

AN AUTOMATIC MODELLING APPROACH TO MOBILE ROBOTS

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Abstract. Both mechanical and mathematical models of a robot, whatever is its configuration or application, are the most significant steps on a robot design to fulfil. The mechanical model is normally used to present the visualization of the robot, to define the direction of the movements, to accomplish the coordinate systems, to provide the mechanical plans for the components construction as well can be used for some mechanical interference simulation between its moving parts. The mathematical model composed by kinematics and dynamics equations is the base to simulation, to determine trajectories, angles and necessary torques for certain movements. This work presents an automatic approach for robot modelling using CAD software together with MatLab SimMechanics as well a comparison with the classical one. A four legged tree climbing robot example is used to illustrate the procedure.

1 Introduction

Legged robots were demonstrated to be the ideal option for many applications where the working environment is difficult to access or even dangerous or risky for human beings, such as exposure to hazardous substances or environments and risk conditions. Productivity increase and quality issues are also extremely relevant and are considered [1, 2, 3, 4].

However, together with the larger mobility offered by legged robots, a more complex modelling emerges depending on the robot structure and configuration. This complexity depends on if the robot has identical or different legs, a rigid or flexible body, number of legs and the corresponding DOF (degrees of freedom) for each one.

In this way, the modelling task can be arduous, take a lot of time and the most relevant factor to be considered is that this assignment is critical since it is susceptible to insert errors to the final model.

A method that can be used in order to minimize possible errors is an automatic robot modelling using CAD software translation together with MatLab SimMechanics.

Simulink and SimMechanics software use a block diagram approach to model control systems around mechanical devices and simulate their dynamics. With CAD translation, it is possible to combine the power of CAD and SimMechanics software. The translator transforms geometric CAD assemblies into Simulink blocks using a so called CAD-to-SimMechanics translator.

The translation process is based on two major steps: i.) to export the CAD assembly into a physical modeling XML format file and ii.) to import the generated XML file into a SimMechanics model in Simulink environment.

This work presents some results obtained using the process above applied to a legged robot modelling, as well a classical model for complexity comparison.

2 Kamanbaré Platform

Besides the varied applications and areas, there still remains a little explored area: environmental research. As in any other area, different applications or problems can be addressed or solved with the help of a robotic platform. As an example, one can mention the tasks:

- Gathering of botanical specimens;
- Gathering of vegetable material;
- Gathering of insect specimens;
- Climatic studies;
- Studies on biosphere/atmosphere interaction;
- Studies on arboreal fauna;
- Sensors network.

Purporting the main goal to climb trees for environmental research applications, to be applied in tasks such as presented above, a bio-inspired robotic platform named Kamanbaré was proposed [5].

The project's main application is climbing trees for non-invasive search purposes, reaching points (at high altitudes) that may offer risk to humans, Figure 1.

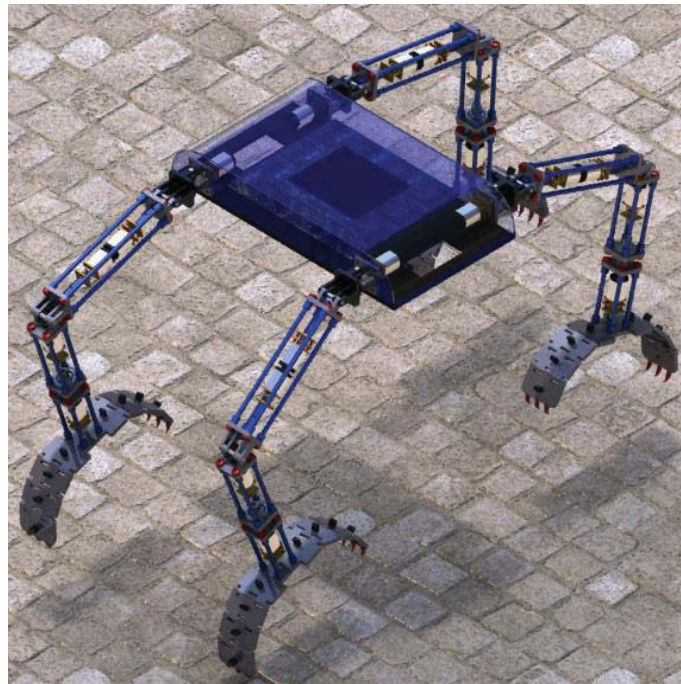


Figure 1: Kamanbaré robot platform.

3 Mechanical Model

The mechanical structure of the Kamanbaré platform consists of a central rigid body with four legs, identical and symmetrically distributed. Each leg comprises three links connected by two rotating joints, and it is coupled to the central body by a third rotating joint, while each joint has 1 DOF. Identical motor and reduction groups make the rotary movements. Figure 2 shows the kinematic configuration of a leg. Each leg also has a paw, which is forked just as the chameleons' paws, but with only two fingers, one on each side, for simplification purposes. The paw connects to the leg by a rotating joint; it also has another motor and reduction group that provides for its opening and closing movements.

Since each leg has four joints, this means 4 DOF. Considering the four legs, the platform will have a total of 16 DOF. Therefore, sixteen motor and reduction groups were necessary to produce all the movements.



Figure 2: Kamanbaré leg - kinematic configuration.

4 Classical Modelling

When one leg is on the fly (i.e., no contact with any surface) its model is similar to a serial manipulator, where the base of the system is attached to the platform and the end of the system is the paw. Hence the first joint axes point to the vertical, the second and the third are parallel to one another, and the last joint axes are in the same direction of the motor axis, Figure 3.

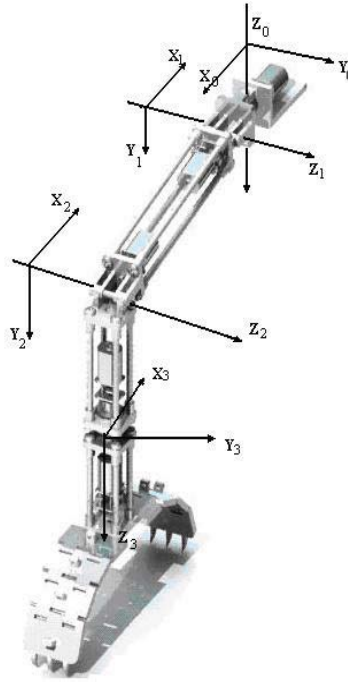


Figure 3: Coordinate systems adopted for classical modelling.

Having established the coordinate systems in Figure 3, the Denavit-Hartenberg parameters can be used to compute the position and orientation of the paw as functions of the joint angles. Table 1 lists the Denavit-Hartenberg parameters for one leg of the Kamambaré.

Joint i	α_{i-1}	a_{i-1}	d_i	θ_i
0	$-\frac{\pi}{2}$	L_1	0	θ_1
1	0	L_2	0	θ_2
2	0	L_3	0	θ_3
3	$\frac{\pi}{2}$	0	L_4	θ_4

Table 1: Denavit-Hartenberg parameters for one leg of the Kamambaré.

The leg model can be written in the general form [6]

$$\tau = M(q)\ddot{q} + V(q, \dot{q}) + G(q) \quad (1)$$

where $M(q)$ is the leg inertia matrix, $V(q, \dot{q})$ is the Coriolis and centrifugal torque vector, $G(q)$ is the gravitational torque vector, q is the vector of joint generalized coordinates and τ is the vector of joint torques.

Some dynamical effects like friction were not included in (1) although they may be significant for some legs. In addition, a more detailed model of the leg dynamics could include various sources of flexibility, deflection of the links under load and vibrations [7]. Nevertheless, this model is sufficiently accurate for our purposes since these effects are not significant for the Kamambaré leg under consideration.

All joints are driven by identical DC motors. The space-state model that describes the dynamics of the DC motor corresponding to the i -th joint is given by:

$$\dot{x} = Ax + Bu \quad (2)$$

$$y = Cx + Du + E\tau \quad (3)$$

where

$$A = \begin{bmatrix} 0 & 1 \\ 0 & -b/J \end{bmatrix} \tag{4}$$

$$B = \begin{bmatrix} 0 \\ K_m/J \end{bmatrix} \tag{5}$$

$$C = [0 \quad -K_b/R_a] \tag{6}$$

$$D = 1/R_a \tag{7}$$

$$E = r/(R_a K_m) \tag{8}$$

and

$$x = \begin{bmatrix} \theta_i \\ \dot{\theta}_i \end{bmatrix} \tag{9}$$

$$u = V - \frac{r}{K_m} \tau_i \tag{10}$$

J is the moment of inertia of the rotor, b is the viscous damping coefficient of the mechanical system, V is the armature voltage (control variable), R_a is the armature resistance, i_a is the armature current, K_m is the torque coefficient of the motor, K_b is the counter-electromotive coefficient, τ_i is the load torque, $r < 1$ is the gear reduction factor, θ_i is the angular position of the rotor and $\dot{\theta}_i$ is the angular speed of the rotor. Notice that the input variable u depends on both the control variable V and the load torque τ , which also depends on V through θ_i and $\dot{\theta}_i$.

5 Simulink Models

With CAD translation, it is possible to combine the power of CAD and SimMechanics software. The translator transforms geometric CAD assemblies into Simulink blocks using a so called CAD-to-SimMechanics translator. The translation process is based on two major steps: i.) to export the CAD assembly into a physical modeling XML format file and ii.) to import the generated XML file into a SimMechanics model in Simulink environment. The XML files contains all relevant parameters necessary to create the Simulink blocks, such as mass, inertia matrix, coordinates of center of mass, etc of each link.

The CAD model of the Kamanbaré robotic platform shown in Figure 1 above was designed using Solidworks CAD software. Thus a Kamanbaré model was generated using the SolidWorks-to-SimMechanics translator.

For the translation procedure, some configurations like the name of the joints and legs were adopted as well the directions of both the desired movement and the gravitational acceleration, as indicated in Figure 4.

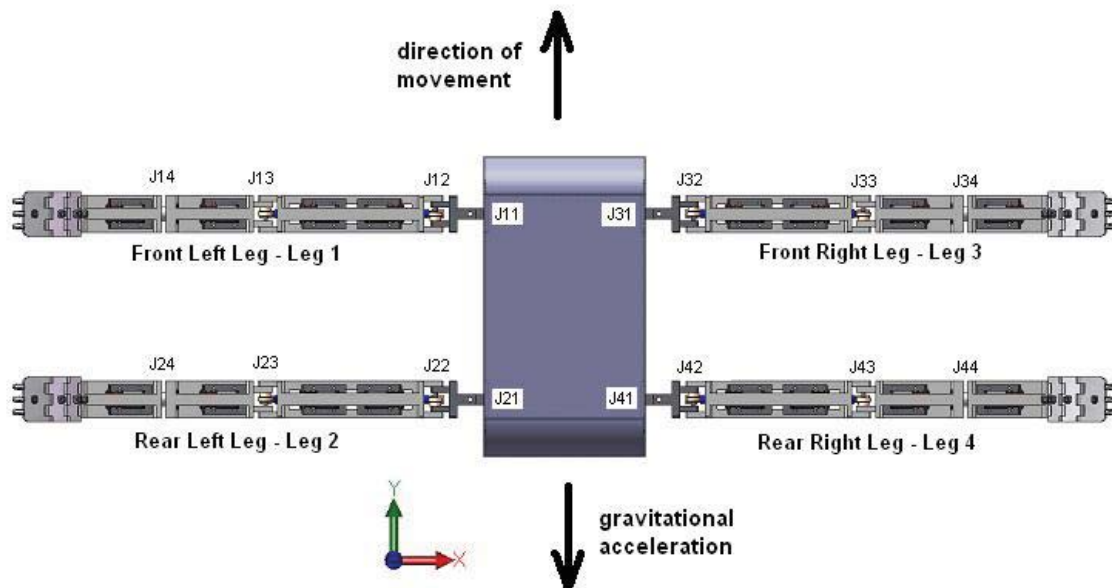


Figure 4: Kamanbaré top view presenting the joints terminology adopted.

The resultant model obtained for the Kamanbaré platform is depicted in Figure 5. For a better understanding and visualization the legs were represented as model blocks.

Due the fact that all four legs are identical, one detailed leg model block, the Front Left Leg, is shown in Figure 6.

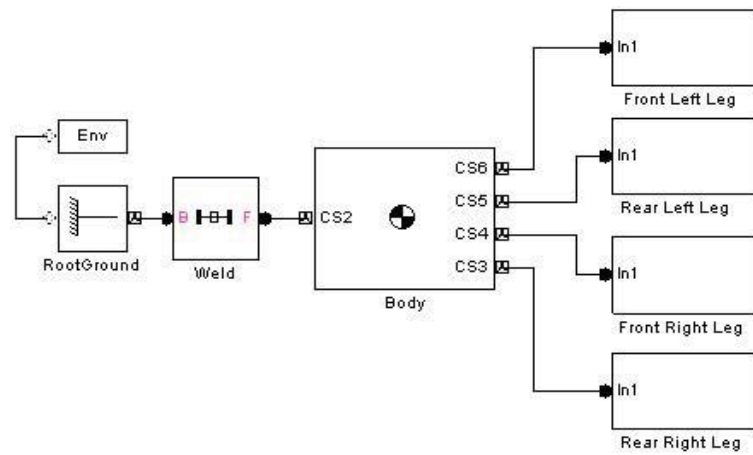


Figure 5: Kamanbaré's Simulink model.

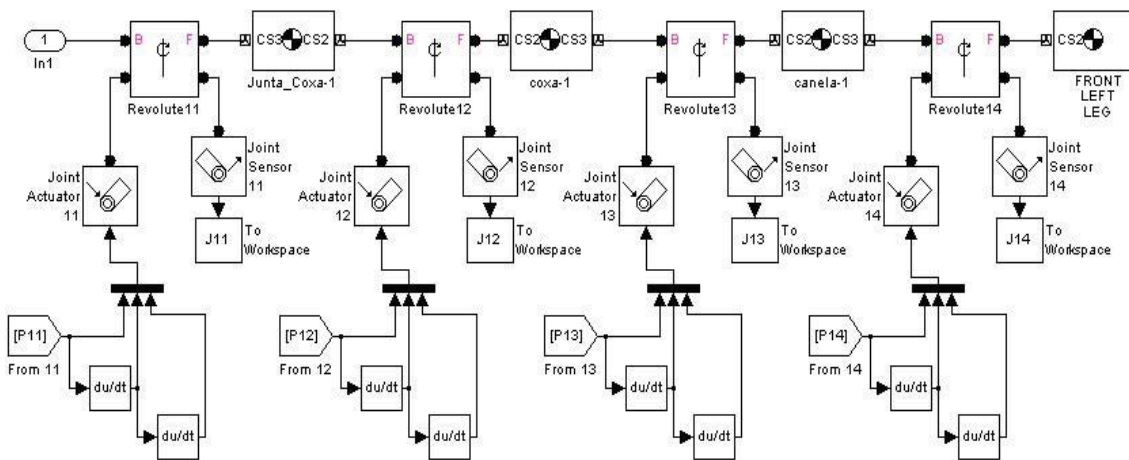


Figure 6: One leg model detailed.

6 Simulation Results

For the simulation process a simplest mode of movement generation, or gait, was initially implemented, i.e., the robot follows a straight path at the highest speed allowed by the surface (no waiting time will be introduced, besides those produced by the legs when searching for support points).

The proposed realistic and practical SimMechanics model is further employed to simulate the designed controller which is implemented using Simulink, in this case just a gait generator.

Figures 7 and 8 shown the model machines obtained. These models are useful during simulations since all joints and legs movements can be observed.

The mode of movement (gait) generation contains information corresponding to the body movement and the foot trajectories, as well as the joint angles of the legs. Using these inputs and running simulations in an inverse dynamics option in Simulink, all the joint torques can be obtained.

The results presented in the following, Figure 9, are the necessary torque to produce a simple desired movement for each joint of the Front Left Leg (Leg 1).

7 Conclusion

This paper has shown a straightforward procedure to model and simulate mobile robots.

Starting from the design of each robot part or component and adding all its mechanical characteristics and material properties it is possible to obtain the CAD assembly model.

Since the CAD assembly is ready a XML file can be generated.

The XML file (physical model) contains all relevant parameters necessary to create the Simulink blocks, such as mass, inertia matrix, coordinates of center of mass, etc of each link.

At this time, this physical model can be imported into a SimMechanics model in Simulink environment.

The Simulink model obtained can be used to determine the necessary torques to produce a given movement. With the torques values the actuators can thus be chosen.

Obviously the same approach could be used to model any robotic manipulators.

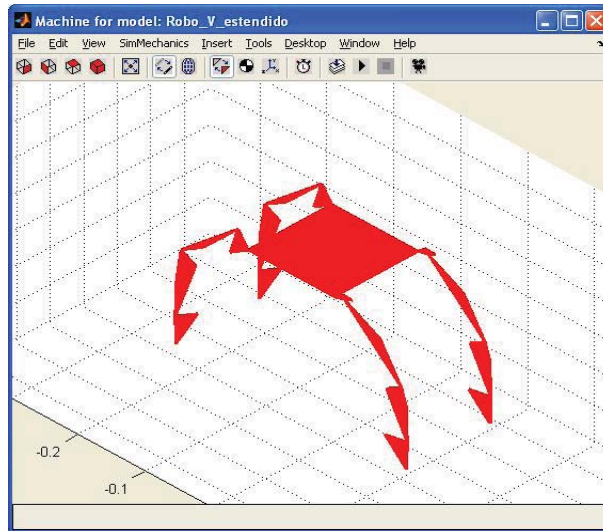


Figure 7: Kamanbaré's model machine in convex hulls view mode.

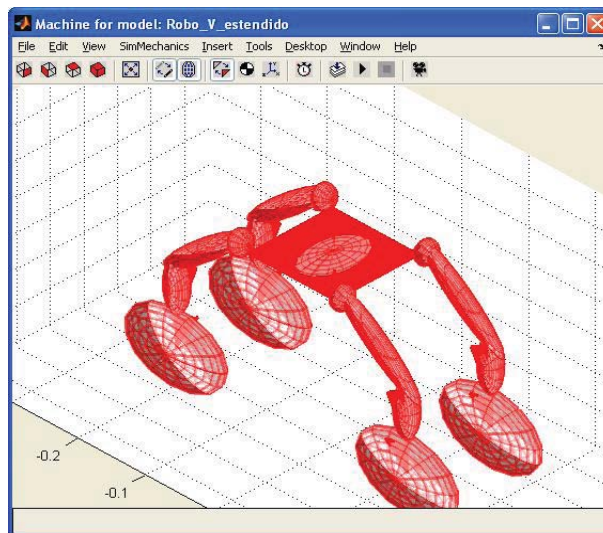


Figure 8: Kamanbaré's model machine in convex hulls + ellipsoids view mode.

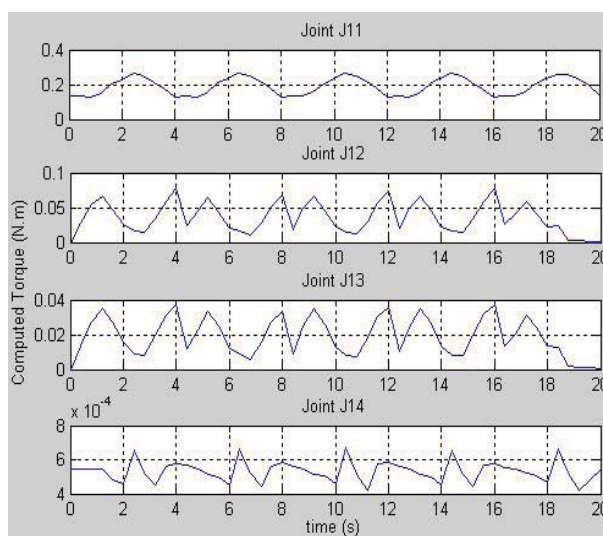


Figure 9: Computed torques for Leg 1.

8 References

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