International Journal of Current Engineering and Technology
ISSN 2277 - 4106

Available at http://inpressco.com/category/ijcet

Research Article

Modeling improvement of a Humanoid robot Archie

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Accepted 20 July 2013, Available online 1August 2013 **Vol.3, No3 (August 2013)**

Abstract

This paper is focused on modeling improvement and ZMP (Zero Moment Point) trajectory generation of the Archie humanoid robot. It seems more difficult to analyze the dynamic character of walking robot because of the complexity of mathematical description. So most humanoid robots are based on the model of control, and this method needs to model the robot itself and the surrounding environment. In this paper, is used SimMechanics of MATLAB toolbox to build the computer model of the humanoid robot and perform overall robot movement simulation.

Keywords: *Kinematics, dynamics, humanoid, archie, simulink, SimMechanics.*

Introduction

SimMechanics has a number of blocks of physical components, such as bodies, joints, constraints, coordinate systems, actuators, sensors and so on. SimMechanics provides a variety of simulation and analysis modes for mechanical systems: Forward Dynamic Analysis-Solves the response to a given excitation of the mechanical system; Reverse Dynamic Analysis-Solves the required force and torque according to the results of given movement of the mechanical system; Kinematic analysis-Solves the system's displacement, velocity and acceleration under constraint conditions, and check the consistency; Linear Analysis-Obtains the linear model of the system in the designation of small perturbation or initial state to analyze the system's response performance; Equilibrium point analysis-Determine the steady-state equilibrium point for system analysis and linear.

SimMechanics sets its fixed coordinates in the geometric center of the robot's main body and regards it as the reference coordinate system. Some institutions use indirect coordinate method, that is, according to the coordinates of reference point to describe the location of other joints indirectly. The leg and foot's structure of the robot is composed of six components: leg bottom, thigh shot, calf rod, servo motor connecting rod, big calf connecting rod, foot rod. One of the ends of the lower leg and one of the ends of foot rod are welded together. The following part mainly takes the modeling of leg as an example to describe the modeling process.

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Gait Analysis

Gait analysis is the study of animal locomotion, including locomotion of humans. Describing human gait requires some specific terms, which are defined in this section. The gait cycle begins when one foot contacts the ground and ends when that foot contacts the ground again. Thus, each cycle begins at initial contact with a stance phase and proceeds through a swing phase until the cycle ends with the limb's next initial contact. Hence, the human walking step is composed of two different phases:

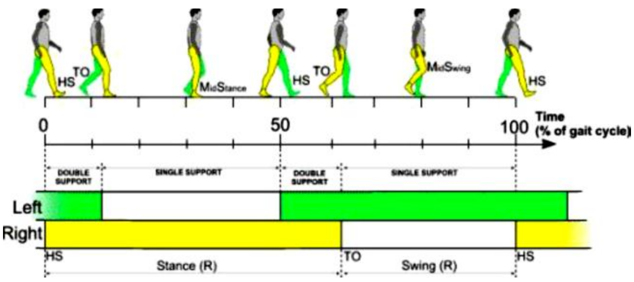

Fig. 1 Human gait cycle

The first phase is the swing phase or single support phase. This term is used for situations where the body has only one leg on contact surface with the ground. The second phase is called the double support phase; which is used for situations where the body has two isolated contacts surfaces with the ground. In human gait, this situation occurs when the person is supported by both feet. The gait phases of normal dynamic walk consists of eight steps but only four of them are different as the right and left leg execute the same motion mirrored in the median plane delayed by a half gait cycle.

Kinematics

Humanoid locomotion requires an accurate forward and an inverse kinematic model in order to specify desired joint angles which are related to the base and effectors trajectories. In addition, controller design and development justifies employing precise inverse kinematics and dynamic models to satisfy stability and agility requirements in humanoid robots such as Archie, Fig. 2.

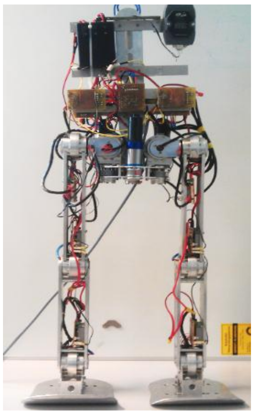

Fig. 2.Archie Humanoid robot-TU-Wien-IHRT 2012

Archie has 30 degrees of freedom (DOF), including 7 DOF in each leg, 3 DOF for each hip joint, 6 DOF on each arm including, 2 DOF for neck and head joints, 2 DOF for Torso which are introduced as ankle roll, ankle-knee-hip pitch, hip roll, and hip yaw-pitch. Yaw-pitch joints of hips are physically bound and driven with one servo motor.

Kinematics and stability analysis of humanoid walking

In this model the mass of robot is assumed to be lumped at the center of mass of the robot, and the legs of the robot are assumed as masses. The following discussion is based on the research performed by Kajita.

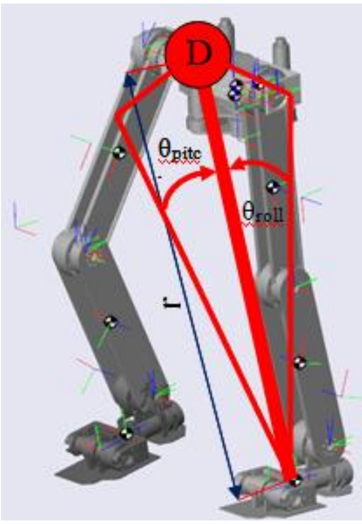

Fig. 3 Inverted pendulum

The position of the mass point D is specified by a set of state variables, (θ_{roll}, θ_{pitch}, r) related to the Cartesian coordinates by:

$$\left.\begin{aligned} x &= r\cdot\sin(\theta_{pitch}) \\ y &= -r\cdot\sin(\theta_{roll}) \\ z &= r\cdot\sqrt{1-\left(\sin(\theta_{pitch})\right)^2+\left(\sin(\theta_{roll})\right)^2} \end{aligned}\right\} \quad \text{......................(1)}$$

If τ_{roll}, τ_{pitch} and f are the actuator torque and force associated with these state variables, then the equation of motion is given by:

$$m\cdot\begin{bmatrix}\ddot{x}\\ \ddot{y}\\ \ddot{z}\end{bmatrix} = (J^T)^{-1}\cdot\begin{bmatrix}\tau_{roll}\\ \tau_{pitch}\\ f\end{bmatrix} + \begin{bmatrix}0\\ 0\\ -mg\end{bmatrix} \quad \text{............................... (2)}$$

In the above equation, the Jacobian is given by:

$$\left.\begin{aligned} J &= \frac{\partial p}{\partial q} \\ J &= \begin{bmatrix} 0 & r\cdot\cos(\theta_{pitch}) & \sin(\theta_{pitch}) \\ -r\cdot\cos(\theta_{roll}) & 0 & -\sin(\theta_{roll}) \\ A1 & A2 & D \end{bmatrix} \\ A_1 &= \frac{-r\cdot\cos(\theta_{roll})\cdot\sin(\theta_{roll})}{D} \\ A_2 &= \frac{-r\cdot\cos(\theta_{pitch})\cdot\sin(\theta_{pitch})}{D} \end{aligned}\right\} \text{.. (3)}$$

Then for the dynamics of the pendulum, the following equation can be derived:

$$\left.\begin{aligned} m\cdot(-z\cdot\ddot{y}+y\cdot\ddot{z}) &= \tau_{roll}\cdot\frac{D}{\cos(\theta_{roll})} - mg\cdot y \\ m\cdot(-z\cdot\ddot{x}+x\cdot\ddot{z}) &= \tau_{pitch}\cdot\frac{D}{\cos(\theta_{pitch})} - mg\cdot x \end{aligned}\right\} \text{.......... (4)}$$

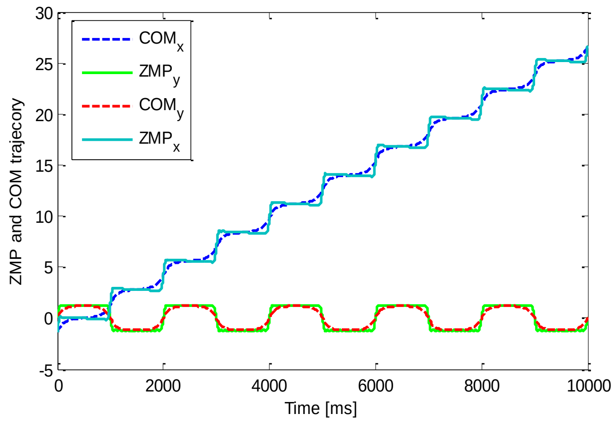

Fig. 4 ZMP and COM trajectory in xy - direction

Robot Simulations

The simulator which is used as robot is developed in the SimMechanics Toolbox of Matlab/Simulink. The simulator is made in such a way in order to develop the motions and predict the real results prior to their application to the real robot.

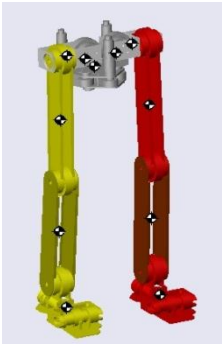

Fig. 5 Simulation of Archie's lower body

The model shown in 3D was build using the already designed model for double foot. For this matter it was necessary to allow motion and calculate the forces in the third dimension. Furthermore, the Archie structure is composed as a combination of 2 legs, add the physics of the main body, and implement the hip abduction joints between the main body and the legs. The block subsystem (see Fig. 6 gray color) contains the whole model of the Archie. Firstly was modeled the connection between the main body and the environment and the connection between main body and the legs (see Fig. 6).

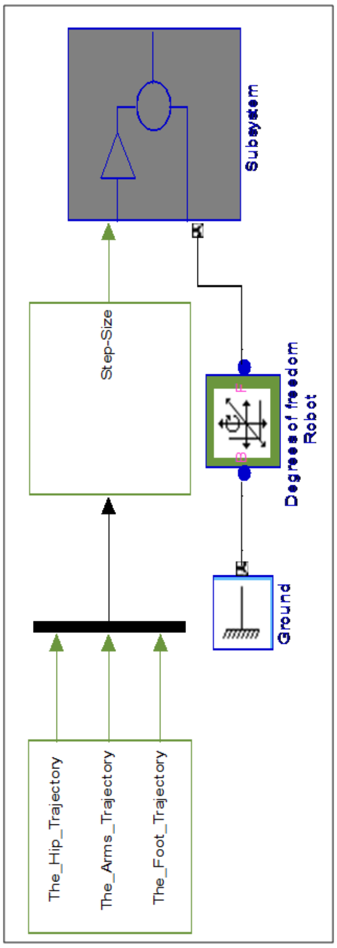

Fig. 6.Model Scheme solution for Archie with SimMechanics in 3D

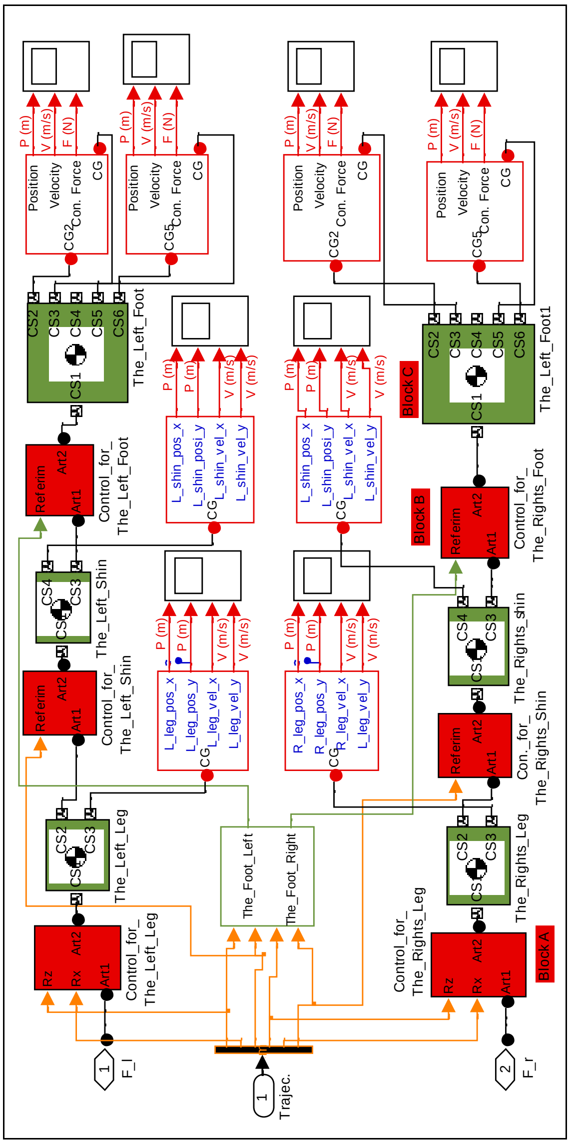

Fig. 7 Modeling of the lower body

Modeling of the floor

The view of case C is shown with double click in block Fig. 7 (red color and block The_Floor_Level_1_Left). The problem with the SimMechanics toolbox was the lack of

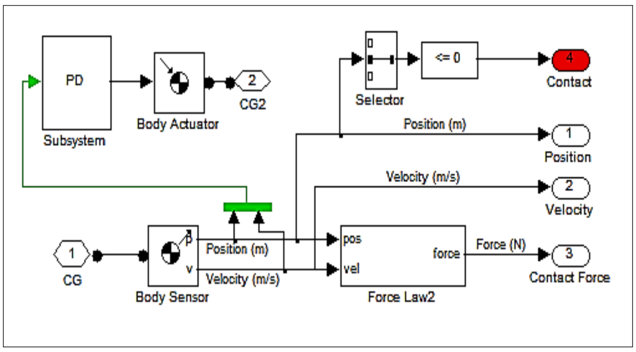

Fig. 8 Ground Contact

object collision, which is crucial for the simulation, as the normal and friction forces between the floor and the robot are key for gait. To solve this problem, the floor was modeled as a PD controller. This controller exerted normal forces on a few selected points of the robot sole, only when these points were on or below the floor.

The error input of the PD controller shown in Fig. 8 was the deviation of the points from the floor level. High proportional and derivative gains were used to minimize the sinking of the feet on the floor. The floor also exerted viscous friction forces, when the foot was in contact with the floor.

Fig. 9 and Fig. 10 (*xy* – direction) show the three continually step positions of Archie's left leg. Fig. 11 and Fig. 12 (*xy* – direction) shows the three continually step positions of Archie's right leg. During the time when the left leg is on ground, the right leg is on air (up).

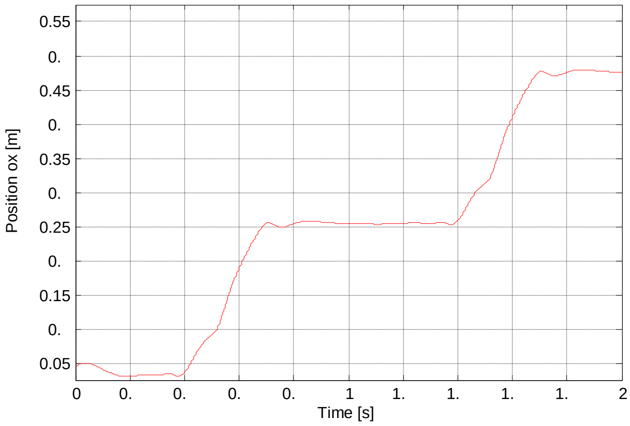

Fig. 9a Position (x) of the left foot

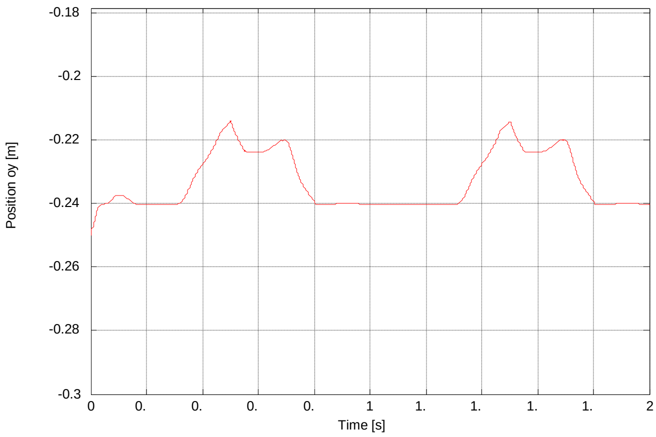

Fig. 9b Position (y) of the left foot

The simulation of this entire system can take a considerable amount of processing time, depending on the number of degrees of freedom, CPU power, etc. Here's a tip about the animation, where we can speed up a little the animation (not the simulation), by accessing the menu Simulation, Control Animation Speed and reducing the Delay per frame and tweaking the Visualization sample time. The visualization of the model was done automatically by SimMechanics in Matlab, another great advantage of this Toolbox.

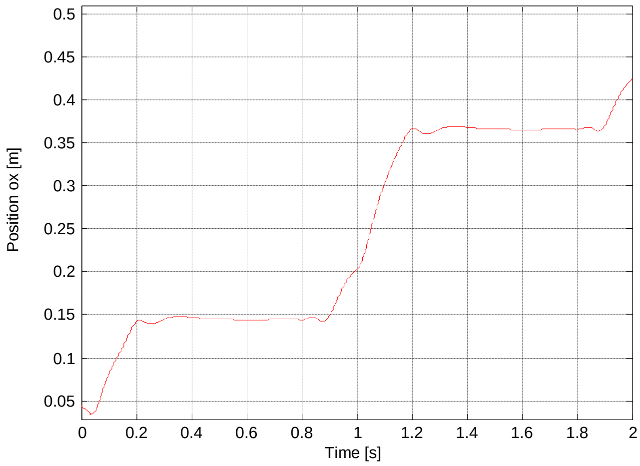

Fig. 10a Position (x) of the right foot

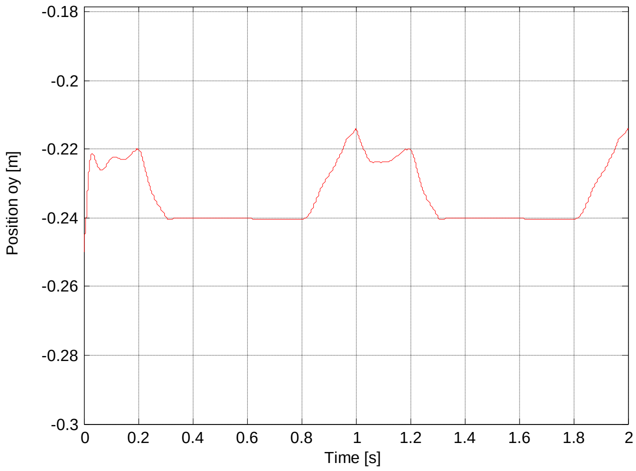

Fig. 10b Position (y) of the right foot

This simulation approach shows that without PID controller huge errors may occur (see Fig. 11). Errors of the contact force will be reduced by using PID controllers, (see Fig. 12).

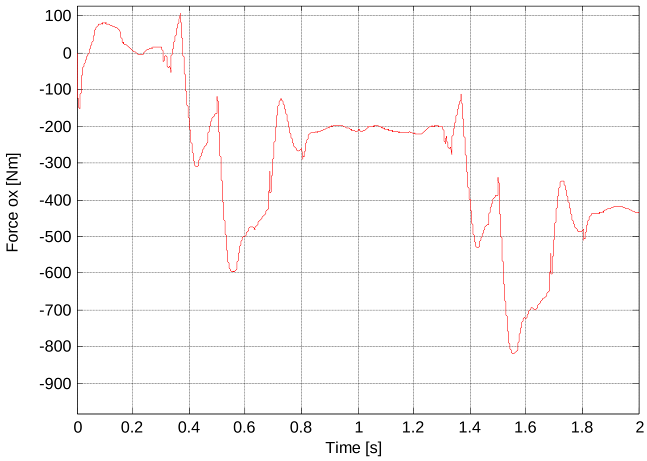

Fig. 11a Force of the left foot x- direction without PD

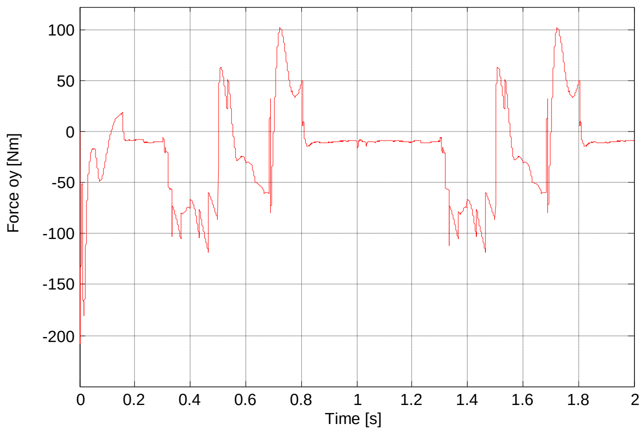

Fig. 11b Force of the left foot y-direction without PD

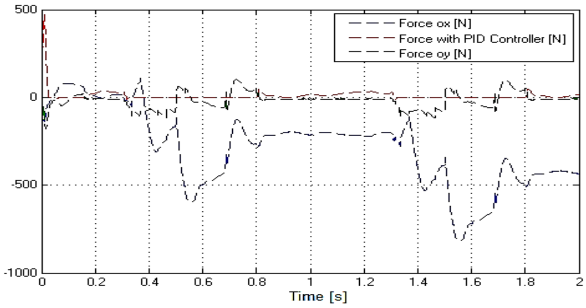

Fig. 12 Force of the left foot with PID controller

Fig. 13.Modeling of the Archie Robot in SimMechanics

In Fig. 13 for the modeled Humanoid Robot, are shown the observations from Simulink after the stabilization of the robot arm.

Conclusions

In this paper is presented the modeling of a humanoid robot. We considered as an important task for the humanoid robot is walking and its stability during walking. Our approach can be applied to a wide range of step lengths. The performance evaluation is done out by carrying out simulation. Thus, based on the simulation results, we conclude:

- Dynamic model of humanoid robot Archie contains several mathematical operations.
- To avoid high math a SimMchanics Toolbox is used to design a virtual model of the Archie robot.
- One of the main benefits of using a simulator is the possibility of monitoring of the trajectories which are caused by the movements of the robot.
- Appling arm for robot stability is necessary.
- In future work for a better performances of Archie robot, it is useful the application of FNC.

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