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System for Lunar Rover Virtual Simulation with Independent Movement of the Rover

Sakib Mujawar[1], Monika Ghadge[2], Sakshi Tonemare[3], Parth Mulye[4]

Students

Department of Mechanical Engineering

DYPIEMR, Akurdi, Pune (India)

Corresponding Author's Email: - *monikaghadge4532@gmail.com*

Abstract

The work investigated and presented a virtual simulation system based on an entirely digital model of the moon, coupled with modules for kinematics and dynamics as well as a module for simulating autonomous navigation. The simulation models for the systems have been created. Investigated are enabling technologies, including autonomous navigation, kinematics and dynamics simulation, and a digital lunar surface module. Based on these technologies, a prototype system for simulating the movement of lunar rovers is created. Despite being infrequently used in virtual simulation systems, autonomous navigation is a crucial component of lunar rover systems. This prototype system includes an autonomous navigation simulation module, which was added to demonstrate that the system can effectively support research on the autonomous navigation of lunar rovers. The simulation results showed that the system's synthetic simulation and visualising analysis systems are established.

Keywords: *- Lunar rover, virtual simulation, autonomous navigation, full-digital lunar terrain.*

INTRODUCTION

The sole natural satellite of the earth and closest celestial body is the moon, which is likewise rich in resources and has many potential uses. Growing international interest in lunar navigation has been observed in recent years. Lunar exploration will serve as the foundation for

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China's future interplanetary adventures. China is one of the world's leading nations in aerospace research. A lunar rover is a type of detector that can adapt to the various lunar environments, is outfitted with scientific detection tools, and transmits the collected data back to Earth. Numerous tests are necessary for a detection system. Computer simulations with the use of virtual reality technology are, in comparison to actual ground simulation tests, a high-efficiency, low-cost method that offers a reliable means of verifying detector design and control algorithm optimization.

The National Aeronautics and Space Administration (NASA) has been doing several studies on the modelling of lunar and Mars rovers. The NASA Jet Propulsion Laboratory (JPL) conducted research on several types of lunar rover navigation systems [3, 7] and created a ROAMS [2] simulation system. Additionally, a lot of work has been done on autonomous navigation systems by France's LAAS-CNRS and Carnegie Mellon University (CMU) [1]. Despite being infrequently used in virtual simulation systems, autonomous navigation is a crucial component of lunar rover systems.

The primary focus of this article was on a virtual simulation system that used a fully digitalized model of the lunar surface and included modules for kinematics, dynamics, and autonomous navigation. Chinese researchers studied the navigation systems for lunar rovers and virtual simulation systems, but they rarely considered how to combine them. The virtual lunar rover simulation system described in this study is based on the geometry and physical characteristics of the lunar surface and includes an autonomous navigation module.

THE SYSTEM ARCHITECTURE

Fig. 1 shows the system architecture of the virtual simulation of a lunar rover. First, we have a module for geometric modelling that creates a digital lunar rover and digital lunar terrain. This system depends heavily on the digital lunar landscape for path information parsing and collision detection. Kinematics, dynamics, and motor drive control are three crucial modules for dynamics. While the terrain parameters are required from the path information, those can offer analysis for rover navigation.

The lunar rover simulation platform's virtual environment is where navigation and collision detection are combined and

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carried out as a whole. The path planner, a key component of the exploration mission, may be tested and validated virtually depending on the surroundings.

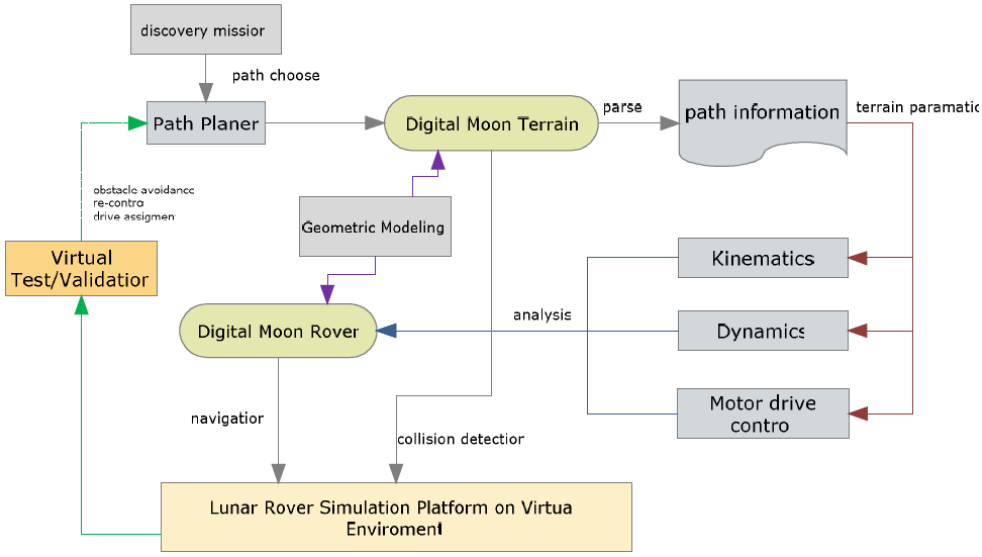


Fig.1 System Architecture

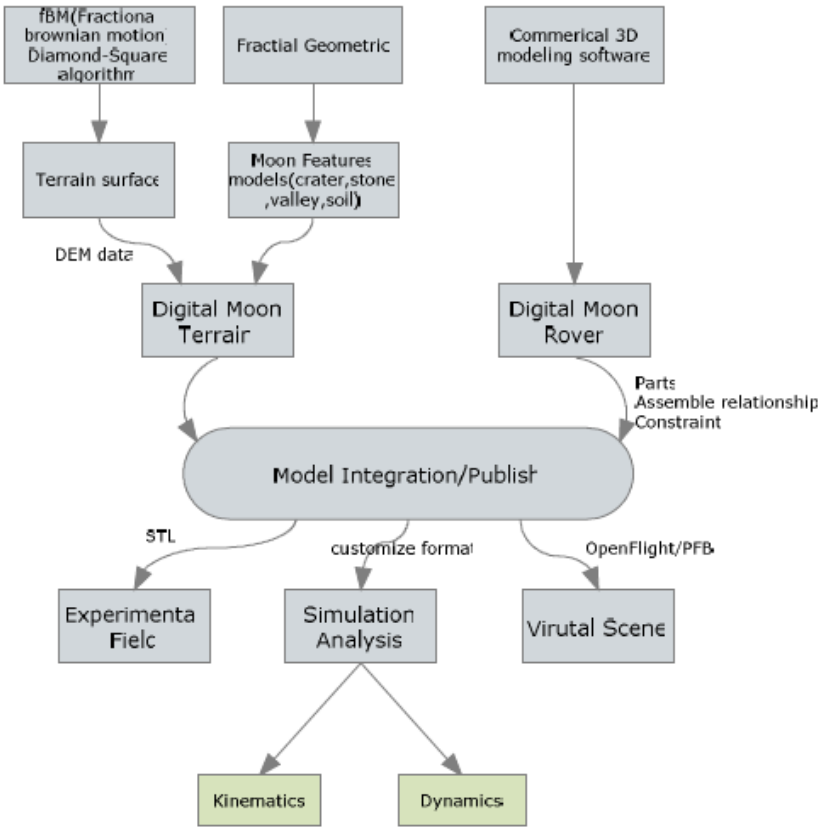


Fig. 2 Geometric Modeling

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Kinematics and Dynamics

According to conventional wisdom, because the lunar rover moves so slowly, we may disregard its dynamic impact. Additionally, it will waste a lot of computing resources to take dynamics into account. Thus, the majority of the comparable systems completely disregarded the dynamic effect. However, making too many assumptions would ultimately produce "distortion simulation," which reduces the accuracy of the lunar rover in real life.

Results from a single-wheel bench test on a lunar rover have demonstrated this. According to recently released domestic papers, a lot of domestic research institutes have been concentrating on dynamics modelling and its connected fields. We anticipated that comparing the simulation to the test result would take a while.

The initialization of the lunar rover's geometric property parameters and physical attributes, the definition and solution of constraints, the collision detection and collision response, and the control signal processing interface are all tasks that the motion control module of this system uses the Vortex software to complete.

The objective of the dynamics module is the interaction between wheels and soft lunar soil, which is accomplished mostly through the creation and resolution of kinetic models.

Visualization Module

The main purpose of the visualisation module which serves as an interface between the simulation system and the operators, is to import the terrain and lunar rover files, build up a scene tree, and then use three-dimensional graphics rendering techniques (scene model management, texture mapping, lighting, real-time shadow, three-dimensional text, and others) to display the virtual lunar environment and analyse the rover's real-time status, including 3-D full-digital lunar terrain, dynamic lunar terrain, and so on. After importing the moon rover model and landscape information, they should be transformed into OpenGL Performer scene visuals.

A channel describes a perspective on the scene graphics. An OpenGL Performer software pipeline renders this view, which is subsequently shown in a window on a chosen screen. Figure 3 illustrates this rendering procedure.

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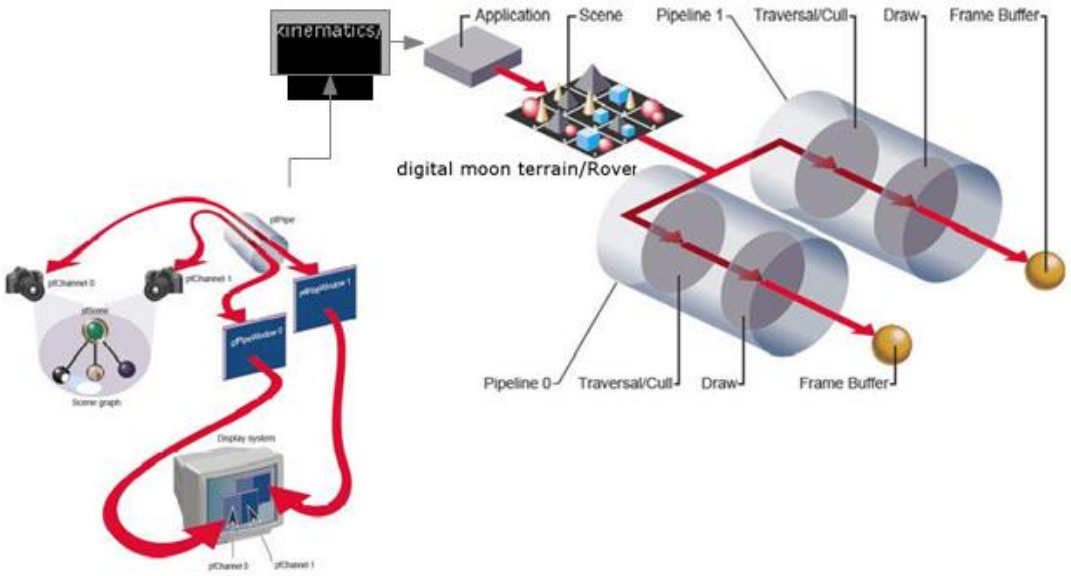


Fig. 3 Visualization module based OpenGL Performer [11]

Visual Navigation

This module models autonomous lunar rover navigation. Real-time frontal picture acquisition, image analysis, obstacle detection, path planning, and autonomous navigation control decisions are all made by the system. Visual navigation modules will often interact with other modules, making interface and information exchange crucial during the integrating process.

KEY TECHNOLOGIES

Full-digital Lunar Terrain

Virtual simulation's foundation is digital lunar landscape. Craters and valleys continuously rise and fall on the lunar surface. Therefore, the digital lunar landscape should incorporate these fundamental features, such as slopes, craters, and stones, while also being as accurate to the actual lunar surface as possible in order to provide a superior simulation result. The lunar surface exhibits extremely clear fractal properties as a natural terrain. It makes sense to create the lunar base landscape using fractal technology. A realistic parameterized virtual lunar surface for lunar rover simulation is created by first creating the lunar base terrain and stones on the lunar surface using fractal technology, adding lunar craters and stones to the terrain in accordance with real statistical data, and then constructing joint hill models around it, as shown in Fig. 4.

An autonomous navigation simulation also needs geometric attributes and position

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data, in addition to the necessity to portray the terrain feature in this lunar rover simulation platform. In a digital simulation, it is not enough to just have a basic, lifelike lunar landscape.

A full-digital lunar landscape is created using the terrain attribute files and geometric characteristics. In this article, we use XML to express three geometric geometric properties and position attribute by means of XML. characteristics and the position property.

An effective tool for working with structured documents is XML (eXtensible Markup Language), a general-purpose specification for developing unique markup languages. Custom tags are supported by XML, which also offers a robust extension mechanism. For expressing the properties of geographic information, XML is therefore a great choice.

Base terrain, pits, stones, and soil characteristics are several types of lunar landscape. Make a terrain tree for the lunar landscape first, and then explain the branches that correspond to the basic terrain, pits, stones, and soil qualities.

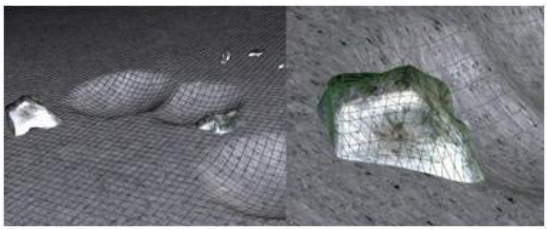


Fig. 4 Lunar digital terrain

Dynamic Module

Wheel-Terrain Interaction Model

The wheel-trail interaction model has previously been the subject of several studies. However, the majority of them believed that the connection would be stiff, which would reduce the accuracy and dependability of the dynamic analysis of the lunar rover. This research makes the assumption that the wheel is stiff while the lunar surface is soft and uses the Bekker pressure and torsion model to analyse the interaction between the rover wheel and terrain (see Fig. 5).

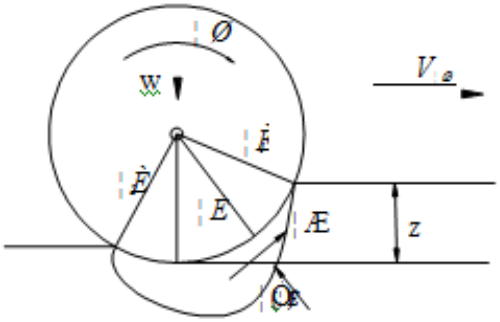


Fig. 5 Rigid Wheel—Lunar Surface Interaction Model

By vertically, rigid wheel's load W passes to lunar oil through interact-face and should be balanced by lunar surface's counter-force. If the stress in the width b

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of rigid wheel is same, then W can be presented as follow:

$$W = rb\left[\int_{\theta_1}^{\theta_2}\sigma(\theta)\cos\theta d\theta + \int_{\theta_1}^{\theta_2}\tau(\theta)\sin\theta d\theta\right] \quad (1)$$

b is the width of rigid wheel in the equation above.

The pull force of rigid wheel cruising on soft lunar surface is:

$$F_{DP} = rb\left[\int_{\theta_1}^{\theta_2}\tau(\theta)\cos\theta d\theta - \int_{\theta_1}^{\theta_2}\sigma(\theta)\sin\theta d\theta\right] \quad (2)$$

Wheel distance Mw :

$$M_w = r^2 b\int_{\theta_1}^{\theta_2}\tau(\theta)d\theta \quad (3)$$

2) Real-time Collision Detection

Virtual reality systems must have real-time collision detection as a fundamental feature. Every collision model in the system requires collision detection to calculate all of the geometry relationships with other models, and determining the relationship between two aspects is a difficult task that uses a lot of computing resources. Real-time collision detection technology plays a significant role in this research's whole virtual environment since there are intricate models of the rover, surface, and rocks there, as well as a high need for real-time and realism. Several distinct layer structures make up the collision model. By combining rough collision and accurate collision, the efficiency of collision detection is increased. This technology's major feature is O(N2) times detection for N models, which results in significant computational complexity when N is large. We can save a lot of time and resources if we partition the system into numerous detection spaces, quickly collide the spaces to locate probable collisions, and then use a faceted model to perform accurate collision and obtain collision information. Additionally, alternative layer structures may be applied to the virtual world to speed up collision detection even more because the collision space can be mutually compromised.

C. Path Planning and Visual Navigation

Normally, a lunar rover can navigate and be controlled wirelessly, but this is occasionally not possible due to changes in the relative geometry caused by the rotation and revolution of the Earth and the moon. Thus, self-navigation and control by the lunar rover's equipment are a significant trend [6, 9]. Numerous studies have been conducted on navigation, some of which are included in this essay.

Today's navigation technology comprises stereo, sun-sensor, inertia, and other navigation methods [1, 7, 10]. Stereo navigation provides significant benefits over other navigational technologies in terms of accuracy and informational depth,

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and as the field has developed, its use in actual rovers has become increasingly feasible.

In this study, simulations of the navigation process and algorithm verification are included in addition to those of the visual effect. The three components of the navigation simulation are picture capture, image processing, and path planning and navigation. By using a simulated CCD camera, the image acquisition module captures the surface in front of the rover. The picture is analysed by the image processing module using a digital terrain query to obtain information about the altitude and obstacles. The last module is in charge of path planning and using the appropriate algorithm to steer the rover clear of obstacles.

In a practical system, the rover's integrated CCD camera provides the navigation system with a forward-looking view.

We employ the same image-acquisition approach to obtain a picture in a virtual simulation system in order to attain the realness of the laws of physics. The rover model is first modified to include two cameras, which are visible in the virtual landscape. The cameras are used as a fixed point of view in the simulation system for the rover. The dynamic module's computation of position coordinates (x, y, and z) and posture matrix provides the rover with geometry and location information about the perspective. The interaction between the camera and the virtual terrain is thus determined by relative geometry. Therefore, using the theory of camera and terrain information, the range of the landscape and picture in the viewing volume may be collected. The picture (in RGB format) is kept in the system and may be used for image processing and visualisation modules.

2. Image process

The XML properties file of the digital landscape may be used to query information about obstacles, such as the sorts of obstacles (rock, hole, and slope), their positions (x, y, and z), and their sizes (altitude, diameter, and cover area). The obstacle information file contains all of this data in a single XML file. The system is capable of offering information services for upcoming modules.

3. Path planning and control

When the path planning and control module receives the obstacle information, it first generates a list of possible paths and assesses each one's steering ability using the information provided by the obstacles.

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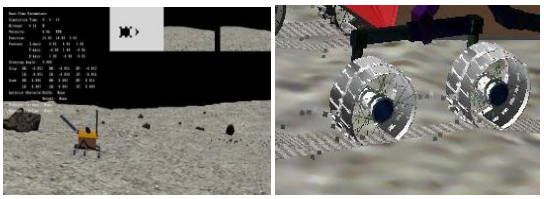
The assessment criteria are displayed in Table I. The eventual course will be determined by its degree of steerability. Then the system sends commands to the motion control module to keep the rover moving or turning (keep continuing in the same direction, change direction, or turn back). In the visualisation module, the direction is displayed simultaneously.

Table I Criteria of Evaluation

Type	By-pass/Cross	Standard
bulge	By-pass	gradient>30o
bulge	Cross	gradient :15 o ~30o
dent	By-pass	depth :0.25 ~ 0.4m
dent	Cross	depth :0.1 ~ 0.25m
obstacle	By-pass	altitude>25cm
obstacle	Cross	altitude <25cm

PROTOTYPE SYSTEM AND ITS APPLICATION

A SGI ONYX 350 supercomputer, three BARCO projectors, a FOB, a data glove, a stereo CrystalEye, and other components are used to construct the prototype system. Fig. 6 depicts the simulation interface for a lunar surface rover. The rover may be moved forward, backward, left, or right via keyboard input. A mouse click can be used to complete the pan and rotation. As a result, the operator may view the rover's location and gesture in real time from various angles. Two tiny windows in Figure 6(a) show the real-time image captured by the rover's two cameras, and a texture on the left side displays the real-time parameters. Through the study of parameters and images, the rover can perform autonomous navigation.



(a)Simulation interfaces (b) Track effect

Fig. 6 Interface of simulation system

CONCLUSION

The major focus of this work is a modelling system for a lunar rover that includes dynamic and visual navigation. First, using fractal technology and statistical regularity, a complete computer model of the complicated lunar surface is created. Then we conduct research, establish the wheel-soft-terrain interaction model, and create a simulation system prototype. In order to compare genuine test data with simulation data, the follow-up work is anticipated to create a digital environment that is identical to the real experimental terrain. Another area of research is to create a high-performance computational (HPC) system to assist simulation systems due to the high computing demands of 3D rendering and image processing.

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