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# THE MODEL AND EVALUATION OF SWAYING ARM TO THE TORSO TORQUE OF HUMANOID ROBOT DURING WALKING

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**Master of Science In Mechatronic Engineering**

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# THE MODEL AND EVALUATION OF SWAYING ARM TO THE TORSO TORQUE OF HUMANOID ROBOT DURING WALKING

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**A thesis submitted in fulfilment of the requirements for the award of**

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## DECLARATION

I hereby declare that this thesis entitled "The Model And Evaluation Of Swaying Arm To The Torso Torque Of Humanoid Robot During Walking" 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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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.

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## DEDICATION

To my beloved mother and father

## ABSTRACT

The humanoid robot stand is the posture where the net torque and force generated by gravity is zero. Thus, the balance of the robot body is produced and keeping the vertical axis equilibrium behaviour. However, during the robot walking, the torque of the torso is disrupted by the internal forces of lower limbs motion. The increase of torso torque will then cause the robot to stumble or fell down. The swing arm motion is a natural phenomenon that realized in the humanoid robot walking. The swaying arm angle range is introduced in this study to utilize the humanoid robot arm motion during walking. The main idea of this technique is the employment of the right shoulder and left shoulder joint angle to reduce the torque at the torso in the vertical direction. The torso torque is computed using a method which utilized the servo torque of right hip, left hip, right shoulder and left shoulder. The torso torque, $\tau_t$ equation is developed in order to model the torque at the torso of humanoid robot in the vertical direction during walking. The torso torque, $\tau_t$ is a method proposed theoretically to determine the torque at the torso of humanoid robot during walking at the vertical axis. Then, the performance of the diversified swing arm angle range, $R_{sa}$ with the torso torque, $\tau_t$ is investigated during humanoid robot walking. The swaying arm angle range, $R_{sa}$ is an approach proposed to reduce the torso torque, $\tau_t$ using swing arm motion. The approach is tested using the NAO humanoid robot version 3.3 (NAO V3.3) in the Webot$^{TM}$ Robotic Simulator. The approach also tested using the real NAO humanoid robot version 4.0 (NAO V4) for hardware experiment. The simulation results indicate that the method is successfully reducing the torso torque, $\tau_t$ from 0.0595 N at $R_{sa} = 0^{\circ}$until 0.00614 N at $R_{sa} = 28^{\circ}$during humanoid robot walking. Then, the hardware experiment results indicate that the method is successful in reducing the torso torque, $\tau_t$ from 0.06921 N at $R_{sa} = 0^{\circ}$ until 0.007101 N at $R_{sa} = 28^{\circ}$. In this investigation, the aim was to assess torso torque, $\tau_t$ is approximately to 0 Nm when the swing arm angle range, $R_{sa}$ and is same with the swing leg angle.

## ABSTRAK

Keadaan robot humanoid ketika berdiri adalah posture yang dimana daya kilasan bersih dan tenaga yang dihasilkan adalah sifar. Oleh itu, keseimbangan badan robot dapat dihasilkan dan menjaga keadaan keseimbangan paksi menegak. Walau bagaimanapun, semasa robot berjalan, daya kilasan torso telah terganggu oleh daya-daya dalaman gerakan anggota kaki. Peningkatan daya kilasan torso akan menyebabkan robot tersadung atau terjatuh. Pergerakan ayunan tangan adalah satu fenomena semula jadi yang direalisasikan dalam pergerakan berjalan kaki bagi robot humanoid. Ayunan tangan berjulat sudut diperkenalkan dalam kajian ini untuk menggunakan tangan robot humanoid semasa berjalan. Idea utama untuk teknik ini adalah penggunaan sudut sendi bahu kanan dan bahu kiri untuk mengurangkan daya kilasan pada bahagian torso dalam arah menegak. Daya kilasan torso, $\tau_t$ adalah satu kaedah yang dicadangkan secara teori untuk menentukan daya kilasan pada torso robot humanoid semasa berjalan di paksi menegak. Daya kilasan pada bahagian torso dapat dikira menggunakan kaedah yang menggunakan daya kilasan servo daripada peha kanan, peha kiri, bahu kanan dan bahu kiri. Persamaan daya kilasan torso, $\tau_t$ dihasilkan untuk modelkan daya kilasan pada torso robot humanoid dalam arah menegak semasa berjalan. Kemudian, prestasi ayunan tangan berjulat sudut, $R_{sa}$ dipelbagaikan dengan daya kilasan torso, $\tau_t$ dikaji semasa robot humanoid berjalan. Ayunan tangan berjulat sudut, $R_{sa}$ adalah pendekatan yang dicadangkan untuk mengurangkan daya kilasan torso, $\tau_t$ menggunakan gerakan ayunan tangan. Pendekatan ini telah diuji dengan menggunakan NAO robot humanoid versi 3.3 (NAO V3.3) di Webot™ Robotic Simulator. Pendekatan ini juga diuji dengan menggunakan robot humanoid NAO yang sebenar versi 4.0 (NAO V4) untuk perkaksan eksperimen. Keputusan simulasi menunjukkan bahawa kaedah ini berjaya mengurangkan daya kilasan torso, $\tau_t$ daripada 0.0595 N pada $R_{sa} = 0^\circ$ sehingga 0.00614 N pada $R_{sa} = 28^\circ$ semasa humanoid robot berjalan. Kemudian, keputusan eksperimen menunjukkan bahawa kaedah ini berjaya mengurangkan daya kilasan torso, $\tau_t$ daripada 0.06921 N pada $R_{sa} = 0^\circ$ sehingga 0.07101 N pada $R_{sa} = 28^\circ$. Dalam kajian ini, tujuannya adalah untuk menilai daya kilasan torso $\tau_t$ dianggarkan bernilai 0 Nm apabila ayunan tangan berjulat sudut, $R_{sa}$ adalah sama dengan sudut ayunan kaki.

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| | |
|---|---|
| Rsa | Swing Arm Angle Rnge |
| $\tau_t$ | Torso Torque |
| $\tau_{RS}$ | Right Shoulder Torque |
| $\tau_{LS}$ | Left Shoulder Torque |
| $\tau_{RH}$ | Right Hip Torque |
| $\tau_{LH}$ | Left Hip Torque |
| $F_{RS}$ | Right Shoulder Force |
| $F_{LS}$ | Left Shoulder Force |
| $F_{RH}$ | Right Hip Force |
| $F_{LH}$ | Left Hip Force |
| $F'_{RS}$ | Right Shoulder Component Force |
| $F'_{LS}$ | Left Shoulder Component Force |
| $F'_{RH}$ | Right Hip Component Force |
| $F'_{LH}$ | Left Hip Component Force |
| $d_{RS}$ | Right Arm Distance |
| $d_{LS}$ | Left Arm Distance |
| $d_{RH}$ | Right Leg Distance |
| $d_{LH}$ | Left Leg Distance |
| SSP | Single Support Phase |
| DSP | Double Support Phase |

## LIST OF PUBLICATION

1. Shaari, N. L. A., Razali, M. R., Miskon, M. & Isa, I. S. M. 2013. PARAMETER STUDY OF STABLE WALKING GAITS FOR NAO HUMANOID ROBOT. *International Journal of Research in Engineering and Technology (IJRET).*
2. Razali, M. R., Miskon, M. F. & Shaari, N. L. A. 2014. The Effect of Swing Arms Posture Motion on Walking Straightness of Humanoid Robot. In: *International Conference on Design and Concurrent Engineering (iDECON)*, 2014.
3. Razali, M. R., Miskon, M. F., Bahar, M. B. 2015. The Study Of Limbs Torque Behaviour During Humanoid Robot Walking. *ARPN Journal of Engineering and Applied Sciences.*
4. Muhammad Razmi Razali, Muhammad Fahmi Miskon, Mohd Bazli bin Bahar. 2015. The Influence Of the Swaying Arm Angle Range To The Torso Torque Of The Humanoid Robot During Walking. *2015 IEEE International Symposium on Robotics and Intelligent Sensors (IEEE IRIS2015).*

# CHAPTER 1

# INTRODUCTION

## 1.1 Research Background

One of the most significant current discussions in humanoid robot is walking. It is becoming increasingly difficult to ignore most of the humanoid robots that invented to become a partner or human assistant nowadays. It is also expected humanoid robot will be active in an environment designed for human. In human walking, the external forces act in three dimensions is the leading cause to move the body. Sagittal forces are involved in propulsion and deceleration. Vertical forces both support the body weight and play an important role in the exchange of potential and kinetic energy (Cavagna et al., 1977). It is approximately the same as in humanoid robot walking. Transverse force is small and has received a relatively minor attention. Both tranverse and sagittal forces can change the state of the body rotation about the vertical axis and also can become a force component which is the vertical free moment. The difficulty of measuring transverse forces may explain why these have received little attention other than normative studies (Li et al., 2001).

Rotational forces are a common thought characterized by the swing arm motion. The study (Elftman, 1939) proposed that the swing arm motion during walking balances torso torques caused by swinging motion of the lower limbs. The swing arm motion is an important component in the human walking and plays a key role in helping to stabilize the rotational body motion indicated by the mechanical analysis (Zehr and Duysens, 2004). The same general conclusion has been proved after the idea studied by other researches such as (Hinrichs, 1990, Li et al., 2001). The primary mechanical effect of arms swing motion is the leading cause of reducing the body twisting torque along the vertical axis during walking. The torque of contra lateral upper and lower limbs partially balances each other when the upper limbs and contra lateral lower limbs moves forward simultaneously.

It is to be expected that the study of humanoid robot walking has been focused more on the lower body motion rather than the upper body motion. Therefore, most of the trajectory generations of humanoid robot walking have been often simplified to exclude the arms. However, when dealing with the anthropomorphic humanoid robot system, the effect of the swing arm and swing leg motion causes the transverse and sagittal forces motion. The transverse and sagittal plane forces could change the condition of the torso about the vertical axis. The vertical axis rotation can be a further force component which called as vertical free moment (Li et al., 2001). Apart from that, the study by (Li et al., 2001) also explained that the common feature of swing arm and the major feature of vertical moment during walking is that both of them affect the torque of the torso (and of the lower limbs) in the vertical direction. This is because it is expected that the utilization of swing arm motion could reduce the vertical axis moment and give the robot recovery from stumbling.

Based on the research by (Shibukawa et al., 2001, Bruijn et al., 2010, Haruna et al., 2001a) stated that swing action of arms has also stabilizing effects on the walks. This is because there is no researcher measure the torque at the torso in the vertical direction produced by the swing arm motion during humanoid robot walking. Therefore, in order to analyze the swing arm motion can reduce the effects on the humanoid robot walking, the role of the swing arm motion is at the centre point of this study. This approach will be use as a comprehension to understand the swing arm angle range affected the torque of the torso in the vertical direction.

## 1.2 Motivation of Research

The humanoid robot stand is the posture where the net torque and force generated by gravity is zero (Cisneros et al., 2014). Thus, the balance of the robot body is produced and keeping the vertical axis equilibrium behaviour (Li et al., 2001). However, during the robot walking, the torque of the torso is disrupted by the internal forces of lower limbs motion. In the single support phase, the torques shift the COM into the support polygon of the stance leg and thereby increase the torso torque because of the swing leg motion at the same time. The increase of torso torque will then cause the robot to stumble or fell down. In this study, during humanoid robot walking, the robot has the highest chance to get the reduction of torque at the torso during walking.

## 1.3 Problem Statement

In human walking, the external forces act in three dimensions to shift the body from one point to another point. Sagittal forces are involved in propulsion and deceleration and vertical forces both support the body weight and play an important part in exchange of potential and kinetic energy (Cavagna et al., 1977). Tranverse forces are relatively small and have received relatively less attention (Li et al., 2001). Both tranverse and sagittal forces can change the condition of the rotation of the body about the vertical axis. Both forces also can contribute to the vertical axis moment.

The vertical axis moment is a combination of two forces (transverse and sagittal). The moment has the similar action on any vertical axis regardless of its position. However, the rotation effect of the transverse and sagittal forces will depend on the position of the axis. For a free body, the axis passes through the Center of Mass (COM) from above which is called the vertical axis, gives the smallest moment while walking. This study examine the characteristics of transverse forces and torso torque (vertical axis moment) and the effects of torque produced by the swing arm motion during humanoid robot walking. Therefore, the vertical axis is particularly important in this study. It is possible to analyze the value of torso torque. The findings are based on the effect of the swing arm motion to the torque at the torso during humanoid robot during walking.

The swing arm motion which is performing as the force combination also contributed to the vertical axis moment. A common feature of the swing arm motion and a major feature of the vertical axis moment is that both of them affect the torque at the torso in the vertical direction. Furthermore, it can be expected that the utilization of the swing arm motion provides good performance to walking by soothe the effects of the torso torque during walking.

The only net torsional effect from the swing arm motion is a moment about the vertical axis of the torso. This happened because of the inertial effects of swing arm motion about the vertical axis. The forces from the arms to the torso (one to move one arm forward and one to move the other arm backward), both contribute to the moment about the vertical axis in the same direction. This causes the forces to add up rather than cancel each other out.

Furthermore, the external torque applied to the legs and torso, required to counter the behaviour from the motion of the leg swing and torso, can come from only two (2) sources as explained by (Park, 2008):

1. The ground reaction moment about the vertical axis of the stance foot (this reaction is transmitted through the stance leg to the torso).
2. The torsional effect to the torso from swing upper and lower limbs motion.

The torso torque of contra lateral upper and lower limbs partially balances each other when the upper limbs and contra lateral lower limbs moves forward or backward simultaneously (Shafii et al., 2009).

The swing leg motion is necessary needed to move the leg and torso forward during the single support phase (SSP). For example, when the left leg is in the stance leg condition, a positive torque (clockwise) with respect to the torso is necessary to move the right leg (which in the swing leg condition) and torso move forward. The motion contributed to the production of a positive torque with respect to the vertical axis of the torso but in the different direction with the swing arm motion vertical axis moment. The motion contributed to the production of a positive torque with respect to the vertical axis of the torso but in the different direction of negative torque (anti-clockwise) with the swing arm motion at the vertical axis.

However, nobody study about the relation between swaying arm and lower limbs motion. In this study it is hypothesized that during humanoid robot walking, the swing arm angle range can influence the torque about the torso vertical axis. The vertical axis moment produced by the swing arm motion is needed to counter the torque from leg and torso motion. However, if the swaying arm angle range, $R_{sa}$ is bigger than the swaying angle of the lower limbs motion, the magnitude of the torsional effect from the swing motion to the torso in the vertical axis will be excessive. Therefore, the swaying arm angle range, $R_{sa}$ values need to be optimised in order to determine the minimum torso torque with respect to the swaying angle of the lower limbs.

## 1.4 Objective of Research

The objective of the study is to model and validate the relationship between the swing arm motion of a robot and its torso torque, $\tau_t$ at the vertical direction of the humanoid robot body during walking. It is based on the following points:

1. To develop the torso torque, $\tau_t$ equation in order to model the torque at the torso of humanoid robot in the vertical direction during walking.
2. To monitor the performance of the diversified swing arm angle range, $R_{sa}$ with the torso torque, $\tau_t$ during humanoid robot walking.

## 1.5 Scope of Study

The scope of the study is as follows:

1. The walking pattern generation that used in this study is assumed as a tool to make the robot walk.
2. The walking speed is constant and the ground reaction moment is the same all the time.
3. The collected data is from rotational servo of right shoulder, left shoulder, right hip and left hip.
4. The simulations are run using NAO humanoid robot version 3.3 (NAO V3.3) in Webot$^{TM}$ Robotic Simulator.
5. The experiments are run using real NAO humanoid robot version 4.0 (NAO V4).

### 1.6 Significant of study

There are many benefits when the using the upper limbs motion in the study of the humanoid robot walking. The idea of using swing arm motion in humanoid robot walking come about through the observations of human walking. The advantage of the swing arm motion in synchronization with the swing leg can be a way of counter balancing the system.

Furthermore, the humanoid robot walking study has been performed focusing on lower limbs and the study of the swing arm motion is not performed. The swing arm motion is important as it generally told (Shibukawa et al., 2001). The reason for the swing arm motion not performed is to be assumed that the swing arm motion is not a necessary a part for walking. But it can be guessed that the swing arm motion has done a certain role about the torque at the torso of humanoid robot in the vertical direction during walking.

Finally, this suggests that the swing arm motion is related the torso torque,$\tau_t$ during humanoid robot walking. The swing arm motion would move in unison with the swing leg such that the arm will be fully extended forward when the leg strikes the ground (Tay, 2009). The support arm swing in the opposite direction. This approach was intended to explore the use of arms, with the arm swaying angle range, $R_{sa}$ tested heuristically through trial and error.

## 1.7 Contribution of Research

The following are the list of contribution of this study:

1. A new model that describe the influence of the torque about torso in the vertical axis during humanoid robot walking.
2. A new approach of swing arm motion is proposed to influence the torso torque, $\tau_t$ during walking.

## 1.8 Thesis Outline

The outline of the rest of the thesis is as follows. In CHAPTER 2, the problem statement of torso torque, $\tau_t$ at the vertical axis is discussed after focusing a review on the humanoid robot walking and the role of arm swing motion.

In CHAPTER 3, methodology to generate the trajectory of the swing arm motion using the cubic polynomial method is discussed in order to reduce the torso torque, $\tau_t$ during humanoid robot walking.

In CHAPTER 4, it will discussed about the simulations and experiment that conducted using NAO humanoid robot version 3.3 (NAO V3.3) in the Webot$^{TM}$ Robotic Simulator for simulation and NAO humanoid robot version 4 (NAO V4) for experiment. . The behaviour of the swing arm motion was implemented by setting fifteen (15) different swaying arm angle range, $R_{sa}$. The simulations and experiments are carried out by conducting the arm swaying angle ranges from $0^{\circ}$ reduced until $56^{\circ}$. They were aimed to reduce torso torque, $\tau_t$ at the vertical axis.