Lunar Rover Virtual Simulation System over A 3D Terrain Environment

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Abstract

Virtual Reality Simulation plays important role in teleoperation of lunar rovers during exploration phase as well as in the design of rover and its systems, performance evaluation during R&D phase. Present simulation methods for lunar rovers have several drawbacks in terms of difficulty in simulating terrains, rover terrain interfaces, simulating dynamics of slip and slide to realize smooth mobility in simulation systems. Considering this, our paper presents an approach to construct a virtual simulation system that integrates the rover modelling, terrain construction and mobility of rover using ADAMS-Matlab interface. In addition to this we have simulated terrain using 3dsMax software and a suitable program is developed in Matlab to simulate the 3D representation of terrain in ADAMS. The 3D model of terrain is also developed using Matlab software and the rover model is constructed with ADAMS. By interfacing ADAMS with Matlab a suitable virtual simulation system is constructed to implement the behaviour of rover over terrain environment. The controller is implemented by using Matlab/Simulink to carry out joint simulation with ADAMS. This paper will provide a method for teleoperation and gives performance analysis in different terrain environments. The simulation environment runs on Z-400 workstation with 16GB RAM.

Real tests require equipped rover platform and a realistic terrain. It is very time consuming and high cost. To improve the development efficiency, a rover simulation environment that affords real-time capabilities with high fidelity has been developed. We have made use of FBM technique as well a other software techniques to generate lunar surface as well as its features like crater. The lunar rover is modelled using ADAMS software with high realism is integrated in the visualization environment. The dynamics of rover is tested in Matlab-ADAMS simulation environment.

Keywords: *Terrain Model, Rover Model, Virtual Simulation*

1. Introduction

With the success of planetary exploration missions by India mainly Mars and Chandrayaan missions, ISRO plans to launch lander and rover in Chandrayaan-2 for further investigations over interplanetary surface.

Integrated virtual terrain and rover simulation system plays an important role in the lunar and interplanetary surface exploration missions. In the futuristic missions rovers need to travel over challenging terrain to achieve larger and ambitious scientific objectives. Rovers are expected to do complex jobs by travelling over longer distances for achieving greater mission goals. Considering this virtual reality simulation can be used to guarantee the success of lunar rover, since it can provide platform for optimal design, evaluation and control during preliminary and R&D phases. This also can support 3D predictive displays for continuous teleoperation or command-sequence validation of rover during exploration phases. In this regard, a comprehensive virtual terrain simulation system with rover interface that combines the features of 3D modelling, dynamics, analysis, visualization and control. A good simulation environment for rover needs good 3D terrain model, kinematics and dynamics model for rover and a contact model between them.

US Space agency NASA has been doing research activities in lunar, Mars and other interplanetary exploration. NASA Jet Propulsion Laboratory (JPL) has come up with a simulation system called ROAMS which can be used for stand-alone simulations, closed loop simulations with onboard software, or operator-in-the-loop simulations. RCET is another tool developed by European institutions to support the planetary rover missions. RCAST is developed before RCET to characterize and optimize the mobility of Exo-Mars Rover. As to 3D terrain model, it can be generally categorized as empirical and synthetic. Empirical terrain data is collected from manual measurement and optical surveying to high-precision radar and laser scanning techniques. Synthetic terrain is generated by using some algorithms. Using algorithmic methods we have the flexibility to change the parameters such as rock sizes and distribution densities as well as

craters. We have used the FBM and 3D software tools to generate terrain in our experiment.
As far as modelling of rover is concerned, many have gone for rocker-bogie model of rover. This paper also uses a six wheel model as some of the previous exploration mission used this model. There has been plenty of kinematics and dynamics analysis in literature[9,4], we have designed a simple model with base parameters for the rover movement.

2. Literature Survey

Haibo[4] explains virtual simulation system with wheel-soil interaction dynamics and path control. But there is no mention of navigation related behaviour. Also it seems to be a complex dynamics technique for implementation of rover over rough terrain surface. Yibing[17] and his team has researched on Walking wheel design for lunar rover in a virtual simulation environment by importing a 2D terrain surface into ADAMS. This paper puts more light on walking wheel design, not much light upon terrain modelling and application in a visual environment. Hacot[3] presents the simulation of rocker bogie exploration rover. 3D mechanics of rocker bogie rover with kinematics simulation is explained in [3]. But there is no mention of interaction motion in different kinds of surfaces of terrain. Hegde[7] has proposed method for wheel slippage and detailed study has been conducted on soil and its interaction with wheel. Zhou[5] presents the path planning and navigation which needs improvement by using image processing technologies. Mobility and navigation with soil analysis and laser based navigation are explained in Watergreen[12]. Virtual lunar navigation simulation is not complete with terrain factors. Some light upon digital terrain model and integration of navigation and rover dynamics is proposed by Jinsing[16]. Yang[9] explains key technologies and the framework required for the whole setup. But there are disadvantages of combining the entire system in one place.
In this paper we tried to bring a simple rover and terrain model with most significant features and implementation of motion of rover in a visualization environment.

3. System Architecture:

The system architecture of virtual simulation environment for rover simulation is illustrated in fig.1. First, we have a terrain module which has properties of lunar terrain. The rover module is connected to kinetic and dynamics module of lunar rover.

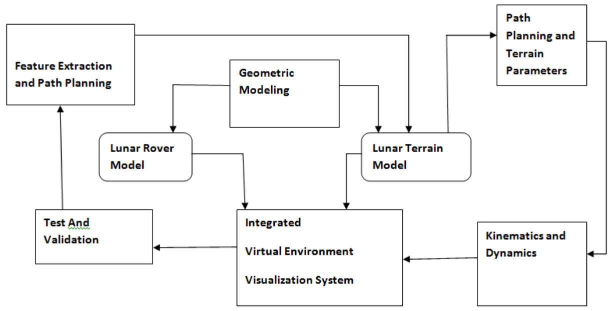

Fig 1.VE System Architecture

3.1 Rover Model

A six wheel rover is modelled in this paper. It has six independent wheels mounted on an articulated passive suspension system. The lunar rover as the rigid body has six degree of freedom, translation along the x, y and z axes and rotation about these axes roll(rotation about x-axis), pitch(rotation about y-axis), yaw(rotation about z-axis). The primary motions associated with the behaviour of the rover are longitudinal, lateral and yaw motions. Rover is the integration of locomotion, navigation system, communication system, manipulator and science equipment.

3.2 Terrain Model

Normally terrain is represented by Digital Elevation Map (DEM). This terrain model is used as a reference for other modules such as rover, wheel-soil interaction as well as navigation modules. Since features on terrain vary on various surfaces, traversability should be checked for roughness and type of soil. Fractional Brownian Motion (FBM) is used to model rough surfaces and complex shapes of nature like terrains, rivers, mountains, clouds and so on. We have provided a realistic method where we can create a base terrain using FBM and adding craters and other features.

3.3 Kinematics and Dynamics Module

Rover needs payloads and instruments near the objects of interest. Some manipulators have 5-6 degrees of freedom. The rover modeled as six wheeled with payloads on it used for surface exploration and communication and control system. Rover is treated as an articulated multi-body system connected by free joint, differential joint and spring-damper mechanism. In every simulation step, collision detection is called to get the result including geometry information and contact force as an input. An integrator is used to find the solution values at time t+h, given a time t, adjusting the state of all the rigid bodies for the new time value.

3.4. Feature Extraction and Path Planning

The Feature Extraction module collects the surrounding data/image to process it and identifies obstacles and Path planning module is responsible for accepting goal commands and generating a sequence of path information, which guides the rover to the goal while avoiding hazardous areas, according to the specific path planning algorithm.

3.5 Integrated Visualization System

The 3D graphics visualization component of Virtual Simulation is built with Matlab-ADAMS interface in Windows environment. We have used OpenGL and graphics libraries and 3Ds max software for developing applications. OpenSceneGraph and visualization tools can be used for 3D graphics applications in Linux platform. OpenSceneGraph supports rendering, such as viewpoint management, lighting and shading, camera control and scene-graph traversal.

4. Virtual Simulation system with Lunar Rover

The structure of the comprehensive virtual simulation system for lunar rover is shown in fig.2. The simulation system integrates the software of 3DsMax, ADAMS and Matlab to realize the function of rover modelling, terrain modelling, kinetic and dynamics respectively.
The 3D model of the lunar rover that is constructed by using ADAMS is imported to Matlab-Simulink interface. By configuring the simulation parameters of rover model, and the terrain model in ADAMS, a virtual rover is constructed whose kinematics and dynamics is solved by the ADAMS/Solver.

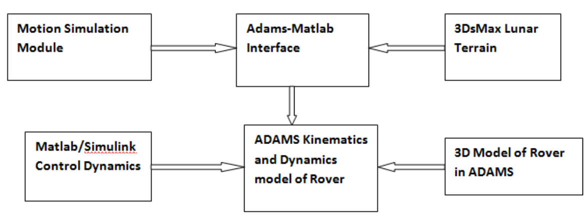

Fig.2. Dynamic Simulation of Lunar Rover in ADAMS

A virtual rover created by ADAMS software can be controlled through the interface between ADAMS/Control and Matlab/Simulink. ADAMS/Control provides an interactive environment for establishing and demonstrating an S-function "controlled object", which can be controlled by the simulink toolbox of Matlab. In each integration step, ADAMS/Control is called as a subprogram by simulink. The control instructions generated by Simulink are then directed to the corresponding mechanisms of lunar rovers in ADAMS through ADAMS/Control. The rovers motion is then calculated by ADAMS/Solver based on dynamics simulation, and the related information is fedback to Simulink through ADAMS/Control. The entire transmission process is automatic and transparent.

5. Terrain Model Construction

Lunar terrain can be modelled in many ways. Fractional Brownian motion technique of self similarity has been used in various applications for constructing random terrain surface. In this paper, we have constructed and modelled the terrain surface using FBM method in Matlab as well as by using 3DsMax software. Following are details of terrain construction.

5.1 Terrain model using FBM method

Lunar terrain construction is the basis of virtual simulation. The surface of lunar is the continuous ups and downs of craters and valleys. So the lunar surface should include basic elements such as craters, valleys, stones etc., In order to achieve better simulation results, the model surface should as near to lunar terrain surface. As lunar surface has self similarity characteristics, it is reasonable to use fractal technology to create terrain features. In this modelling, first we use fractal technology to form the lunar base terrain and then we add craters and stones over it by making use of real statistical data. The craters that are widely distributed over the lunar surface can be divided into 3 types: fresh craters, young craters and mature craters,. Table 1 shows the parameters of typical craters. It can be seen that their height is usually no more than 25% of their diameter, and that the margin height is no more than 6% of their diameter.

Table 1 .Shape of typical lunar craters

Type of crater	Ratio of depth to diameter	Ratio of edge height to Diameter
Fresh crater	0.23~0.25	0.022~0.06
Young crater	0.17~0.19	0.016~0.045
Mature crater	0.11~0.13	0.008~0.03

Lunar rocks are covered with soft lunar soil, which makes them be different from hard rocks due to their weathering over a long period, so that they can actually be well characterized as a soft and bumpy terrain. Table 2 shows the number of blocks in 100 m^2 of the landing area of surveyor 3 spacecraft[4].

Table 2 Block distribution in 100 m^2 of lunar surface

Height of blocks	Number of blocks
60 mm < $h \leq$ 250 mm	100
250 mm < $h \leq$ 500 mm	3~4
$h \geq$ 500 mm	0.6

Mandelbrot's fractional Brownian motion (FBM) is an effective mathematical method for modeling shapes found in nature[9].
The one-dimensional fractional Brownian function, $V_H(t)$, which is a single valued function of one variable, t. $\Delta V_H(\Delta t)=V_H(t2)-V_H(t1)$ follows a Gaussian distribution with variance $<V_H^2(\Delta t)>\alpha\ \Delta t^{2H}$, where the "<>" denotes the expected value, $\Delta t=|t_2-t_1|$, and the parameter H has a value 0<H<1 .
The fractal dimension of $V_H(t)$ is D=2-H.
Expanded to x-y plane, ΔV_H can be expressed in the form of $\Delta V_H(\Delta r)$where $\Delta r^2 = \Delta x^2 + \Delta y^2$, and the fractal dimension is D = 3-H .

5.1.1 Simple crater models

Craters are caused by the high velocity impact of meteorites. There are mainly two basic types of crater that appear on the lunar surface: Simple Craters which are up to 10-20 km diameter which have a bowl shaped appearance and Complex Craters which are above 10-20 km diameter which have steep walls and relatively flat floors[9]. According to the simulation needs that the area of the virtual lunar surface is not so wide, we only model the simple craters. Figure 3 shows a typical section plane of a simple crater.

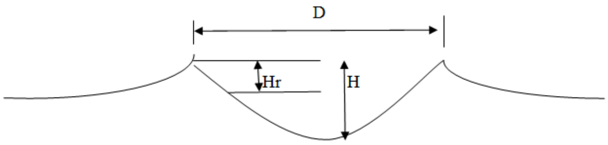

Fig.3 a section plane of Crater

The depth of the crater, H, is given by

$$H=0.196D^{1.01} \text{ and } D<11km \qquad (1)$$

And the height of the crater rim above the surrounding terrain by

$$Hr=0.036D^{1.014} \text{ and } D<21km \qquad (2)$$

where D is the rim peak-to-peak crater diameter.

5.1.2 Adding the crater model to the terrain

Craters are created due to meteorite impacts. In order to make meteorite impact craters appear realistic on a surface, the crater size density distribution must be correct as well as the individual crater models. The crater size density distribution varies across the lunar surface and has been measured in many areas [4]. The general form of the crater size density distribution is given by

$$N = cD^{-b} \qquad (3)$$

where N is the cumulative numbers distribution per unit area, D is the crater diameter, and b and c are constants.
When b = 2, the constant c becomes dimensionless.
Measurement of crater size density on the moon has provided a typical value for b of 1.8. Every time when we add a new simple crater to the base terrain, the relationship between the new crater and the existed craters should be judged and processed.

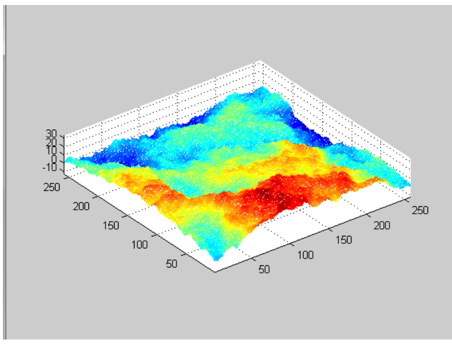

Fig. 4. Terrain using FBM method.

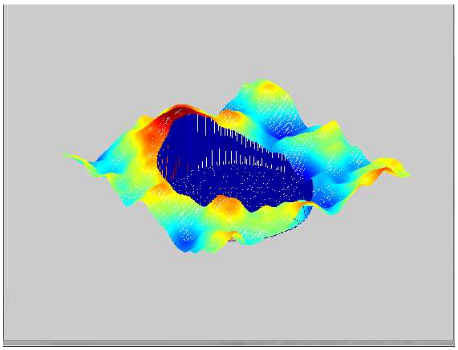

Fig.5. Terrain using FBM method with crater

5.2 Terrain Model using 3DS MAX software

3DS Max software was adopted to model the rough lunar surface based on a mesh grid, as it is powerful and convenient to use. The basic terrains such as the lunar mare, land, craters, and rock, can be created according to their parameters, which can also be combined to construct a complex lunar surface. Fig. 5 shows the surface like lunar mare and a complex combined terrain with land ups and downs constructed by using 3DS Max.

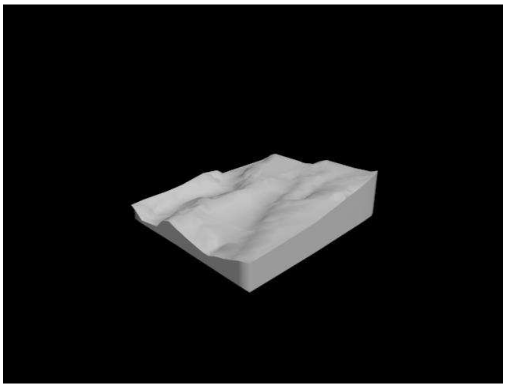

Figure 5. Model of Lunar Terrain in 3DsMax

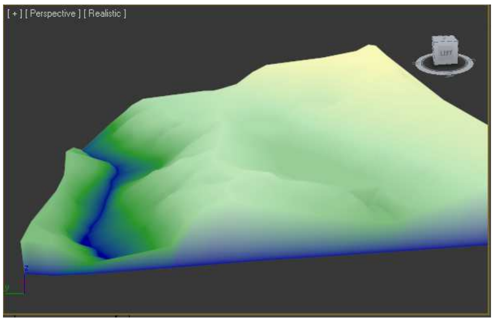

Figure 6. 3D model of Lunar Terrain in 3DsMax

6. Interfacing of lunar terrain in ADAMS

The transformation of the terrain data that are used for modeling and simulation of the lunar terrain from the format of 3DS Max to that of ADAMS is a key challenge.
To address this, two problems must be resolved: (1) extraction of the digital evaluation data from the lunar surface model in 3DSMax, and (2) transfer of the data to a roadmap file and reproduction of the data in ADAMS without distortion. The first problem can be solved by transferring the file formats of 3DS Max. By saving the *.max terrain model file as an *.ASE file, one can obtain the digital evaluation data and the relationships of their connection. The second problem is actually the interface between the 3DS Max data file and the ADAMS roadmap file that is composed of nodes data and triangular grid units. In this , the node points position determines the lunar terrain, the parametric format of which can be shown as a parametric format by constructing a table nodes with co-ordinate axes x, y and z.

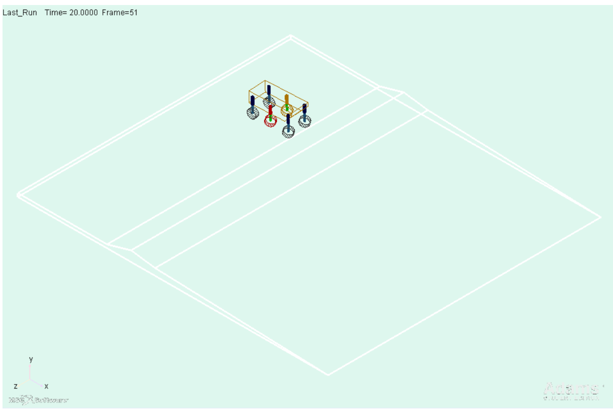

Figure 7. rover appearance over plane surface at end time 30secs

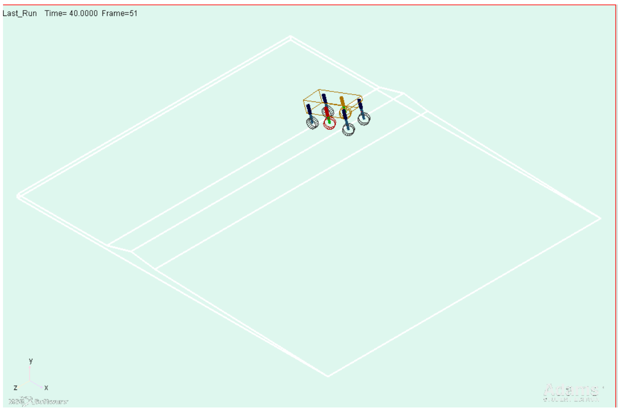

Figure 8. Rover appearance over deformed surface at end time 50secs

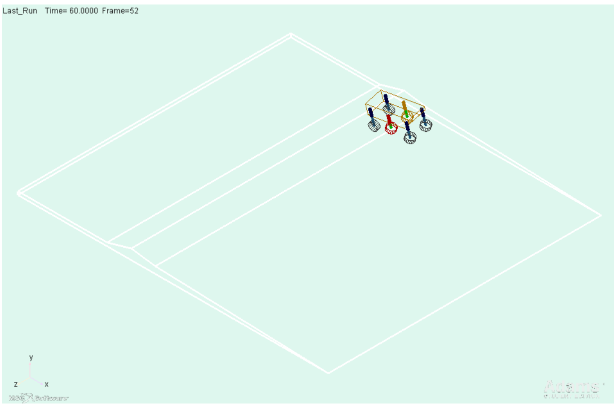

Figure 9. Rover appearance over deformed surface at end time 60secs

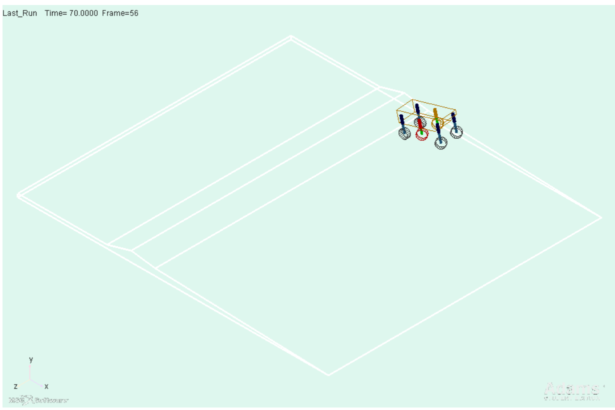

Figure 10. Rover appearance over deformed surface at end time 70secs

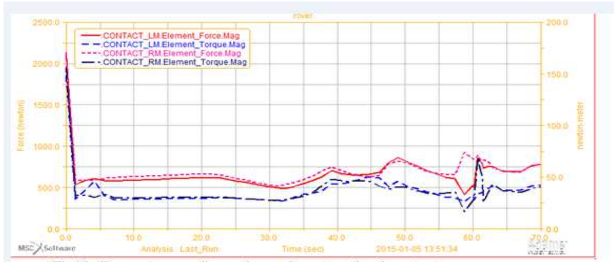

Fig 11. Force, torque dimensions of centre wheel contacts

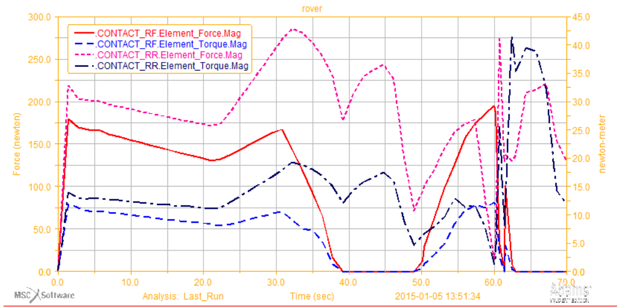

Fig 12. Force, torque magnitudes of left wheel contacts

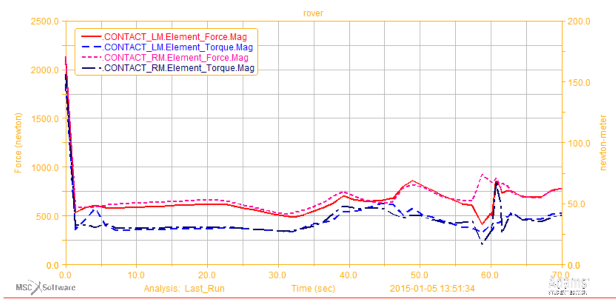

Fig 13. Force, torque magnitudes of right wheel contacts

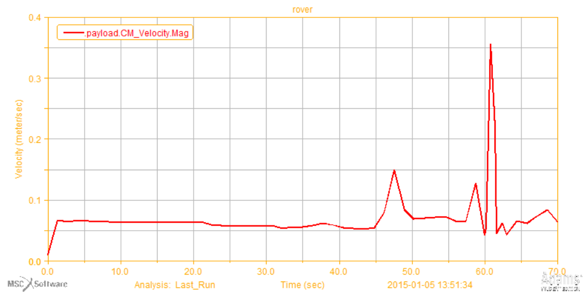

Fig 14. Velocity plot during wheel motion

7. Results

Lunar rover is tested over plane and deformable surface environment. The prototype system is developed over HP Z-400 workstation constituting Xeon processor with 16GB RAM and the packages used are Matlab, ADAMS and 3DSMax graphics application software. Dynamic motion simulation results are shown in figs. 11,12,13 and 14.

8. Conclusions

(1) The interface program developed with Matlab solves the problems of extracting data from a 3DS Max file, data transformation, and the reappearance of lunar terrain in ADAMS. ADAMS, and Matlab can be used to construct a virtual simulation system that integrates the features of 3D modelling, mobility control, and visualization for lunar rovers.
(2) A simple rover model has been presented. Under reasonable assumptions, it is possible to determine the rovers configuration, given its position and ground characteristics, and whether the rover will slide, tip over or maintain its balance. The mechanism of the rover has been developed, and it shows that over-actuation of the system affects the normal forces on application of specific wheel torques.
This virtual simulation system successfully simulate the motion of lunar rover over a plane and deformed terrain environment.

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