Dynamics and control of a 6-dof biped robot on Matlab/SimMechanics

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Abstract. This paper plans to demonstrate a biped robot on Matlab/SimMechanics, which tackles dynamics problems with time efficient numerical models. Biped robot model has 7-links and all the joints connecting links are revolute in nature. Two identical legs have hip joints between upper leg and torso, knee joints between the lower leg and upper leg parts, ankle joint between the lower leg and foot. A rigid body forms the torso. Modelling of ground contact forces is done using inbuilt Matlab contact library. A PID controller is used in order to simulate the dynamics of the system. Results obtained from the dynamic simulation are presented.

Keywords: Biped Robot · SimMechanics · Dynamic Modelling · Control

1 Introduction

In the most recent couple of decades objective of copying human movement through strolling biped robots has gotten huge consideration among scientists. Biped robots can move in obscure landscapes, climb staircases which wheeled robots are unfit to perform. They can be employed in hazardous works such as rescue operations [4], disaster situation[1] or rehabilitation of disabled people for example, dynamically controlled prosthetics [8]. Made humanoid and biped, to rescue injured victims into safety they can prevent human life from being put to danger. Due to the complexity of human walking, which increases with the increase of no of links and degree of freedom (DOF), research progress in this area has been limited.

Few researchers contributed to modelling a biped robot in Matlab/SimMechanics environment. A SimMechanics model represents physical model through blocks and converts it into time efficient mathematical model [3] . Mester-G [6] applied the Euler-Lagrange method for dynamic modelling of a 20 D.O.F(Degree of freedom) underactuated biped robot and verified his results by Robotics toolbox of Matlab/SimMechanics. Marlon Fernando Velsquez-Lobo et al [11] presented

a methodology for modelling of a 5 link biped robot, which is connected through revolute joints, in Matlab-SimMechanics. They have modelled ground contact as well. Mathworks Student development team [10] developed a SimScape model of walking robot implementing genetic algorithm to find optimal trajectory for walking.

The main objective of this project is to make a model of a biped robot and simulate it in MATLAB/Simulink in order to improve its dynamic stability. The model has seven links and six revolute joints. Finally, Proportional-integral-derivative (PID) control on ankle joint is applied.

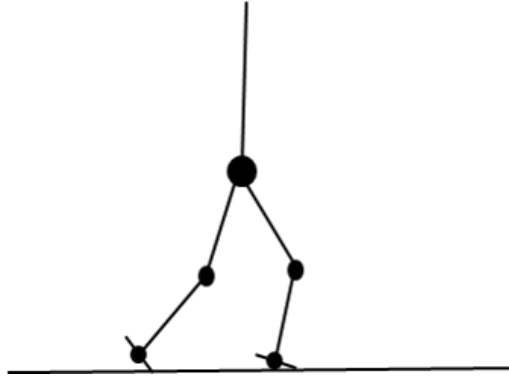## 2   Modelling of System in Matlab/SimMechanics

Fig. 1. Kinematic structure of the biped robot

Fig. 1 shows kinematic structure of 6 D.O.F biped robot to be modelled. Different approaches for biped locomotion control existing in the literature are Zero moment point (ZMP) detection, [9] Passive walking method [5] and Walking primitive [2]. Walking primitive approach is followed for our biped locomotion in Matlab/SimMechanics. In this approach positions for all joints are set in prior and required torque for motion is calculated at each step.Biped robot is modelled using SimMechanics which accepts its system as a combination of block diagrams and performs dynamic simulation using the standard Newtonian dynamics of forces and torques.The model will have foot, lower leg, and upper leg and torso/trunk blocks. The foot is connected with the lower leg through a rotary joint. Lower and upper legs are connected via knee joint and hip joint connects the upper leg with the torso. Therefore, one leg is having three joints and four links (torso is common to both the legs). Torso, leg, foot are modelled specifying geometric parameters and ground contact is modelled using Sphere to plane force block of SimMechanics [7] from Matlab contact library.

2.1 Torso modelling

Torso is modelled as a rectangular block connected from right to left hip.Representation of torso in SimMechanics environment is shown in Fig. 2. Dimensions of the torso are represented in Table 1

Table 1. Torso Parameters

Torso Parameter	Value
Length	10 cm
Breadth	8 cm
Width	5 cm
Density	950kg/m^3
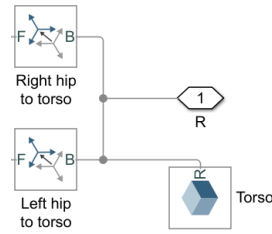
Fig. 2. SimMechanics block diagram for torso

2.2 Leg modelling

Legs are modelled as rigid cylinders. Each leg contains three links named as foot, lower leg and upper leg(Simulink block diagram is shown in Fig. 3). They are connected by revolute joints which are named as ankle joint (between foot and lower leg), knee joint (between the lower leg and upper leg) and hip joint (between upper leg and torso). All joints are actuated by input motions.Required parameters for legs are represented in Table 2.

Table 2. Leg Parameters

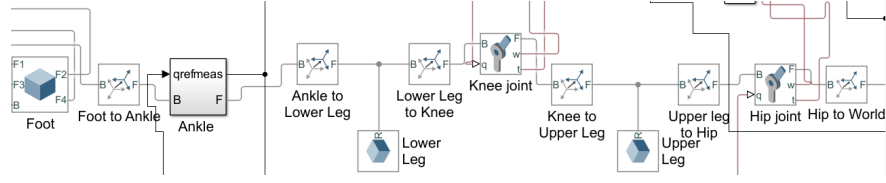| Leg Parameter	Value
Leg radius	.75 cm
Lower leg length	10 cm
Upper leg length	10 cm

Fig. 3. SimMechanics block diagram for leg

2.3   PID control modelling

Proportional-Integral-derivative controls are applied at ankle joints of each leg(block diagram of it is shown in Fig. 4). An initial torque is applied at ankle joint by motor. The difference between the reference and actual angular position of ankle joint is taken as input to the PID controller which actuates necessary torques to that joint.

Parameters of PID controller as found after PID tuning are given as K_p (proportional gain) =0.1, K_i (Integral gain)=0.57,K_d (differential gain)=0.1

Equation for calculating actuation torque at ankle is given in equation 1

$$\tau = K_p(q - q_r) + K_d\frac{d(q - q_r)}{dt} + K_i \int (q - q_r)dt \tag{1}$$

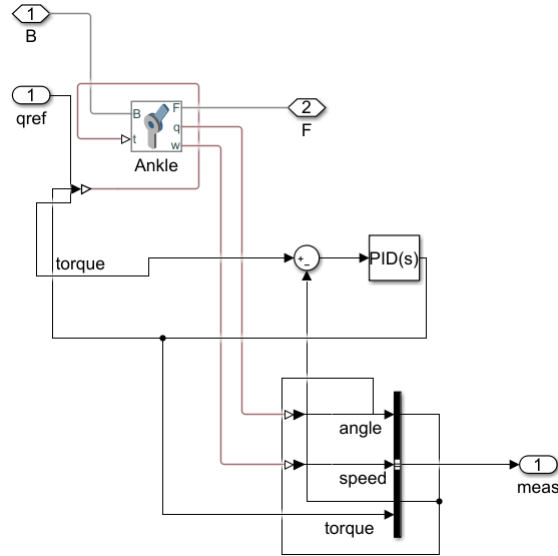Here q is the actual ankle joint angle after application of torque whereas q_r is

Fig. 4. SimMechanics block diagram for PID control at ankle

the reference ankle joint angle

2.4 Ground contact modelling

Contact force between foot and ground is unilateral i.e. only repulsive force exists between them when they come to contact. To model this kind of contact, Sphere to plane force [7] SimMechanics block has been used. This block implements a contact force between a sphere and a plane. Feet are placed at the spherical end and the ground is at the plane end.Block diagram of ground contact in SimMechanics environment is shown in Fig. 5. All parameters of ground contact are represented in Table 3.

Table 3. Ground contact Parameters

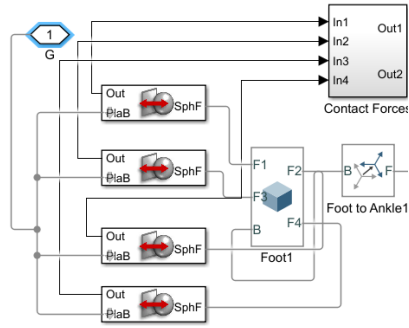| Ground contact parameter	Value
Contact stiffness	2500N-m/deg
Contact damping	100N-m/deg/s
Ground static friction coefficient	0.6
Ground kinematic friction coefficient	0.8
Ground plane width	3m
Ground plane height	0.025m
Ground plane length	25m

Fig. 5. SimMechanics block diagram for Ground contact

3 Simulation and Results

All simulations are based on the ODE 15s solver which is used for solving stiff problems i.e. problems in which two or more solution components vary on drastically different time scales [3]. Performance of PID controller also depends on

the selection of controller gains. Initially, simulation was performed with default gains. Later on, auto-tuning was applied and optimal PID controller gains are noted as K_p(proportional gain) =0.1, K_i(Integral gain)=0.57 and K_d (differential gain)=0.1. Bipedal motion achieved with the these control parameters show that robot walking is continuous, smooth and dynamically stable i.e. it does not fall off during locomotion.

Fig. 6 shows that required torque at ankle joint is maximum when it leaves the ground (changes from support phase to swing phase). Otherwise, torque requirement at the hip joint is greater compared to the other joints.It can be validated from the fact that in a serial chain system revolute joint that connects fixed base and 1st link requires more torque than others as 1st joint needs to move the whole system. Here hip joint is serving the same purpose.Torque profile is similar in right leg and left leg as shown in Fig. 7.

Angular speeds of three joints (ankle, knee and hip) for both the legs are presented in Fig. 8 and Fig. 9 Maximum speed is seen for ankles and knee and hip joints are moving in similar manner. Maximum speed of all the joints are not seen at the same time and maximum torque is seen for hip joint when it moves with maximum hip speed. The 3-D model of the robot during simulation is shown in Fig. 10.
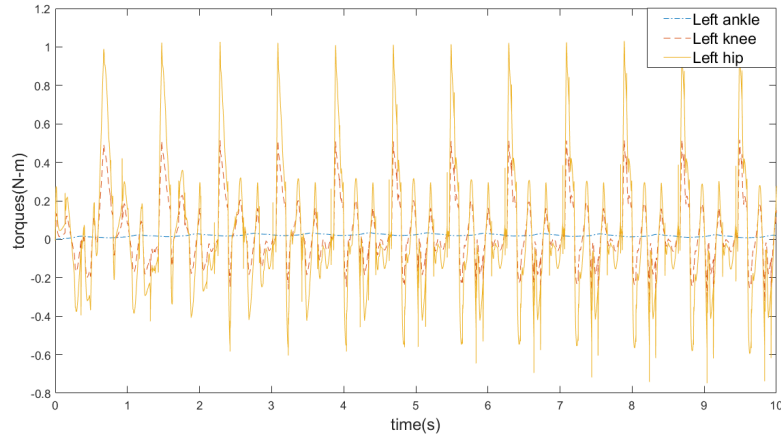

Fig. 6. Plot of torques at joints at left leg

4   Conclusion

This paper presented a way to model 6 DOF biped robot system in Matlab/SimMechanics. Simulation with and without PID tuning parameters makes noticeable difference. With PID-tuned controller, movement of each joint occurs
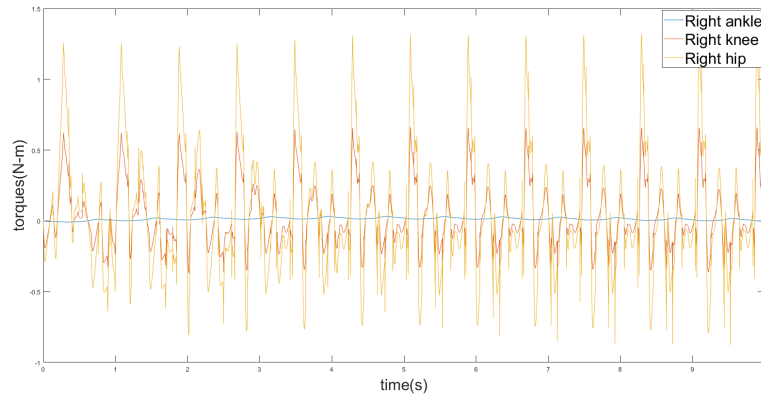
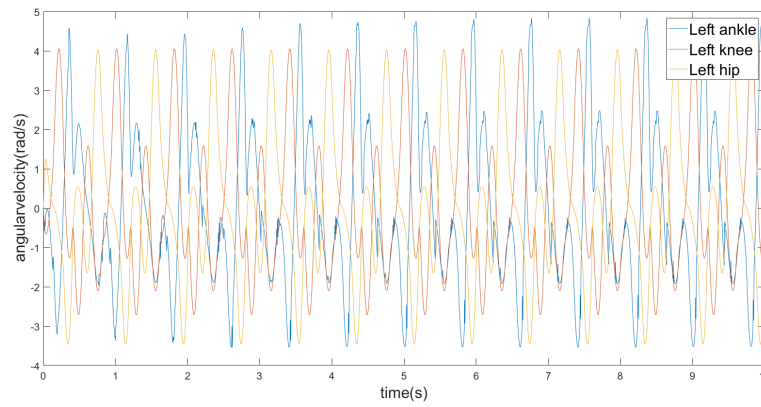**Fig. 7.** Plot of torques at joints at right leg

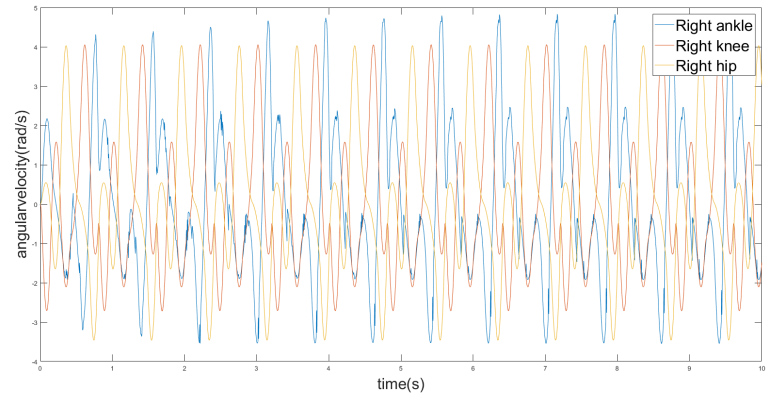**Fig. 8.** Angular velocity at three joints at left leg

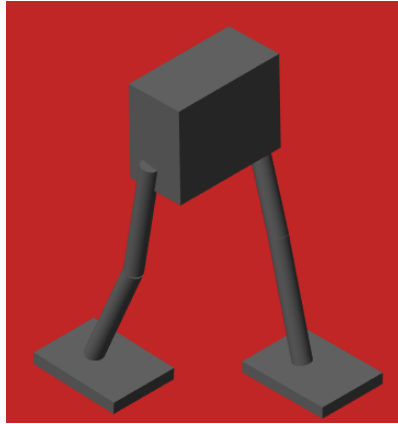**Fig. 9.** Angular velocity at three joints at right leg

Fig. 10. Biped Robot model in SimMechanics environment

in more organized way and more human like movement is obtained. A limitation of this system is that it produces flat feet motion. To overcome this problem toe joints can be implemented at each foot. In turn it will incorporate more complexity to the system. Walking of model can be made more humanoid if contact forces are fed as feedback to movement of the system.

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