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Design and Simulation of a Walking Biped Robot using MATLAB/Simscape/Multibody

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ABSTRACT
This research describes the modeling and control of a humanoid robot using MATLAB/Simscape/Multibody. The focus is to obtain human-like walk, so the robot was designed to resemble human proportions and joints were developed to resemble the hip, knee and ankle joint of humans, and thereby enabling walking. The designed humanoid robot, called “Little”, measures14.94 cm tall and with 31 actuated degrees of freedom. Majority of the humanoids are design with straight links and with the zero position at the torso. The zero position at the torso makes the torso to be at a static position while the legs will be swinging. This research uses MATLAB/Simscape/Multibody as an open-source platform for exploration of humanoid and to support future development on manipulation and walking. The robotic humanoid is designed using MATLAB/Simscape/Multibody with all the joint angles configured to imitate the human joint angles and contact forces are placed on the feet of the humanoid to transfer the zero positions to the feet of the humanoid to enable the humanoid walk like a human. Trajectories are used to drive the humanoid and to obtain stable walking. The simulated results obtain from the MATLAB/Simscape/Multibody humanoid robot design shows that MATLAB/Simscape/Multibody can also be used as a platform for the design and simulation of robotic humanoid.

Keywords: Control, Biped Humanoid, Contact Force, Trajectory, PID and Matlab/Simulink/Multibody

I. INTRODUCTION

The development of humanoid in human form has become paramount, since humanoid movement and behavior are meant to be similar to humans. This will make it easier for people to interact with humanoid. For humanoid to behave like human, it needs some level of artificial intelligence (AI) embedded in its mechanical structure. This AI can first be done using humanoid simulator to create a human with the capability of thinking and acting. This acquired intelligence can then be transferred to a real humanoid robot. The use of simulator software for humanoid makes it easy to perform walking phases and other optimization processes and learning phases. It is also not reasonable to test the algorithm directly on the real humanoid robot since learning needs lots of iterations and humanoids always are very expensive and hard to troubleshoot in the case of falling or breaking.

Paper Overview

Michel (2012) [10] generating human-like reaching movements using neurobiological model, to minimized motor-neurons and those dynamic and static efforts are processed separately. Mario (2008) [9] worked on stable locomotion of humanoid robots based on mass concentrated model by using inverted pendulum model and the cart-table model and center of gravity (COG). Jens (2007) [5] modeled the walking of humanoid robot using trajectories that are simulated and human-like walk model was obtained using two controllers. Ketiegrace (2012) [7] develop a model a framework for a modular robotic leg by investigating the kinematic and dynamic model for leg. Bouwmans (2012) [2] used the ground contact forces estimations to determine the forces of the fact of the robot and these estimations are then used to calculate the required gravity compensation torques. Haitao *et al.* (2018) [4] mimic the ZMP trajectory from human walking data, based on the concept of divergent component of motion (DCM) used in Robo Cup 2018 robot WALKER+. Patrick (2002) [12] developed a natural dynamic motion for small humanoid robots by using the frontal swing of the gait or bipedal walking algorithms by using simple inverted pendulum model. Shuuji *et al.* (2010) [13] used HRP-4C humanoid robot with 42 DOF, by the use of posture/foot-force control they were able to design a tracking controller for walking stabilization using simple linear pendulum with ZMP delay. Jung-Shik *et al.* (2008) [6] used fuzzy algorithm to find the proper angle of the joint ISHURO-II 24DOFs humanoid robot to generate the proper reaction under various ground situations. Vinicius et al (2015) [14] used 3D computational model and numerical simulation of multibody systems using CAD-CAE for humanoid gait simulation. Pandu *et al.* (2011) [11] used 7DOF two-legged robot to move up and down a slope surface by using static balance (instead of semi-inverse method) to check dynamic balance which they calculated using ZMP. Lagrange-Euler formulation was also used to determine the joint torques for sloping surface. Wen-Loong *et al.* (2016) [15] used DURUS platform to simulate a 23 DOF humanoid robot in stable running speed by solving the nonlinear program. Maksymilian *et al.* (2019) [8] present a concept using dedicated simplified dynamic model of robot (extended cart-table model) to generate motion pattern for humanoid robot gait using preview control method. Alessio *et al.* (2018) [1] presents the use of model predictive control MPC scheme capable of generating 3D gait for NAO humanoid robot. Cristyan *et al.* (2019) [3] proposed the use of RL to learn the configuration of the robot joints (pose) that allow it to stand with stability and using the learned pose to avoid falling and keeping straight path.

From the review it shows that the robotic humanoids are designed and simulated in other simulators from MATLAB. Those simulated are imported into MATLAB. But the current research shows how humanoid robots can be designed in MATLAB and are simulated in MATLAB using Simscape/Multibody.

2. DESIGN OF LITTLE HUMANOID DESIGN

The robotic humanoid is designed to enable it, to make human-like movements. To simulate this, a trajectory has to be chosen. In other to let the robotic humanoid move like a human, the robotic humanoid should have the same DOFs like human. This robotic humanoid has 23-DOFs as shown in Table 1. The neck has two DOFs; there are two DOFs at the shoulder, one at the elbow and three at the wrist. The effect of two DOFs at the wrist is negligible and can be adopted by the other two joints. Therefore, the wrist joint will only have one DOF which gives full control over the orientation of the gripper. The waist is assigned one DOF, two for the hips, one for the knee and one for the ankle, therefore the design robotic humanoid simulation in this research has 23-DOFs. Figure 1 shows the proposed lengths of each link of the humanoid with all measurement in mm. The degrees of freedom of each joint are shown in Table 1. Figure 1 and Table 1 is used to design the robotic humanoid on MATLAB/Simscape/Multibody [16]. The humanoid was simulated using trajectories for the limb and sinusoidal wave for the arm to drive the motor connected to the joint of the humanoid.

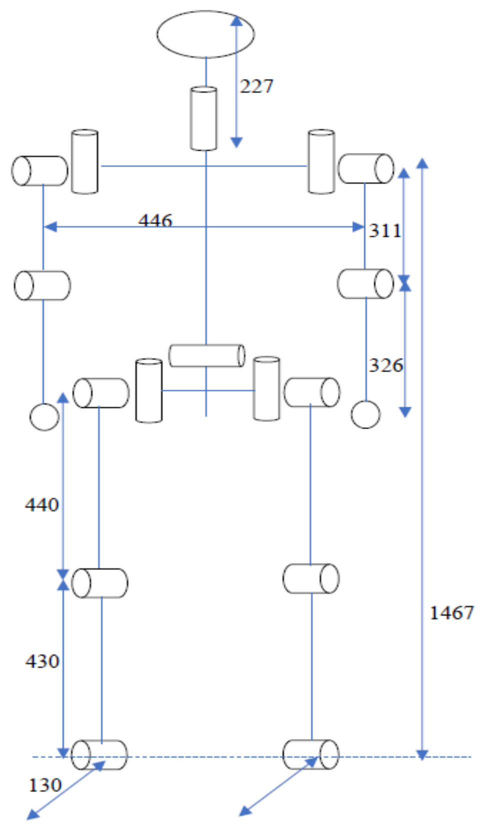


Figure 1: Measurements of the Humanoid Robot

Table 1: Degrees of Freedom of Humanoid Robot

Chain	Joint	Degree of Freedom	Angle of Rotation
Head	Neck	$2DOF \times 1 = 2DOF$	$\theta 1 = -60$ to $+60$ $\theta 2 = -30$ to $+30$
Arm	Shoulder	$2DOF \times 2 = 4DOF$	$\theta 1 = -45$ to $+120$ $\theta 2 = +10$ to $+90$
	Elbow	$1DOF \times 2 = 2DOF$	$\theta 3 = 0$ to $+135$
Hand	Wrist	$2DOF \times 2 = 4DOF$	$\theta 4 = -45$ to $+45$ $\theta 5 = -10$ to $+45$
	Finger	$1DOF \times 2 = 2DOF$	$\theta 6 = 0$ to $+45$ Linear motion
Trunk		$1DOF \times 1 = 1DOF$	$\theta 1 = +10$ to $+60$
Leg	Hip	$2DOF \times 2 = 4DOF$	$\theta 1 = -15$ to $+90$ $\theta 2 = +10$ to $+90$
	Knee	$1DOF \times 2 = 2DOF$	$\theta 3 = 0$ to $+135$
	Ankle	$1DOF \times 2 = 2DOF$	$\theta 4 = -30$ to $+20$ Linear motion
Total		= 23DOF	

3. MATERIALS AND METHODS

Figure 2 shows the humanoid designs using Simscape/Multibody and MATLAB script [16]. Figures 3show the designed model with zero point at the feet of the robot [17]. Figure 4 shows the complete humanoid robot design with figure 2 as the subsystem called robot, while figure 5ashows the motion trajectory used as input force to the joint of the robot to make it walk and Figure 5b shows the motion trajectory for the swing of the humanoid arms. MATLAB PIDs were used to tune the humanoid walking processes for the humanoid to have a stable walking movement.

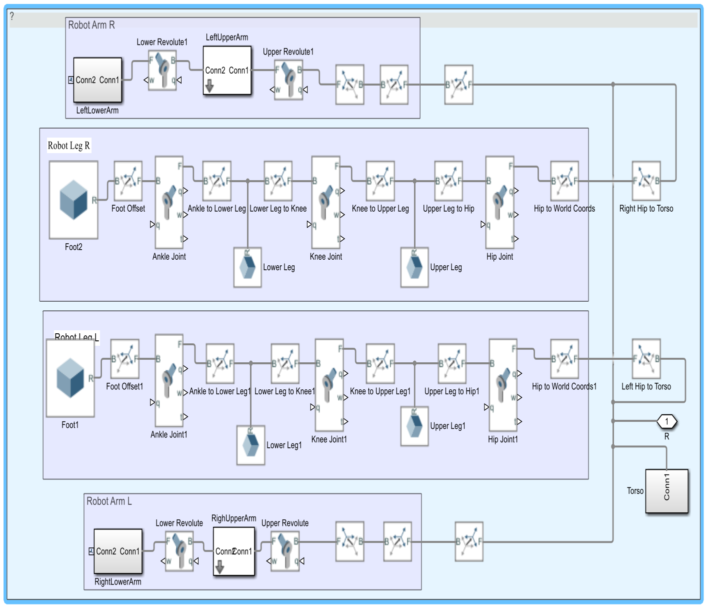


Figure 2: Simulink Design of the Walking Robot using Simscape/Multibody

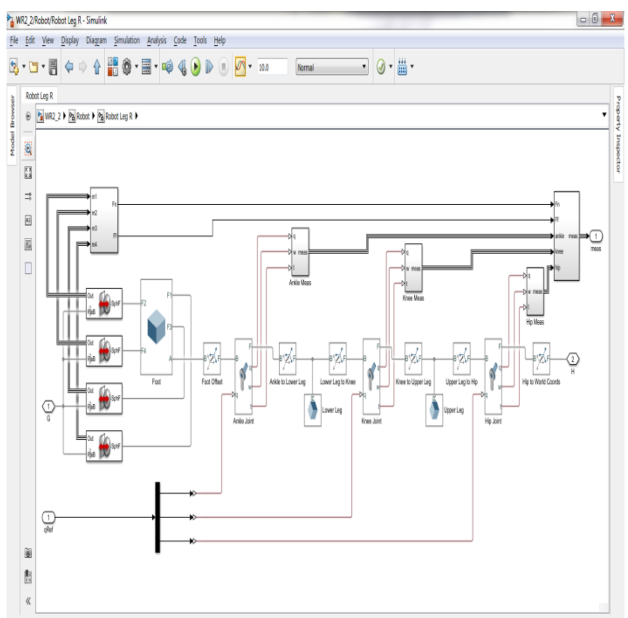


Figure 3: The Process of attaching the Contact Force at the Feet of the Walking Humanoid Robot

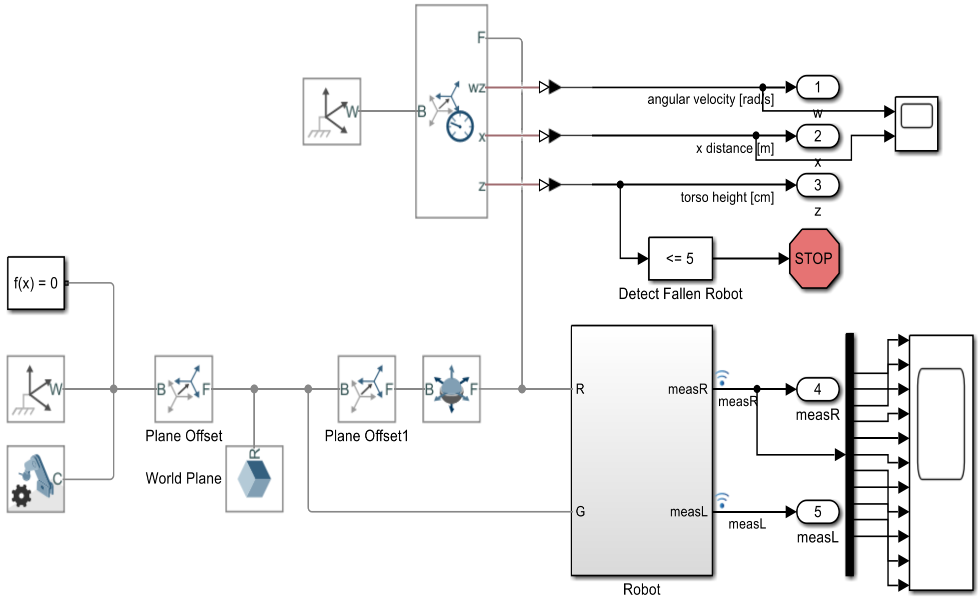
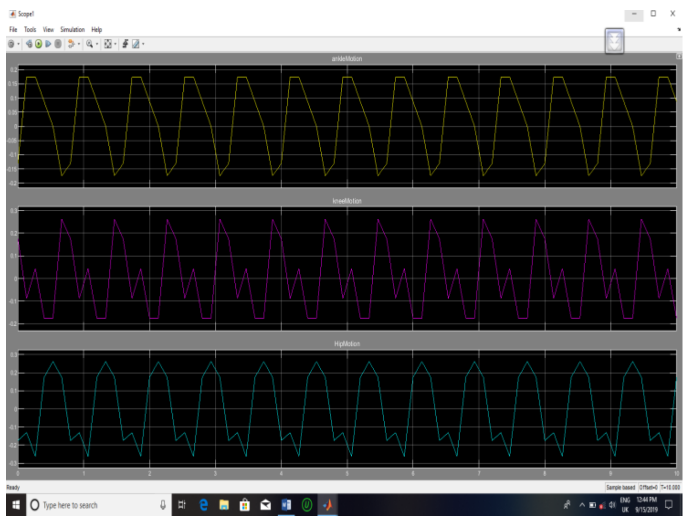
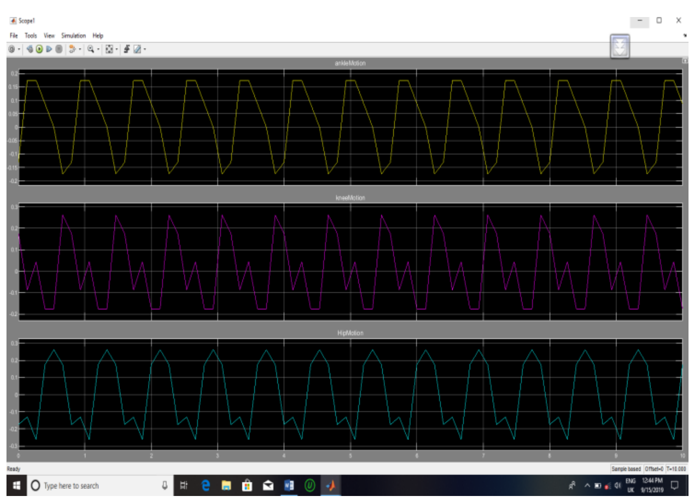


Figure 4: Complete design of the humanoid robot "Little"



(a): The Motiontrajectories for Limb[18]



(b): The Motion trajectories for Arm

Figure 5: The Motion trajectories

4. RESULTS

Figures 6 to 10 show the walking humanoid designed in Simulink with the zero position at the feet and the waveform generated while the humanoid is walking. Figure 6 represents the design of a humanoid robot on MATLAB using Simscape/Multibody toolbox and coordinated trajectory to drive the shoulder, elbow, hips, knee and ankle of the humanoid robot. Figure 6 shows the right leg making the first move and the left leg providing support, figure 7 shows when both legs are the same stance, Figure 8 shows the left leg making the first move and the right leg providing support, figure 9 shows when both legs are the same stance. Figure 1o shows the trajectory movement of the humanoid. Figure 11 shows the generated wave forms of the shoulder, elbow, hip, knee and ankle joints.

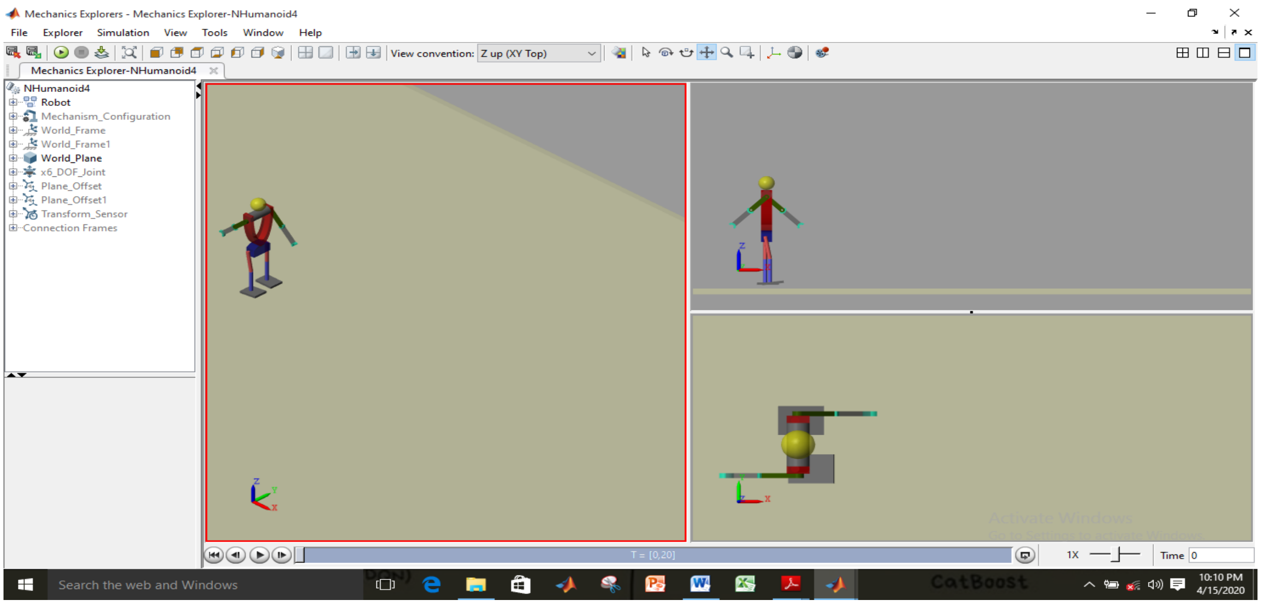


Figure 6: the humanoid taking the first step using the right leg

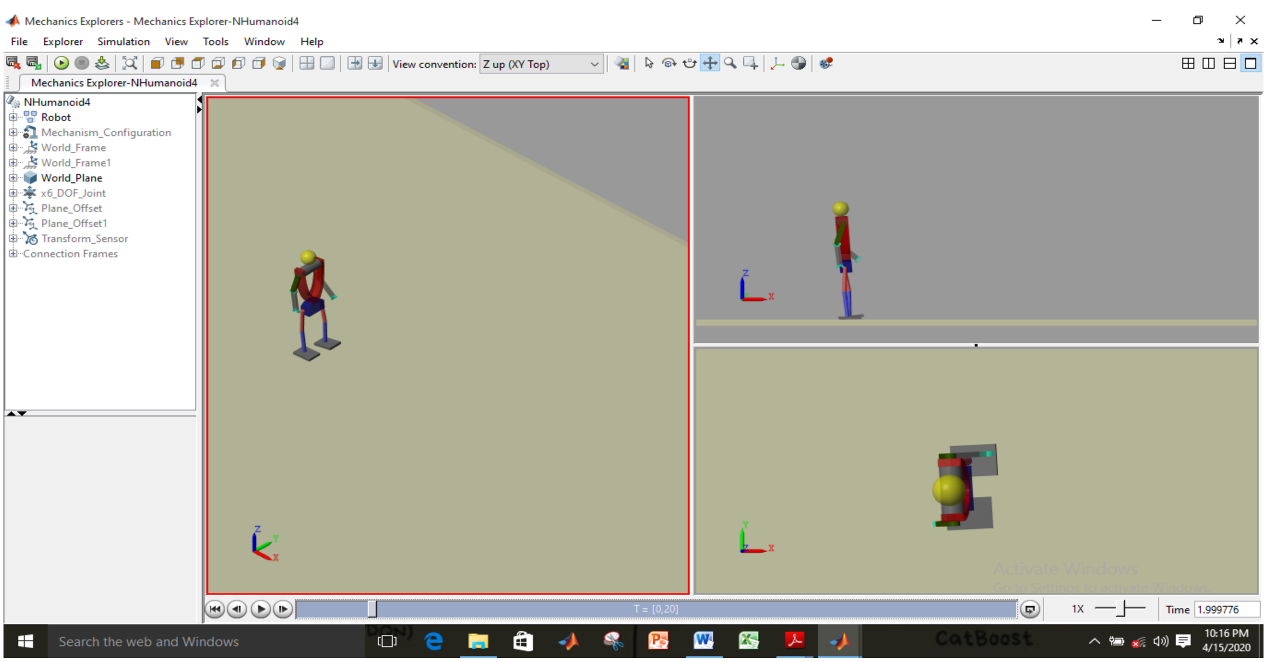


Figure 7: the humanoid with both legs together

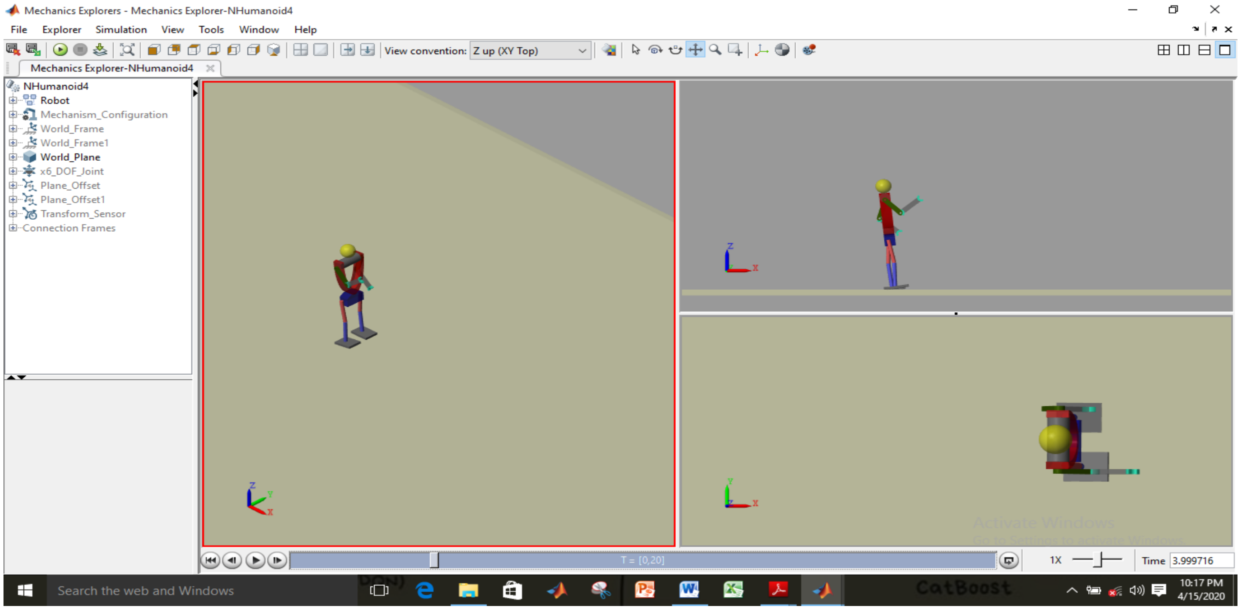


Figure 8: the humanoid taking the first step using the left leg

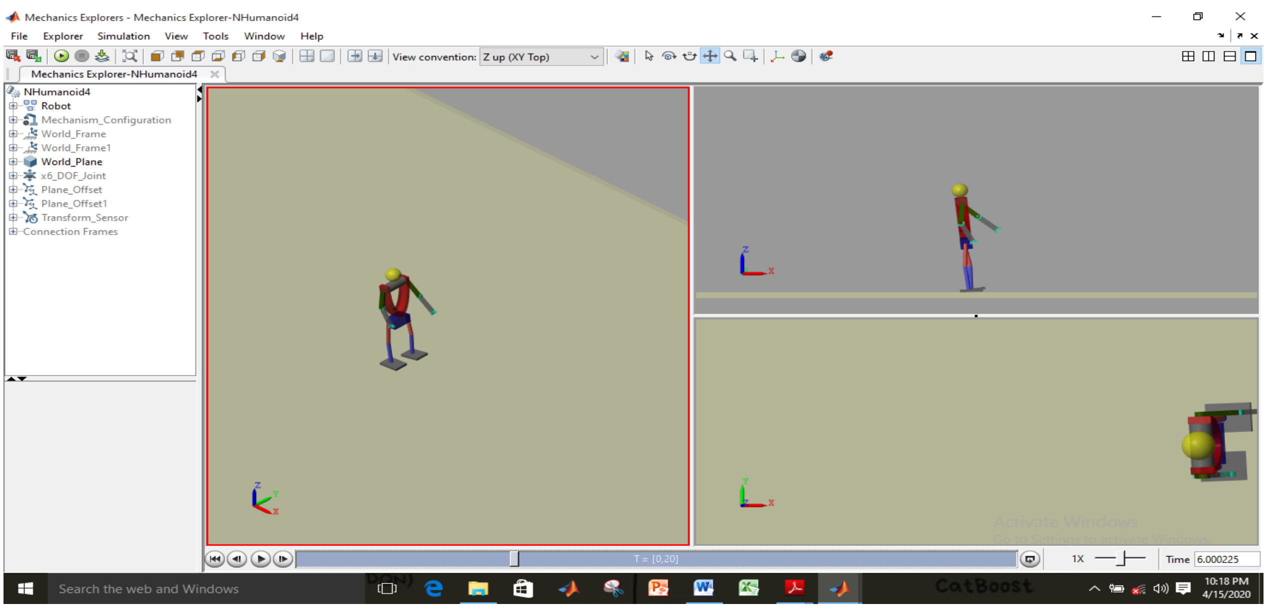


Figure 9: the humanoid with both legs together

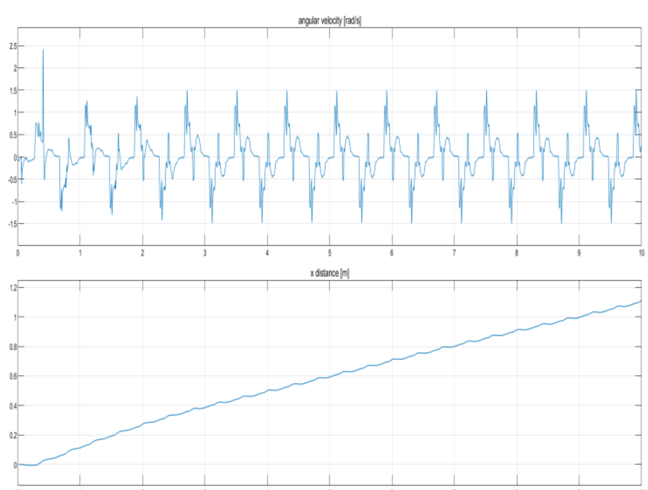


Figure 10: Movement of the humanoid

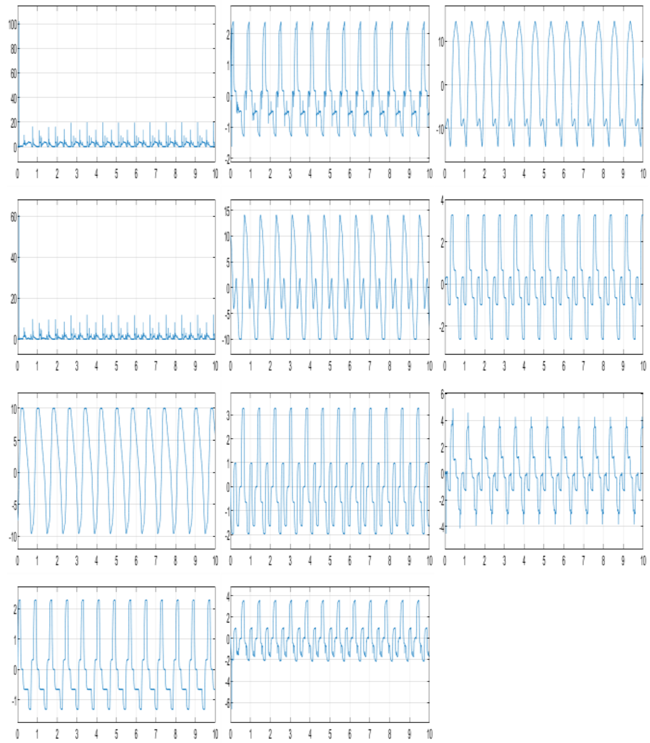


Figure 11: waveforms the humanoid joints

5. CONCLUSION

There has been a significant research interest in the area of humanoid motion planning, control and applications. Majority of the similar humanoids are built with a straight link and rigid torso which does not leverage the shape of the robot in stabilization. The major contribution of this research is the use of MATLAB/Simscape/Multibody as open-sourced humanoid platform for exploration and to support future development on manipulation and walking. Trajectories were used to drive the humanoid and the graphs obtained and the display of the simulations.

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Conflict of Interest

The authors declare that there are no conflicts of interests.

Peer-review

External peer-review was done through double-blind method.

Data and materials availability

All data associated with this study are present in the paper.

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