into the support polygon. Then, the body needed to move backward to complete a standing position at which the joints may change to $\theta_k = 0°$, $\theta_h = 8°$, and $\theta_a = -2°$ respectively. The value of hip joint, θ_h showed that the joint moved clockwise and then changed the direction to anticlockwise. With all joint experiencing the same condition, an external momentum was generated. The momentum pushed the whole body of the subject to the front and may cause the subject to fall forward. The illustration of the lift-off problem is shown in Figure 1.1.

Thus, the second research question *is how to control the robot's motion so that it performs STS motion without falling?*