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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (23): 7201-7207, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.7201.7207

Lunar Terrain Construction and Application for Lunar Rover

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Abstact: The Lunar Rover design is the key problem of planet exploration. This study present how to model the Lunar Rover landing area containing typical terrain characteristic. Here, the crater and boulder models are firstly put forward, using Brown Fratal Motion to construct basic Lunar surface, then to add craters and boulders by means of Known Diameter Algorithm and Random-create Diameter Algorithm. In order to obtain the roughness of lunar terrain and the mechanical vibration characteristics of Lunar Rover, the lunar terrain simulation model is constructed by using software UG, Imageware and ADAMS. Lastly, the spectral characteristic of lunar terrain is acquired based on power spectrum curve by using reverse engineering algorithm. Simulation results demonstrate the dominant frequency vibration mechanics characterastics of lunar terrain with different roughness.

Key words: Lunar rover, fractal brown motion, crater, road spectrum

INTRODUCTION

As is know that the lunar surface is unknown, uneven, covered with the spongy topsoil. As a complex system, the design and optimization of lunar rover need a large number of experimental verifications. Also, lunar surface model and its terrain spectrum are the important factors which impact the rover performance. The simulation is effective to improve design efficiency and low the total cost. At present, the digital lunar surface tends to use plane and slope to mode lunar terrain, which hardly does great benefit for dynamic and kinematic simulation of lunar rover (Peitgen *et al.*, 2004; Shankar *et al.*, 2008; Yokota *et al.*, 2008). In addition, it's difficult to carry out the mechanics analysis owing to the unknown roughness of the lunar surface, especially when Lunar Rover carries the various precise equipment to implement an unmanned Lunar mission. If the detector response (incentives of installation equipment) of the rover closes to the natural frequency of the device, it will generate resonance and lead to fatal damage to the equipment. Under the unknown lunar terrain condition, the experiment or simulation results can effectively help to analyze the design parameters.

This article is organized as follows. Section 2 presents the 3D lunar terrain modeling method for lunar rover area show the application simulation of this kind of wheel. Section 3 describes the terrain spectrum simulation analysis of lunar rover. Section 4 has the conclusions.

3D TERRAIN CONSTRUCTION METHOD OF LUNAR LANDING AREA

Statistical analysis of Lunar landing area characteristics: The CE-3-X suspension of lunar rover simulation model is provided by China Aerospace Science and Technology Corporation eighth Institutes. And the whole simulation vehicle model is composed by the Unigraphics NX solid model of Semi-step Walking Wheel modeled on Impeller in ADAMS. Here introduce some parameters including overall quality of the vehicle, 120 kg. It is uniformly distributed above the six wheels. The diameter of the wheel is 300mm.The width is 140 mm. The effective width of the vane is 122.5 mm. The acceleration of gravity is 1/6 g. The previous article simulates the movement of the lunar rover, under these three conditions: Straight driving, one-side surmounting obstacle and two-sides surmounting obstacle (Wang, 2011).

There is a certain statistical rule between the diameter and quantitative distribution of lunar craters, namely the relationship between the quantity and diameter of craters is approximately inverse proportion (Elachi *et al.*, 1976). In the gentle mare regional, the distribution of craters is N (D) = 0.024 D-2.06 (Connor, 1971). In literature (Zhang *et al.*, 2009; Fan *et al.*, 2008), the formula of craters was introduced. This paper models the lunar landing area for the rover, which is 900m^2, the number of craters with different diameter within the scope is estimated according to the distribution formula used by Apollo 15.

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NASA described the typical contour of craters in literature (NASA, 1969). The shape of craters also has association with the age of craters. The shape of craters can be expressed by formula N = kDm, where N is one feature of, such as the height or width of crater cluster and so on and D is the diameter of craters. Taking new crater for example, the value of the depth of craters (Zd), the height of crater cluster (Zr) and the width of crater cluster (Dr) are shown in the following:

$$Zd = [0.23+ (0.25-0.23) \times rand (1)]\times D$$

$$Zr = [0.022+ (0.06-0.022) \times rand (1)]\times D$$

$$Dr = k^*Dm$$

where, rand Eq. 1 is a random number between 0 and 1. When solving the width of crater cluster, k = 0.25 and m = 1.011 are provided in literature (Patterson *et al*., 2008). Other three kinds of craters are randomly produced and added to the fundamental terrain. The two independent formulas are used to approximately describe the interior and the edge of craters, as is shown in the following.

The interior part:

$$-D/2 =\times= D/2$$

$$\frac{z (x, y) = 4z_d (x2 + y2)}{D2 + z_r - z_d}$$

The edge:

$$x = -D/2 \text{ or } x = D/2$$

$$\frac{z(x, y) = -4z_r(x^2 + y^2)}{D + 3z_r}$$

According to the formula introduced by "Apollo 15", we estimate the number of the boulder with different diameter in the landing area terrain, about 900 square meters. The shape of the lunar surface rocks covers a very broad range, a standard shape of the moon rocks are considered that the smallest scale and the largest scale ratio is between 1/1 and 1/5 (Chu and Zhang, 2007). In this article, the mathematical model of rocks is established as spherical, rectangular or a combination of spherical, rectangular. Due to erosion and rust, boulders surface may be dented. To correct this, a set of disturbance is randomly added to elevation values of boulder s, which makes the boulder surface more accord with its natural characteristics.

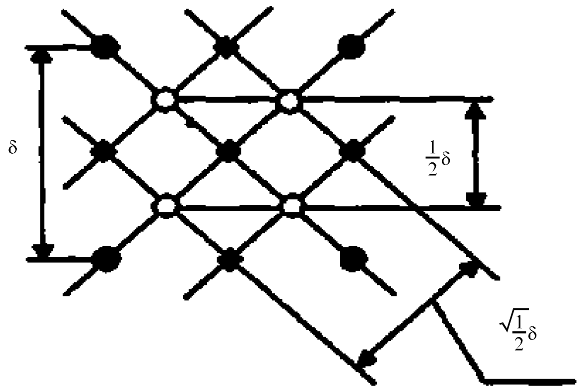

Fig. 1: Refinement of the grid

Construction of fundamental lunar terrain based on the fractal brown motion: The most important features of the fractal theory are self-similarity and fractal dimension. Fractional Brownian motion generates the mathematical model of realistic scenery. It can express many of the non-linear phenomena in nature effectively, which is notable for the random process of describing the real terrain.

Let X $(t_1, t_2 \ldots t_n)$ present stochastic multi-dimensional random function, t_i (i = 1, 2... n) be variable, if X $(t_1, t_2 \ldots t_n)$ satisfies the following properties:

Any random increment

$\Delta X = (t_1, t_2 \ldots t_n)\text{-}X (s_1, s_2 \ldots s_n)$ is gaussian random variables whose mean value is zero.

The variance of random increment depends only on the distance d as follows:

$$d = \sqrt{\sum_{i=1}^{n} (t_i - s_i)^2}$$

Specifically, the variance of increment are in proportion with 2H exponent of distance d.

Where, fractal parameter 0<H<1. The random process constructed by the above random increment is statistical and self-similarity, which can be used to describe two-dimensional or high-dimensional fractional Brownian motion. By inserting grid midpoint into the square grid and performing proper random offset for these midpoints, a vivid fundamental lunar terrain is generated.

A two-dimensional grid, as showed in Fig. 1, the current grid resolution is δ, by inserting the midpoint into a grid and then refining them, a new grid would be generated with the resolution of $\sqrt{2}/2\delta$, meanwhile rotated by 45° and so forth, all grids should be inserted midpoint and then refined. Afterward we get a new grid, whose resolution is ½ δ, has been rotated 45 degrees again. Then this new grid holds the same direction with the original one. We refine the grid by iterating the steps above and exert appropriate random offset onto every newly inserted grid midpoint. While the mean value of the random offset should be maintained at zero and the variance should satisfy the above equation. Then, the natural fundamental lunar surface model is established.

If $\delta = 1$, r is refinement factor in each iteration, σ^2 is the initial variance of the random function, the value of the random function becomes 0 while δ is set for 0, By the equation mentioned above:

$$\operatorname{var}\Delta X = E(|X(t_1,t_2)-X(s_1,s_2)|^2) = r^{2H}\sigma^2$$

When the Nth iteration, the grid resolution is r^n and corresponding random disturbance variance is presented by Δ^2_n. In:

$$\operatorname{var}\Delta X = E(|X(t_1,t_2\cdots t_n)-X(s_1,s_2,\cdots s_n)|^2) \infty (\sum_{i=1}^{n}(t_i-s_i)^2)^H$$

Where, fractal parameter 0<H<1.The random process constructed by the above random increment is statistical and self-similarity, which can be used to describe two-dimensional or high-dimensional fractional Brownian motion. By inserting grid midpoint into the square grid and performing proper random offset for these midpoints, a vivid fundamental lunar terrain is generated:

- The original node
- The generated node of the first iteration
- The generated node of the second iteration

the above process, the grid refining factor and the variance of the random offset should be:

$$\operatorname{var}\Delta X = E(|X(t_1,t_2)-X(s_1,s_2)|^2) = r^{2H}\sigma^2$$

The rectangular grid mentioned above is the base plane. In this paper, a 2D grid surfaces elevation data are calculated by Visual C++ program. The random disturbance range is adjustable, though mean value should be preserved 0 and the variance of Gauss distribution should be kept 1. Calculating elevation value for each point in the fundamental terrain, then store them in the txt file, which can be converted into RDF file format. Finally, import the rdf file into ADAMS and establish the model of lunar landing area by using a triangular mesh method, which could be used to analyze the lunar terrain spectrum properties.

Craters and boulders would be combined with the fundamental terrain according to the random method. The Known Diameter Algorithm and Random-create Diameter Algorithm is employed here, as showed in Fig. 1a. Using Imageware and UG to construct 3D solid model with different roughness for three types of lunar surface, then import 3D lunar surface solid model and the rover model into ADAMS to simulate operation condition. As shown in Fig. 2a shows Imangeware graph with craters and

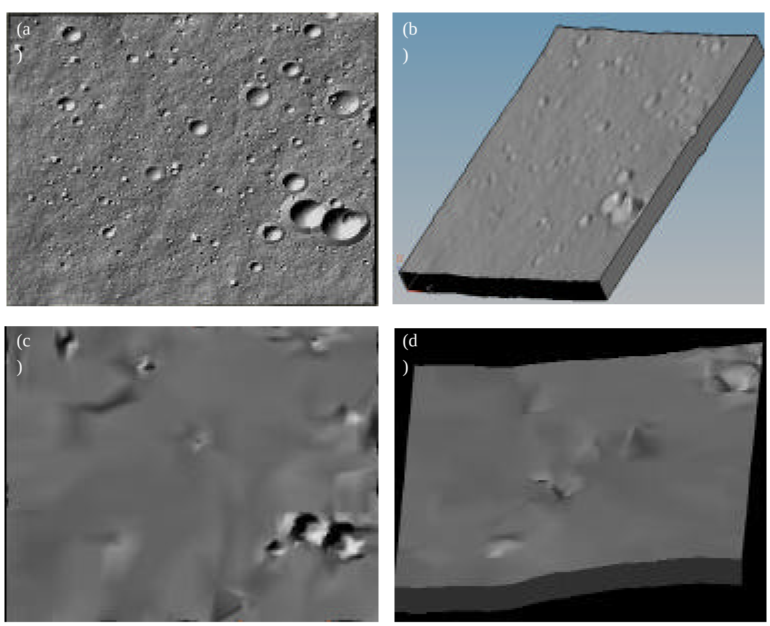

Fig. 2(a-c): lunar surface terrain including craters and boulders

boulders, b illustrates the UG graph related to a-c presents the ADAMS graph of b and d shows the left bottom of c by using ADAMS, the size of the left bottom is 10% of whole area.

TERRAIN SPECTRUM SIMULATION ANALYSIS OF LUNAR ROVER

Referring to the literature related to lunar surface roughness and road spectrum, the lunar surface models with different roughness are developed by using UG, Imageware and ADAMS software. Combining with lunar rover design requirements of the "Chang E" lunar exploration, we fulfill the lunar terrain micro-roughness related to mechanics characteristics.

Based on power spectral curve of three different type of lunar surface (NASA, 1969), multi-point curve fitting method is applied to establish mathematical model of power spectrum on three different types of lunar surface.

Imageware and UG are used to construct 3D solid model with different roughness for three types of lunar surface. The acceleration of the Centroid in vertical direction is shown in Fig. 3-5.

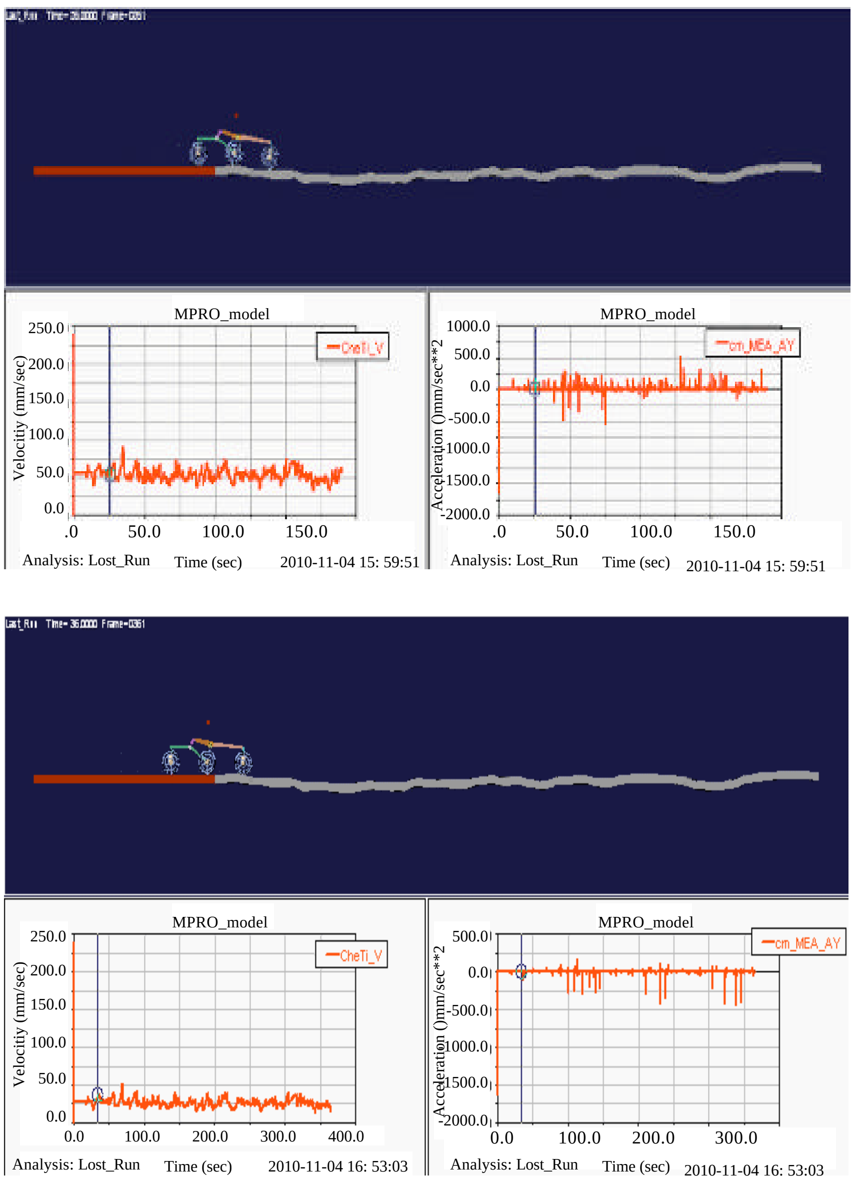

Fig. 3(a-b): Centroid acceleration simulation video and output curve when the rover travels at smooth mare, (a) Rover travels at 200 m h^{-1} and (b) Rover travels at 100 m h^{-1}

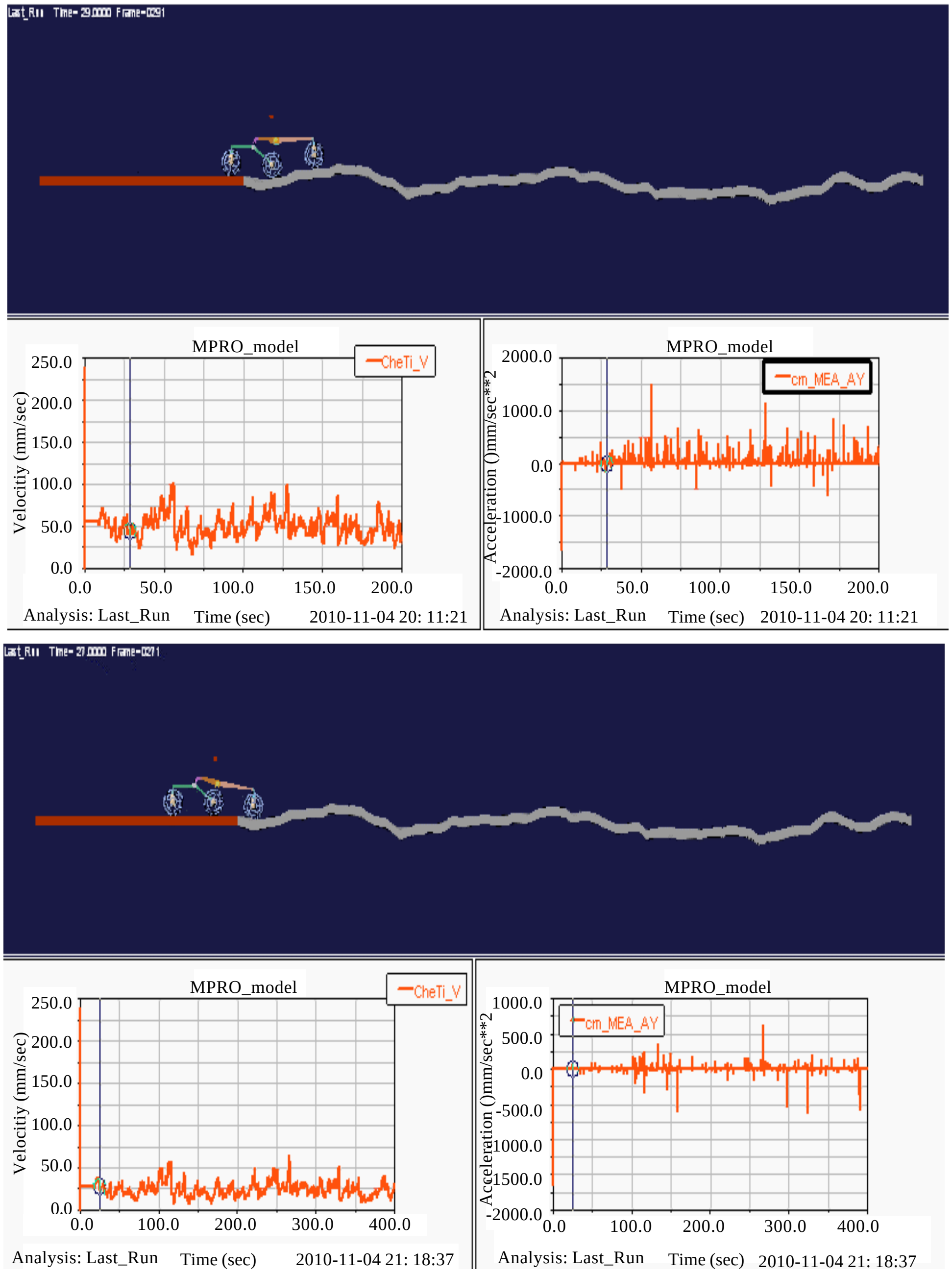

Fig. 4(a-b): Centroid acceleration simulation video and output curve when the rover travels at rough mare, (a) Rover travels at 200 m h^{-1} and (b) Rover travels at 100m/h

The acceleration curves show that: when the rover travels on the smooth mare, rough mare and rough upland at the same speed, the maximum acceleration value of centroid becomes larger and larger. The maximum acceleration of centroid increases with the raising of the rover speed on certain roughness surface. The maximum acceleration of centroid when traveling at 200 m h^{-1} on the smooth mare, rough mare and rough upland approximates 0.5, 1.5 and 1.8 g, respectively.

The centroid acceleration time domain signal of the rover should be processed by Fourier Transform (FFT) and Window function and then it is possible to obtain a

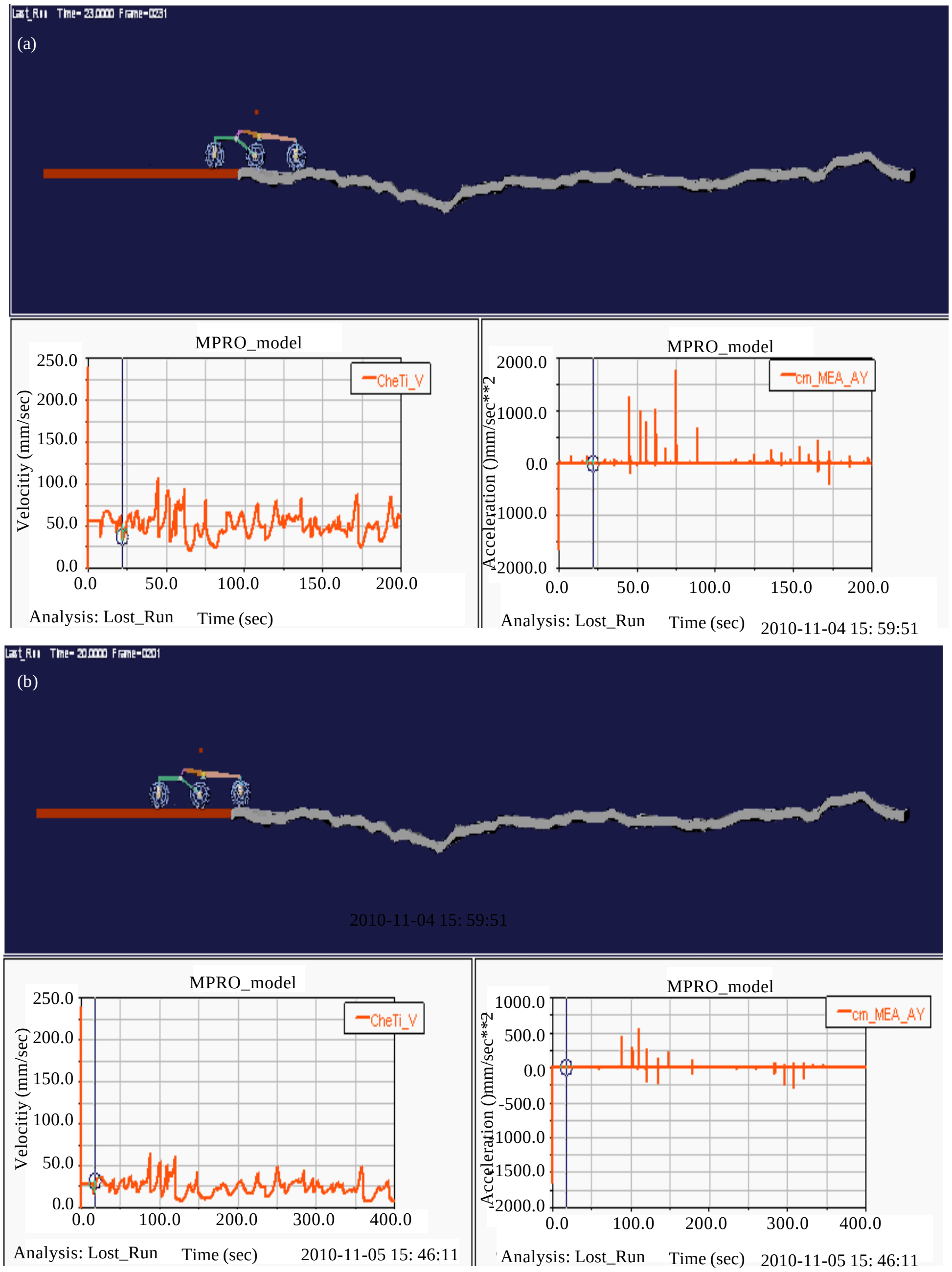

Fig. 5(a-b): Centroidace leration simulation video and output curve when the rover travels at rough upland, (a) Rover travels at 200 m h^{-1} and (b) Rover travels at 100 m h^{-1}

centroid acceleration amplitude spectrum. the centroid acceleration main frequency of the rover maintains approximately 0.5HZ.

CONCLUSION

This study presents how to construct Lunar landing terrain. By means of analyzing statistical characteristics of Lunar terrain, the crater and boulder models are firstly put forward, then to model fundamental lunar surface by using Brown Fratal Motion, the next step is to add cratersand boulders by means of Known Diameter Algorithm and Random-create Diameter Algorithm. Using reversee ngineering software to construct the lunar landing terrain and fulfill Lunar Rover kinematics and dynamics simulation.

Using reverse engineering software to construct the lunar landing terrain and fulfill Lunar Rover kinematics and dynamics simulation. Simulation results demonstrate the dominate frequency of vibration mechanics properties for different roughness surface. The simulation results show that the centroid acceleration frequency rate of lunar rover does not exceed 0.5HZ.

ACKNOWLEDGMENT

Sponsored by Specialized Research Fund for the Doctoral Program of Higher Education (20110041120024); National Natural Science Foundation Project (51205038); Fundamental Research Funds for the Central Universities DUT13JS14and DUT13JS02.

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