

## Development of a Quadruped Robot Model in Simmechanics<sup>TM</sup>

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The presented work allowed the creation of a quadruped robot model (with flexible body, its legs and its hip and knee joints) in the virtual simulation program Simmechanics<sup>TM</sup>. The final objective is to use this simulation model to optimize quadruped robot locomotion. The model developed accepts different gaits by direct introduction of the angular positions of the knee and hip joints. Various parameters of the robot are also easily changed via a configuration file of the model. Feet-ground interaction was also modelled using a theoretic model described in the literature.

*Keywords:* Legged Quadruped Robots, Modelling, MATLAB, SimMechanics.

### 1. Introduction

Increased research in robotics has been remarkable, but the costs and time invested in the development of prototypes are very high which encourages the search for new ways of working that enable the development and testing of machines more quickly, economically and efficiently.

There are many tools on the market that allow to design, simulate and test mechanical systems, such as Adams,<sup>1</sup> Webots,<sup>2</sup> VisSim,<sup>3</sup> Simpack.<sup>4</sup> All these programs allow the analysis and simulation of dynamic systems, with real-time view of the equipment, thus helping to detect problems that may occur and facilitating the design stage of mechanical parts.

The programs for dynamic systems simulation are used in various in-

dustries, with particular interest in robotics due to the possibilities for modelling and simulating different types of systems with varying degrees of complexity. In addition to simplifying the design, these programs also assist in testing the equipments. In some cases it is possible to test the robots in 3-D virtual environment. Although its use does not completely eliminate the need to build a working prototype, it decreases the probability of error due to various tests that can be done before building a real model.

Bearing these ideas in mind, the goal of this paper is to present the development of a quadruped robot model, in SimMechanics<sup>TM</sup>, with the objective of creating a tool for the optimization of quadruped legged robot parameters. The remainder of this paper is organized as follows. Section two briefly presents the SimMechanics<sup>TM</sup> environment and section three the robot model adopted. Sections four and five present the implementation of the robot model in the software, and some simulation results, respectively. Finally, section six outlines the main conclusions of this study.

## 2. SimMechanics Simulation Application

Simmechanics<sup>TM</sup> is a three dimensional modelling tool that allows the simulation of multibody models.<sup>5</sup> Its interface works based on blocks representing bodies (links), joints, motion constraints and forces and torques. The various elements are joined together using lines representing the signals transmitted from one block to another. The blocks required for modelling a robot are of the type *Body*, *Revolute Joint*, *Joint Actuator*, *Body Actuator*, *Ground*, *Machine Environment*, *Body Sensor*, and *Joint Sensor*.<sup>5,6</sup>

Although Simmechanics<sup>TM</sup> simplifies the process of modelling / simulation of the desired system, its implementation can become complex. In the implemented model (Figure 1(a)), the legs are connected to the robot body through joints named "hips". Each leg consists of two parts: (i) the top one ("upper leg") is connected to the robot body by the "hip", and (ii) at the other end to the "lower leg" through a "knee" joint.

## 3. Model of the Quadruped Robot

### 3.1. Kinematics and Trajectory Planning

It is considered a walking system (Figure 1(b)) with  $n = 4$  legs, equally distributed along both sides of the robot body, having each one two rotational joints (*i.e.*,  $j = \{1, 2\} \equiv \{\text{hip, knee}\}$ ).

It was chosen a forward orientation of the joint that connects the upper to the lower part of the leg. The angles of the joints are defined as measured

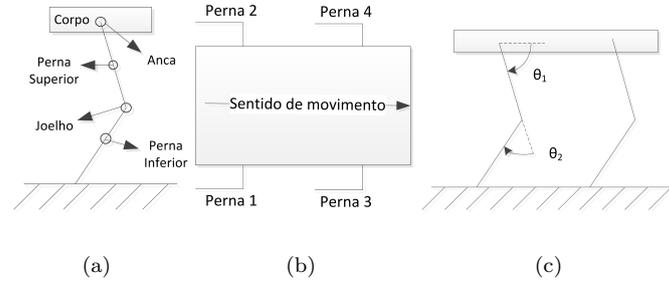


Fig. 1. Scheme of the constitution of the robot leg (a), numbering of the robot legs (b) and disposition of the joints angles.

relative to each other (Figure 1(c)): the angle of the hip is measured from the horizontal body position, and the knee angle is measured relative to an imaginary line extending from the upper leg. This angular relationship is used by Simulink<sup>TM</sup> and is quite common in robotics, because it facilitates the visualization of the position of the members.<sup>7</sup>

In this work is intended to get some flexibility regarding the gait. For that reason, actuators were placed in the knee and hip joints. These actuators receive the angular positions that allow the definition of the robot gait, and therefore variables have been defined to characterize the desired motion of the robot (Table 1). The variables shown in Table 1 are defined as matrices with 2 columns: the first column represents sample time, and in the second column are the desired values for the joints positions.

	Leg 1	Leg 2	Leg 3	Leg 4
Hip angular Position	<i>hip_1</i>	<i>hip_2</i>	<i>hip_3</i>	<i>hip_4</i>
Knee angular position	<i>knee_1</i>	<i>knee_2</i>	<i>knee_3</i>	<i>knee_4</i>

Although this robot allows the introduction of different trajectories on each leg, in this case it was chosen to define the movement of leg 4 equal to the first leg and third leg equal to leg 2.

### 3.2. Robot Dynamic Model

The inverse dynamics is used to calculate the torques/forces needed for the leg to describe a certain movement. For the program to calculate the forces necessary for the intended motion, the inertia matrices of the various body

components have to be defined.

Based on previous studies, it was concluded that to increase the efficiency and stability of locomotion, the robot body should present compliance. Therefore, a compliant robot body model was implemented.

### 3.3. Foot-Ground Contact Model

The model of contact with the ground considers a contact point on the lower end of the leg. When this comes into contact with a given point on the ground, a tri-dimensional force is exerted on the ground, and a force with equal intensity and opposite direction in the robot foot. In the work described are only considered two components of the contact force: normal force (exerted on  $y$  direction, and responsible for ensuring that the robot is always above ground) and tangential force (exerted towards  $x$ , imposes the robot motion).

The two main simulation methods of contact with the ground are rigid or compliant contacts. The method used in this paper calculates the contact forces through an approximate model of the ground based on models obtained by the study of soil mechanics. It was chosen to use a model of contact that uses a spring-damper type system, described by equations (1) and (2).<sup>7</sup> In equation (2) the exponent  $m$  allows the user to more precisely adjust the characteristics of the soil.

$$F_x = -K_x(x - x_0) - B_x\dot{x} \quad (1)$$

$$F_y = -K_y y - B_y(-y)^m \dot{y} \quad (2)$$

## 4. Implementation of the Robot Model

### 4.1. Modelling of the Robot Body

The body of the robot is composed of four identical blocks, interconnected by a spring and damper arranged in parallel to simulate a backbone, making the robot walk softer and cushioning the more abrupt contacts. The body is modelled using four *Body Blocks*, connected by a universal type joint actuated by a "Joint Spring and Damper" block type (Figure 2(a)).

In the body blocks must be introduced its mass, inertia matrix and various CS that will allow to connect the legs to these blocks and also the joints that connect the four blocks constituting the body of the robot. Each block has a mass of 9 kg and a size of 0.3 m by 0.2 m with 0.15 m high.

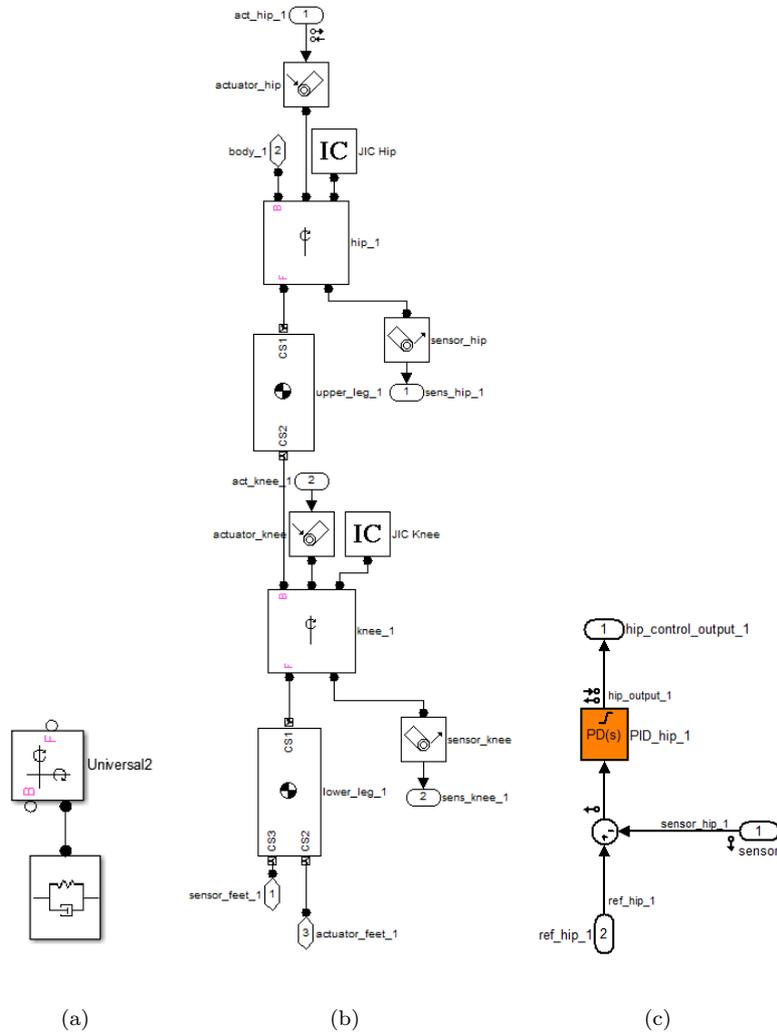


Fig. 2. Spring-damper system of the body (a), model of a robot's leg (b), and PD Controller (c).

The mass of the blocks is calculated based on its volume and the density of the used material (2.8 kg/m<sup>3</sup> for the legs and 1.0 kg/m<sup>3</sup> for the body).

It is necessary to join the different blocks and define the CS, so that the body takes the form previously established. These CS are used as reference

to connect a joint or body actuator / sensor.

In the robot presented are used relative referrals. A "Ground" block is connected in one of the body first block CS using a "6 Degrees Of Freedom" joint type; this assembly enables the robot to move in three-dimensional space. The position of the remaining blocks of the body is defined based on the option "adjoining" of CS. This option "tells" the CS that its position is referenced to the CS which is connected to the adjacent block.

#### 4.2. Modelling of the Robot Legs and its Control System

The two parts that constitute the robot's legs are represented in this model by rigid cylinders. The legs have two rotary joints with one degree of freedom each. The upper joint simulates the hip rotation and the lower one the knee. Figure 2(b) presents the Simmechanics<sup>TM</sup> model used to model the robot's legs.

The block *body\_1* is connected on one side to the CS of the body block 1 and on the other side (Figure 2(b)) to a rotational type joint (*hip\_1*), that models the robot hip. The upper leg segment is depicted in Figure 2(b) with the name "*upper\_leg\_1*". The CS of the upper leg segment, which connects the leg to the body, is defined based on the body CS. Both the CG and the CS2 of the upper leg segment are defined based on CS1. The configuration of the knee rotational joint equals the hip one, being this block identified in Figure 2(b) with the name "*knee\_1*".

The lower leg segment is very similar to the upper one in the way its CG is set. In addition to the CS being used to connect the lower leg segment to the upper one, there must also be defined two CS at its lower end. These CS (CS2 and CS3) will allow the soil model to "read" the position and speed of the foot and also actuate it with the ground reaction forces.

The actuation of the members is carried out directly on the joints through joint actuators. Controllers are connected to these actuators enabling the control of the joints movement. There are also sensors attached to these joints of the legs. These sensors gather the value of the actual position of the joint enabling controllers to calculate the error between the desired position and the actual position and thereby adjust the control signal. The controller chosen to control the joints of the hips and knees of the robot is of the proportional and derivative (PD) type. Its implementation was performed using the PID block, part of the Simulink<sup>TM</sup> tool (Figure 2(c)).

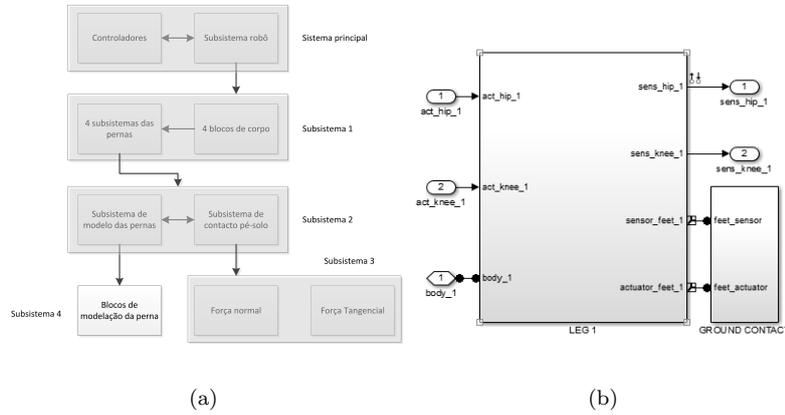


Fig. 3. Organization scheme of the robot model (a) and subsystem 2 (b).

### 5. Final Robot Assembly and Model Tests

The total robot body weight is 36 kg. It was determined that both the robot upper and lower leg segments would have a length of 0.2 m and a radius of 0.02 m, leading to a final weight of 1.4 kg per leg. Thus, the total weight of the robot is 41.6296 kg.

Figure 3(a) presents a schematic organization of the model to facilitate its understanding. Within the *Subsystem 1* are the four blocks that make up the body as well as the universal joints that unite them. Each body block is connected to a subsystem identified in Figure 3(a) as *Subsystem 2* where are defined the subsystems of contact with the ground and the subsystem with the leg modelling blocks (Figure 3(b)).

After tuning the controllers of the robot joints, it was proceeded to the analysis of its movement, as shown in Figure 4, being possible to observe the robot taking several steps.

### 6. Conclusions

This paper described the creation of a quadruped robot model in Simmechanics<sup>TM</sup>, characterized by a flexible body, and the modelling of its feet-ground interaction. The model developed accepts different gaits by direct introduction of the angular positions of the knee and hip joints. Various parameters of the robot are also easily changed in the configuration file accompanying the model. It is the authors intention to further improve this model in order to allow its use to testing distinct gaits and the locomotion

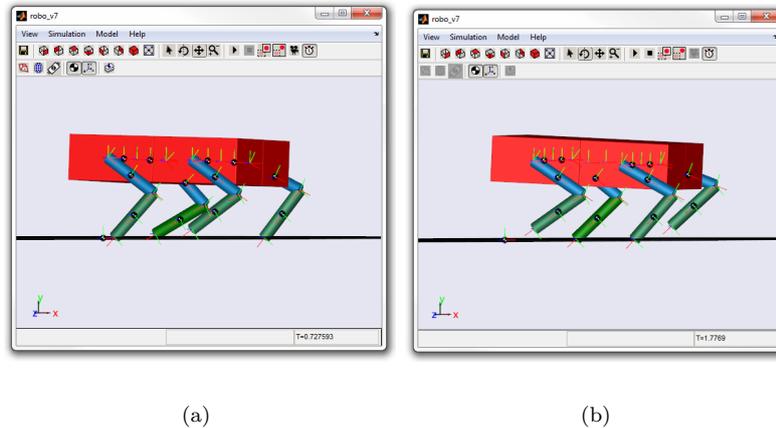


Fig. 4. Robot walking with legs 2 and 3 in the transfer phase (a) and with legs 1 and 4 in the transfer phase (b).

in 3-D and in irregular terrains.

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