DEVELOPMENT OF FUZZY CONTROL AND TRAJECTORY PLANNING FOR NAO HUMANOID STS MOTION

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I declare that this report entitle Development of Fuzzy Control And Trajectory Planning For Nao Humanoid STS Motion is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : KHALID NOR BIN SALIKIN

Date : 24th JUNE 2016

To my beloved family

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ABSTRACT

The motion of sitting and standing up from a chair seemingly simple and commonplace motion we do every day. However, moving the humanoid robot from sitting position to stable standing position become most challenging motion. As known, standing position is less stable than sitting position and it be an important feature in a humanoid robotic. Since there is no actuator is needed to stabilize the robot it prove that less energy used by humanoid in sit position. Planning a successful sit-to-stand motion without falling requires true knowledge of the robot's center of mass (CoM) position during the trajectory. This is because, when the robot's thigh is lifted from the chair's surface there are change of the position of center of mass (CoM) that affecting the stability to the STS motion. In addition, the problem of limiting the ability to move the CoM to suitable position affecting the stability. Due to this issue, the first objective of this research is to plan the trajectory of sit-to-stand motion of humanoid robot without any controller. The method to identify the result is based on the Alexander STS technique by determining the CoM and ankle joint, calculate the needed angle change at each joint to move CoM into the stability region. While, second objective 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 and also control the rise up motion until it completely at standing position.. The proposed control system used the Fuzzy logic method as the action selector. The rules are set based on CoP position and feedback from body's angular direction in y-axis on vertical plane.

ABSTRAK

Pergerakan duduk dan berdiri dari kerusi seolah-olah mudah dan perkara biasa gerakan yang kita lakukan setiap hari. Walaubagaimanapun, pergergerakan robot humanoid daripada kedudukan duduk ke kedudukan berdiri yang stabil merupakan gerakan yang paling mencabar. Seperti yang kita sedia maklum, kedudukan berdiri menjadi kurang stabil jika dibandingkan dengan duduk dan ia menjadi satu ciri penting dalam sebuah robot humanoid. Oleh kerana tiada penggerakan yang diperlukan untuk menstabilkan robot ia membuktikan bahawa kurang tenaga digunakan oleh humanoid dalam posisi duduk. Bagi menbolehkan pergerakan duduk-berdiri tanpa jatuh ia memerlukan pengetahuan yang mendalam tentang pusat robot jisim (KPJ) pada semasa trajektori. Ini kerana, apabila paha robot diangkat dari permukaan kerusi itu terdapat perubahan kedudukan pusat jisim (KPJ) dan menjejaskan ketidakstabilan kepada pergerakan duduk-berdiri ini. Di samping itu, masalah mengehadkan keupayaan untuk bergerak KPJ ke kedudukan sesuai yang menjejaskan had badan dan sendi. Oleh kerana isu ini, objektif pertama kajian ini adalah untuk merancang trajektori pergerakan duduk-pendirian robot humanoid tanpa pengawal. Kaedah untuk mendapatkan hasilnya adalah berdasarkan teknik Alexander STS dengan menentukan KPJ dan pergelangan kaki, kira sudut perubahan yang diperlukan di setiap sendi untuk bergerak KPJ ke bahagian kestabilan. Kemudian, Objektif kedua adalah untuk membangunkan dan mengesahkan satu sistem yang secara autonomi dapat mengenal pasti trajektori untuk memindahkan KPJ ke kedudukan yang sesuai sebelum beralih dari ketinggian kerusi dan juga mengawal kenaikan usul sehingga ia benar-benar pada kedudukan berdiri. Sistem kawalan yang dicadangkan menggunakan kaedah logik kabur sebagai pemilih tindakan. Kaedah-kaedah yang ditetapkan berdasarkan kedudukan pusat tekanan dan maklum balas dari arah sudut badan dalam paksi-y pada satah menegak.

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CHAPTER 1

INTRODUCTION

This chapter represent the motivation, problem statement, objective, scope, list of contribution, significant of the project.

1.1 Motivation

A humanoid robot is a robot with its body designed to look alike of the human body. Actually, a humanoid robot were designed for any useful purposes, like interacting with human tools and environments. It's also can be an experimental purposes function like the study of bipedal locomotion and so on.

In general, humanoid robots have a torso, a head, two arms, and two legs, though some types of humanoid robots could model only part of the body. While, some humanoid robots also may have heads designed to duplicate human facial features like eyes and mouths. Nowadays, humanoid robot are being developed to perform human task like personal assistant and able to do jobs like a workers.

1.2 Problem Statement

This section will show the problem by using Nao Humanoid robot as the humanoid robot platform in the experiment. In addition, movement of Sit-to-Stand motion of Nao robot is demonstrated by simulation performed in V-REP, Virtual Robot Experimentation Platform. Any humanoid robot including the Asti robot, its center of mass (CoM) needs to be within an area called support polygon (SP) in to maintain a stable upright position. While, at the sitting position another support is provided by the chair that in touch with the thigh.

Sit-to-Stand motion also needs a control system after the lift-off to make sure CoM is always in the support polygon. Three joints (minimum) are needed for the Nao robot to standup properly but the movements from these joints create disturbance that will disturb 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.

1.3 Objective

1. To develop a trajectory of sit-to-stand motion of Nao Humanoid robot.
2. To develop and validate the proposed Fuzzy control method to perform balance STS motion.

1.4 Scope

In this project, all the movement of the robot is represent by using V-REP and Python Software and all feedbacks from the robot are learned only from Nao built in sensor. While, the stability of the Nao robot is based from center of pressure (CoP) position that is always in the support polygon until the end of motion. The control method focuses on controlling the motion through sagittal plane.

CHAPTER 2

LITERATURE REVIEW

2.1 Theoretical Background

Sit-to-Stand (STS) process is one of the challenging motion of a humanoid robot and need deeply understanding on the strength, balance and range of motion [1]. Planning a successful sit-to-stand motion without falling also needs accurate knowledge of the robot's center-of-mass (CoM) position during the trajectory. While, trajectory is actually a common way of causing a robot to move from A to B in smooth [15].

Basically in designing the trajectory motion of a robot, a simple system are recommended while is need a complicated functions of time and space in order to make the robot to complete the task. In the other words, designer just need to create a system and leave it completed the task referring the user require goal.

Thus, to design a good machine and robot were necessary the understanding in robotics including artificial intelligence, locomotion, and cognition. However, the basic of robotics which is trajectory generation, dynamics manipulator, and kinematics manipulators should be covered before we go through the complicated parts [15].

2.1.1 Robotics

The study in robotic can represent discovery out features of human perform by the applying in mechanisms, actuators, sensors, and computers [15]. Basically, different feature of robotics research are carried out by professionals in different fields. Nowadays, robot is being demand to easier human works. In the other words, robot can be describe as system that may be controlled, reprogrammable, and also multipurpose manipulator programmable in more than three axis. . However, there are three level of language to program a robot which is teach by showing, robot programming language and task level programming language [15]. The first level, robot will be guide based on the user's hand movement or teach pendant. Whereas the second level, by writing a program and transfer to the robot itself. The last level which is give the command directly to the robot to complete the task.

2.1.2 Trajectory Generation

Trajectory generation is modify position, velocity, and acceleration for every degree of freedom. In addition, the trajectory of a robot is the human-interface of the way to specify a trajectory or path through space. To form the outline of manipulator motion easy for an individual's user, they should not be required to write down complex functions of space and time to specify the task [15]. In the other words, let the user set the objective positon and the system can take the accurate form or path to induce as well as the period, velocity, and other details.

For example, to specify paths as motions of the tool frame relative to the station frame, it will decouple the motion description from any particular robot, end-effector, or work pieces. This results in a certain modularity and would allow the same path description to be used with a different manipulator or a different tool size. The block diagram below shows how trajectory process has been done.

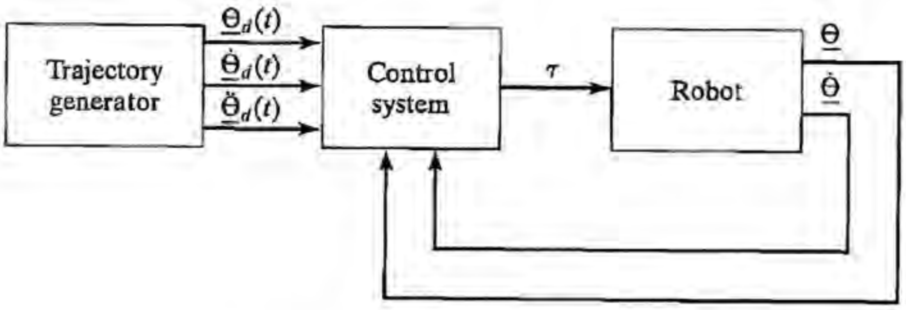

Figure 2.1: Block Diagram of Trajectory process.

2.1.3 Kinematic Manipulator

Kinematics is the science of motion which treats motion without look to the forces which cause it [15]. Within the science of kinematics one studies the position, velocity, acceleration, and all higher order derivatives of the position variables. Hence, the study of the kinematics of robots refers to all geometrical and time-based properties of the motion. In addition, kinematics of the robot were divide into two types which is forward kinematics and reverse kinematics. Forward kinematics is a way to relate the robot's structure or cause to the position and orientation of its end effector. Whereas reverse kinematics is given the position and orientation of the end-effector of the robot, calculate all potential sets of joint angles that might be used to achieve the given position and orientation [15].

2.1.4 Dynamic Manipulator

Dynamics deals with the manipulator in motion. It will be seen that the joint torques control the angular accelerations [15]. There are two problems related to the dynamics of a manipulator that need to be solve. In the first problem, we are given a trajectory point, e, and ë, and we wish to find the necessary vector of joint torques, r. This formulation of dynamics is useful for the problem of controlling the manipulator. These equation are quite complicated. The rigid body dynamic have the form:

$$\tau = M(\theta_d)\ddot{\theta}_d + V\left(\theta_d . \dot{\theta}_d\right) + G(\theta_d) \tag{2.1}$$

The second problem is to calculate how the mechanism move under application of a set of joint torques. That is, given a torque vector, r, calculate the resulting motion of the manipulator, g, é, and 0. This is useful for simulating the manipulator. Which mean the resulting motion of the mechanism is calculated based on the given torque value. The solution for the second problem is very useful in performing the simulation for the manipulator.

2.1.5 Artificial Intelligent

Artificial intelligent is define as the study and designed of intelligent agents. By identify the environment and the intelligent agent will make decision based on the data acquired to increase its chance of success [14]. In robotics, ultimate AI might be the recreation of the human though process that implement into the robot or man-made machine. The real challenge of AI is to understand how the natural intelligence work [15].

2.1.6 Locomotion

Locomotion consist of very different concepts of motions. It is including the rolling, walking, running climbing, jumping, crawling, swimming and flying motions [15]. The motions is difference in terms of energy consumption, kinematics, stability, and abilities of the robot that implement them although some of the motions such as walking, running, jumping, climbing, and crawling seem to be in similar concept.

Basically, locomotion is a critical method in humanoid robot to increases a robot ability to interact with environments. Actually, there are two levels of locomotion which is denominated the inferior level and the superior level. The inferior level is in charge of muscle management and co-ordination that permit the robot to move. While, the superior level is in charge of path that coming up with navigation and different higher level tasks.

2.1.7 Cognition

Cognition suggest that the mental action or method of achievement information and understanding through though, experience, and also the senses [15]. The reason that need to study about the cognition is because it can helps to build a robot that can interact with humans in natural and cognitively-compatible way.

Besides, there are a few sensor that are commonly used in cognition. The first example is sensor that widely used in cognitive field is wireless sensor network. This sensor is used to monitor physically and environment conditions. The condition that monitored by WSN are temperature, sound, pressure and so on. While, the second sensor is the passive infrared sensor (PIR). PIR was used in studying the activity of the elderly with the cognitive impairment. The way of the PIR sensor used in this study was by install it in the subject house and the activity done by the subject is recorded by the sensor.

2.2 State of Arts

Humanoid robot are being used as the research tool in some scientific field. Researchers need deeply understanding on the structural of human body and also its performance in order to achieve the knowledge about the humanoid robot itself. There are many type of locomotion that need to study like walking, moving, holding and also sit to stand (STS) motion [15]. On the other side, the attempt to the simulation of the human body leads to better understanding of it.

Focusing on the STS motion, moving from an unstable position to a stable position, like standing up from a chair, is very frequently elegantly managed by humans [13]. However, in humanoid robot STS motion need a common human task which contains very complex sensorimotor process to control the highly nonlinear musculoskeletal system [11]. STS motion actually is the motion in more simple aspect such as human task that combine musculoskeletal structure and neural control [2].

However, planning a successful sit to stand motion without falling needs exact information of the robot's center of mass (CoM) position throughout the trajectory [12]. Apart of that, there are some challenge occurs when to lift up the humanoid robot from the chair that will discuss and expose in this research.

2.2.1 STS Challenge

The knowledge of the robot's center of mass (CoM) being one of the main challenge to lift-off the robot from the stable sit position to standing position. This problem happen because we need to calculate the center of mass (CoM) of a humanoid robot to letting the reduction of error when sit to stand happen [13]. In the other word, when standing up from the chair support polygon's area will becomes smaller because when in sit position, hip touches the chair and feet will touches the ground. But in standing position it will becomes smaller when only the feet touches the ground in a short period [22].

This condition presented that the calculation of center of mas should be controlled to prevent the sit-back failures [23]. The actuator at the ankle that is not able to rotate the whole body in balancing the STS motion is also state as the lift-off problem occur in humanoid robot [24]. According to the situation, [13] was provide the method based on the algorithm that calculates the real position of the CoM of the biped humanoid robot using only two force or torque sensors located on the feet of the robot.

Since controlling and located of the robot's center of mass (CoM) still being a problem. Thus the lift-off problem in humanoid robot can't be determined. Based on the problem occur, a proper trajectory planning should be taken in order to reposition the center of mass (CoM) at the correct support polygon.

2.2.2 Designing the STS Motion

In STS motion, the planning is concentrating in solving the main components of the humanoid STS motion. There is trajectory planning and motion control. These two components should be designed to overcome the zero moment point (ZMP), centre of pressure (CoP), and centre of mass (CoM) stay in the support polygon [6]. Apart of that, there were several method present in order to calculate the center of mass (CoM) and zero moment point (ZMP) in a humanoid robot [13]. For the CoM, it will be calculated by using two force or torque sensor that located on the feet of the robot. While ZMP will be calculated by the real-time pattern generator of the humanoid robot. Thus, the STS motion control should able to operate in real time and constantly able to adapt any change in between the motion. In this way, the accuracy of the controller rectify the motion error will increase [7] and lift-off from chair problem can be solve.

Back to the two main component that have been state early, trajectory planning will cause the robot joints to be in awkward positions. For example, at sitting position, if a robot bends forward too much, its ankle joint will be unable to provide enough force to balance the STS motion [24]. Then, the motion control of the robot will be change as the change of the support surface of the robot. Based on this problem, a researcher was mention to perform the STS motion, the Alexander technique was creates three main step which is (1) Horizontal distance identification, (2) Joint angle determination, and (3) stability control [1]. The technique also suggests that the feet should be positioned further apart and pointing outward from body but not too far off initially. Then, bring the body to the edge of the chair where at this point, most of its weight is supported by its feet. That success of this task requires whole body coordination and balance, careful control and placement of the body center of mass (CoM) as it moves from a large support basin under the chair to much smaller one above the feet, all the while coping with sudden contact state and force change [12].

2.2.3 Strategy to Reduce Error

In designing the sit to stand motion (STS) in humanoid robot, there are the part that should be keep one or more variable parameter constant within specified limits. In the context of humanoid robot, we should control a mechanism that seem as motion control turns around how well a humanoid robot follows the planned trajectory. The main challenge is how to control the whole body to manage when the system should react [21]. Thus, a good control method needed in order to helps in solving the phase planning problem to select the initial position of the humanoid robot, condition or environment. Apart of that, [6] [7] mention that IF-THEN rules is one of the best action selection to choose the proper effort at certain condition because this rules are using center of pressure using (CoP) position is needed to selecting appropriate action and set based on the knee joint flexion. This statement were be strengthen by not availability of another method that mention in [19] and [21] because the rules are based on a constant variable along the motion.

Besides that, humanoid robot should be able to adapt any environment and condition in performing the STS motion. Moreover, a controller that will monitor the motion of the humanoid robot also should be able to minimize the error then prevent it from falling down. Based on this statement, one of the researcher said that fuzzy modelling is four link biomechanical model of human stable movement is employed to develop the native linear models for every part from sitting on chair to suitable upright standing position [2]. This biochemical movement provide a very useful method to simulate and study the movement. So, combination of $\boldsymbol{H_2}$ and $\boldsymbol{H_\infty}$ is most suitable in that environment to lead a better control scheme.

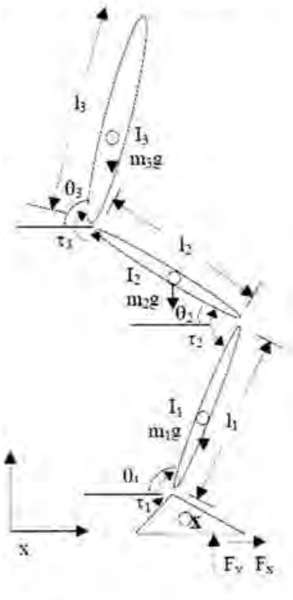

Figure 2.2: 4 link rigid-body biomechanical model