Modelling and Animation of Virtual Autonomous Mobile Robots, in Physically Simulated World, for the Evaluation of Locomotion and Navigation Structures

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Abstract

A mobile robot is the most suited element to transport scientific instruments to diverse scientifically interesting sites on extraterrestrial planets. Instruments to examine geology, mineralogy or exobiology can be easily deployed. Since the Mars Pathfinder mission, new missions for in-situ planetary exploration demand for increased mobility on planetary surfaces.

The realization of robots dedicated to planet exploration requires a number of abilities, such as obstacle avoidance, overcoming of obstacles, displacement of objects using end-effectors or visual recognition, which in most cases are relatively expensive to achieve. In particular, for planetary exploration mission where the robot evolves in unstructured environments without human presence, it is difficult to predict the behaviour and to assess in situ the effectiveness of robots designed to carry out tasks.

This paper presents the modelling and simulations of an autonomous rover. Different mechanical concepts and solutions to overcome obstacles are compared by simulating the displacement of the rover across various virtual ground surfaces (sand, rocks)

1. INTRODUCTION

Since several years, the planet Mars fascinates researchers in particular because it could contain information about life origin. Following this assumption, the missions towards Mars followed one another. Several robots, Sojourner in 1996, Opportunity and Spirit more recently, were sent to Mars. These missions carry scientific instruments making it possible to examine geology mineralogy or the exobiology of planet, with the purpose to obtain information about the state of red planet thousands years ago [1].

The mission required rovers with extended locomotion to move on very rough broken grounds. The potential capability of particular rover concepts to overcome obstacles can be qualified by tests done on Earth with prototypes and by simulations carried out in a virtual environment that has similar physical characteristics to the Martian environment. These simulations allow designing structures at a lower cost by limiting the number of real prototypes on which tests are carried out [2, 3]. In past years, various works have been done in the line of rovers and space exploration [4-9], which prepare the current work, showing a methodology for modelling and simulating of various rover structures.

To solve these problems, software environments allowing to model and to simulate a physically robotized system have recently emerged. These software tools have the advantage to allow the assessment in virtual context of the physical properties without requiring building and testing a rover. This allows cost reduction and the possibility to test various architectures for robotized systems such as mobile autonomous robots.

Among the various software environments for the simulation of autonomous mobile robots, one can mention the software Webots. With this software, autonomous mobile robots having the same structure than those intended to participate to the Swiss and European robotics contest have been modelled and then simulated physically in order to evaluate their capabilities to move and avoid obstacles. More complex mobile structures, like those used in planetary exploration have also been modelled, with an aim of contributing to the evaluation and the comparison of their effectiveness to cross obstacles. Such rovers are designed for any type of ground. It is thus necessary to consider various architectures and various locomotion parameters, in a variety of environmental conditions.

The main components of the modeller include static objects, and, more specifically, mobile structural elements such as joints and servo drives, with predefined torque and force features, friction and elasticity attributes. The modelling of closed-loop kinematic structures, while not functionally impossible, is relatively difficult to achieve with the simulation software used during this project. Nevertheless, current solutions show that the global behaviour of complex kinematic structures, such as rovers with 12 joints, can be effectively handled by Webots, allowing for interesting conclusions in terms of performance and relative merits of alternative architectural choices.

The first section of this paper describes the simulation of the autonomous mobile robot software used for this work. The second section explains the methodology for modelling and simulating various rover structures. Finally the last section shows the results obtained and concludes this paper.

2. THE WEBOTS SOFTWARE

Webots is a software package for the simulation of autonomous mobile robots [3]. It contains various functions making it possible to quickly create virtual worlds in 3D and to simulate their physical properties (friction coefficient, forces, masses, inertias and so on). The user can add to the virtual world various types of objects which are either active, like autonomous mobile robots, or passive, like obstacles.

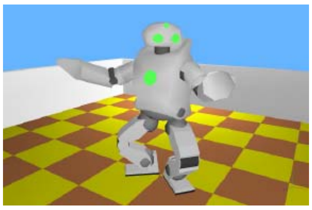

Figure 1. Humanoid robot on Webots

2.1 MODELLING ON WEBOTS

Webots includes its own parser and VRML graph scene, to which specific robotics extensions were added (sensors, actuators, physical simulation...). The format VRML allows the complete description of 3D scenes, rendering displayed objects with polygons, the treatment of lighting, textures and other realistic effects.

Example of VRML code describing a cylinder

```
#VRML V2.0 utf8                 #header obligatory

Shape {
         appearance Appearance
         {
         material Material {}
         }
         geometry Cylinder
         {                       # define cylinder
              height 2.0         # cylinder height
              radius 1.0         # cylinder radius
         }
       }
```

Figure 2. Cylinder in VRML

2.2 PHYSICAL SIMULATION ON WEBOTS

Webots uses the physical engine ODE (Open Dynamics Engine) to manage the physical simulation of the elements contained in a scene.

ODE is an industrial library "open source" which allows dynamical physical simulation of articulated bodies'. This library integrates the collision detection between primitive forms.

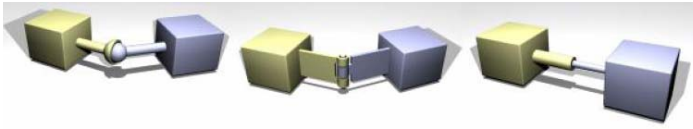

Figure 3. Three different constraint types

```
Physics {
       orientation 0 1 0 0        SFRotation   # orientation of inertia matrix
       density 1000        SFFloat       # (kg/m3) if -1 use mass
       mass -1                    SFFloat      # (kg) ignored if density!=-1
       bounce 0.5                 SFFloat      # range between 0 and 1
       bounceVelocity 0.01        SFFloat      # (m/s)
       coulombFriction 0          SFFloat      # ODE Coulomb friction coeff.
       forceDependentSlip 0       SFFloat      # ODE force dependent slip
       inertiaMatrix []           MFFloat      # 9 float values: inertia matrix
         }
```

3. ROVER MODELLING

For comparison purpose, we make the hypothesis that all structures shall have the or very similar physical properties (mass, dimensions, torque, speed, friction coefficient...). This hypothesis makes it possible to compare the capability of various models to overcome obstacles. The rover Sojourner was chosen as reference chassis structure for several reasons:

- It is the first rover to have ever moved on the surface of Mars.
- The "Rocker-bogie" system which equips the rover Sojourner, Opportunity and Spirit has proven that it this moves under good conditions on the Mars surface.
- Information for this rover is available.

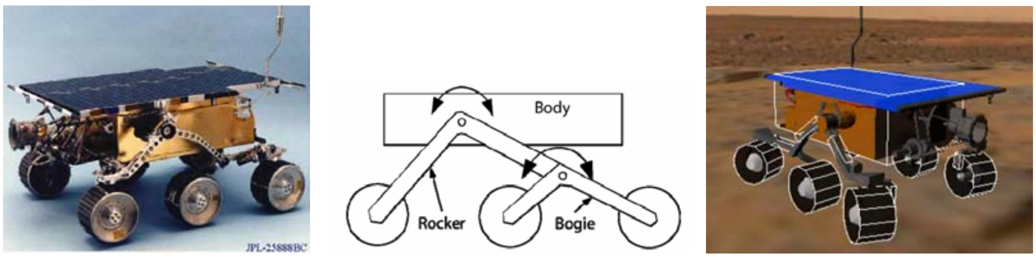

Figure 4. Rover "Sojourner" and its model

Other structures of rover were modelled with the aim of being compared to the structure “Rocker-bogie” of Sojourner.

A similar model to the concept E of the RCL was modelled. The concept E is a structure with three independent bogies giving to the rover a high degree of mobility. The model presented is characterized by the fact that the rotation points of the front bogies are located very high, increasing the height/length ratio of the bogie.

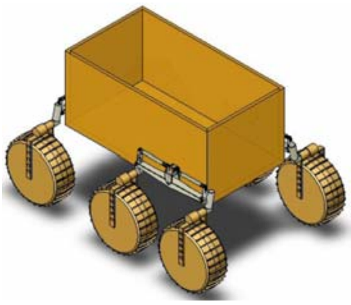
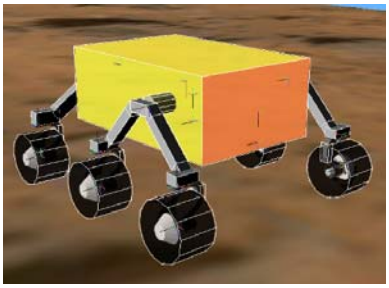

Figure 5. Concept E and variations (“yellow” on right side)

Two models approaching better the concept E, were modelled. The two models are characterized by the fact that the rotation points of the front bogies are located differently.

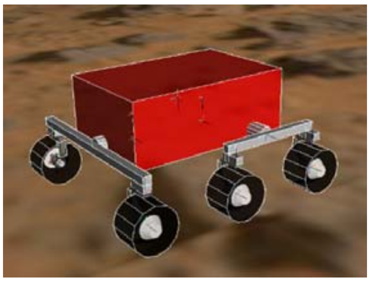
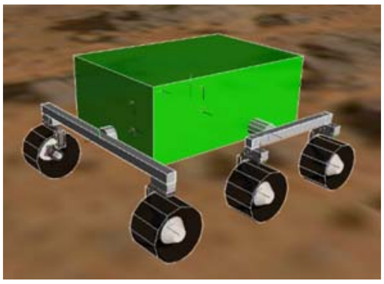

Figure 6. Concept E and other variations (“red” on left side, and “green” on the right)

The “green” model has the rotation points of its front bogies located nearer to the centre of mass (CoM) of the rover. This structure makes it possible to generate an important vertical force on the front wheels when they meet an obstacle (tightening effect).

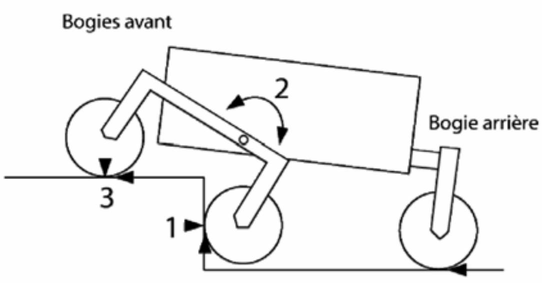

Figure 7. Forces on the wheels of the rover

A model with only four driving wheels was also modelled.

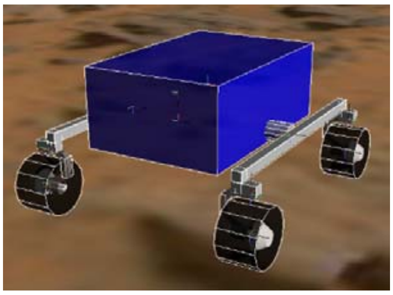

Figure 8. The model four driving wheels

The surface of the planet Mars is made up rocks (which seldom exceed a height of 1m), stones and sand. For the simulation, the type of ground taken into account is mainly the rock. Indeed, the small rocks on which the rovers roll upon while moving on Mars can be represented by simple geometrical forms. Obstacles of simple form facilitate the evaluation and the comparison of the various modelled rover structures.

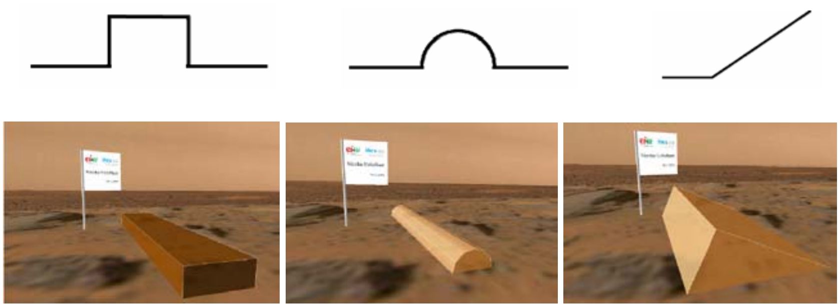

Figure 9. Different models of obstacles

4. SIMULATIONS AND COMPARISONS

The physical parameters that are necessary to model the rover and its virtual environment are very important because they can modify in a radical way the behaviour of the simulation. These parameters are generally based on hypotheses and on technical data about the rovers and the planet Mars. A list of the most relevant parameters is given hereafter:

- The rover mass.
- The mass distribution on the rover and the centre of mass (CoM).
- The wheels-ground coulomb friction coefficient.
- The maximal rover speed.
- The motor torque acting on the rover's wheels
- The physical parameters to describe the virtual world.

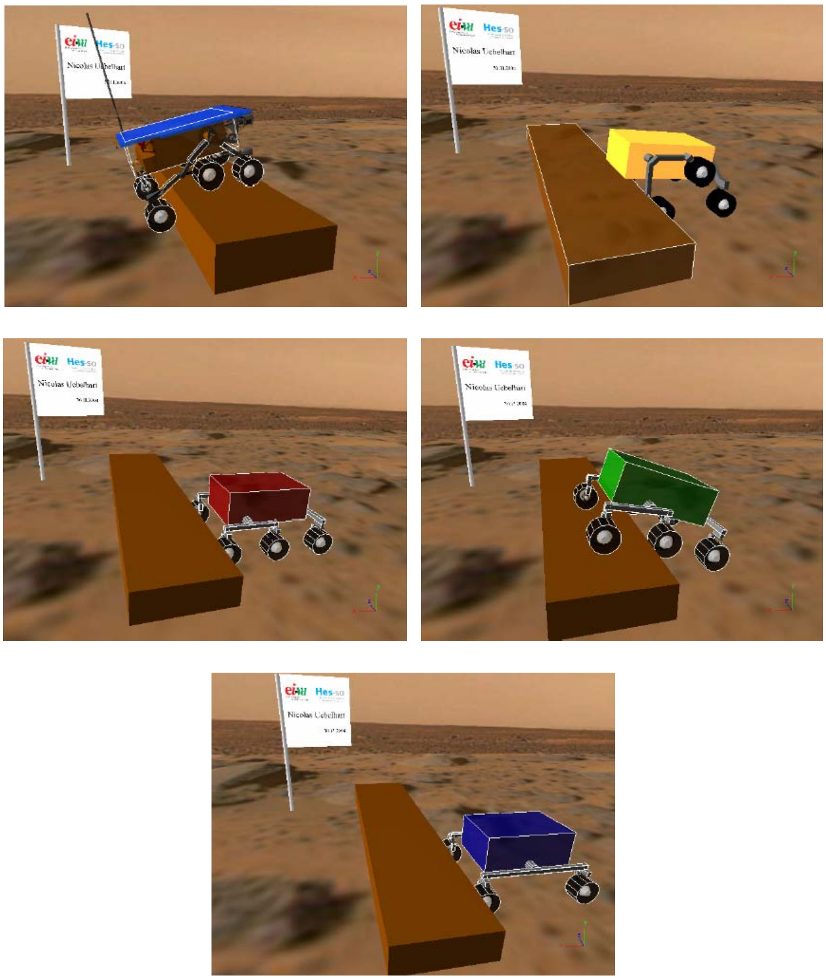

Figure 10. Comparisons between rovers (blue, yellow, red, green, and blue)

The various models realized were compared as regards to overcoming obstacles, with the Sojourner reference model. The majority of the models showed their defects at the time of various simulations.

- The “yellow” model tips over when it tries to overcome obstacles with strong slopes.

- The “red” model cannot overcome obstacles with strong slope but does not have a problem with obstacles having a smaller slope.

- The “green” model can overcome all obstacles, but in only one direction, contrary to the "red" model.

- The “blue” model is very limited with its very low degree of mobility; it can overcome only obstacles of small size (smaller than the radius of wheel) or of weak slope.

According to these comparison tests, the rovers Sojourner and the “green” model offer the best qualitative results as regards overcoming obstacle. Although the model of sojourner is simplified by the fact that it does not have differential joint between the left and the right bogies, it gives a good approximation of the behaviour compared to the real model (sojourner's videos [10]). The "green" model offers some good results although it is limited to only one direction to overcome obstacles, another disadvantages of its structure is that it can't climb high slopes (max.30°) without fall risk.

5. CONCLUSION

The qualitative results obtained from simulations show the possibilities offered by the Webots software as regards simulation of rovers. This software has the characteristic to be able to detect defects of a system at early design stage and asses the quality of a mobile structure. The optimization of the various parameters constituting a rover such as the centre of mass, the diameter of the wheels, the speed, and the positions of the joints, the torques and forces can be carried out by various methods. The method of optimization described in this paper is empirical because the improvement of the models was realized by successive tests. This systematic parametric approach allows finding the optimal solution but is certainly not the most efficient because it takes a lot of time, taking into account the large number of parameters. Another possible method would be, initially, to optimize independently specific rover sub-system such as the wheel and in particular the coefficient wheel-ground, also the number of wheels and the number and position of articulations then, in a second step to carry out an optimization of the all unit. This way allows reduce the number of parameters and therefore the total simulation time. A further attractive goal would be to use such an environment in order to tune-up and optimize architectural parameters, such as centroid location or wheel radius.

This paper shows mainly that the simulation software Webots makes it possible to simulate rovers passive structures compare then and perform some optimization. The simulation process allows the system engineer to have a first idea about the behaviour of a prototype for a specific mission. However, a rover can be optimised only for a specific environment (or mission) for which it is conceived. They also make it possible to carry out tests at lower cost by limiting the number of real prototypes which must be built for the real tests. The simulation allows also coping with particular environmental parameters like the gravity, difficult to test with rover breadboard.

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