An Approach To Navigation For Lunar Rover Based On Virtual Reality Technology

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***Abstract*—This paper presented a method for navigation of lunar rover. This method used the real lunar data to model the virtual terrain. In addition, its path is planned using a knowledge based genetic algorithm accounting for uncertainty of modeling and sensor data. This method overcomes the invalid problem of past methods in complicated rough terrain to plan path. Simulation results show the feasibility and effectiveness of the algorithm in path planning for lunar rover.**

***Index Terms*—virtual reality, lunar rover, navigation**

I. Introduction

The moon is the nearest celestial body and the only natural satellite of the earth; it also possesses rich resources with broad development prospects. In recent years, there has been a growing interest in navigation of the moon among the nations.

China is one of the great powers of aerospace research, and lunar exploration will be the start of its future interplanetary explorations. Lunar rover is a kind of detector which is able to adapt to the different environment of the moon, loaded with scientific detection instruments and transmit the final probe data back to the earth. A detector system requires a large number of tests. Compared with the real ground simulation test, to a large extent, computer simulations with the application of virtual reality technology is a high-efficiency, low-cost way that provides a good means of verification for the detector design and control algorithm optimization.

Navigation is one of the key techniques in research on lunar rover. Based on the different requirements of the task, navigation meanes to design the ideal operating line, guiding the robot to precisely move along the chosen route, avoiding risk factors and safely arriving at destination[1]. Path planning is an important component of a lunar rover navigation technology which is the basis for the robot to perform various tasks. Existing path planning methods can be divided into three types: one is full of environmental information based on the traditional path planning; the other is behavior-based path planning; third is based on sensor information of the local path planning.

The traditional path planning methods are generally assumed that complete information on the surrounding environment is known. However, the lunar rover works on the lunar surface, and there is no complete environmental information.Therefore, the rover must use sensors to sense the environment , and thus achieve the local environmental information for incremental path planning; Behavior-based path planning method than the traditional path planning method is more likely to accept sensor data, and therefore more suitable for the natural environment, but this method does not guarantee the accessibility of goals; Path planning based on sensor information is often completely unknown or partially unknown, the robot must interact with the environment to perceive the environment, and thus achieve local environmental information [2].The main methods of Path planning based on sensor information are: artificial potential field method, neural network, fuzzy logic and genetic algorithms.

However, faced with the complexity of unstructured environment on the lunar surface, the above method is difficult to work. Currently, in the natural terrain common planetary path planning methods are two: First is the Tangent Bug algorithm [3], and the second is the D * algorithm [4]. Tangent Bug algorithm used limited range sensors to plan path, and its two assumptions conditions limited its application. Literature [5] was improved to adapt them to the natural terrain;The D * algorithm use incremental sensor information, therefore,the algorithm is especially suitable for navigation in rough terrain. However, neither considers slip, and uncertainties in modeling and sensor data.

Literature [6] proposed a navigation method, taking into account the impact of sliding on the path planning, however, it only analyzed traversability of the lunar rover in rough terrain , and if applied in practice, there are many factors to considerations, such as velocity of path searching algorithm, terrain parameters on-line estimation, etc.

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This paper presents a method for lunar rover navigation using genetic algorithm based on knowledgefor path planning [7].The path planning method is not only fast, but considering uncertainty of modeling and sensor data, and enhance the practicality of the navigation for lunar rover.

II. MODELING

The products of geometric modelingcontains two parts: digital moon terrain and digital moon rover.For digital moon terrain, we also divide it to two portions forgenerating: terrain surface and moon features models Besides, the digital moon rover is modeled by a commercial 3D modeling software.

The digital moon terrain and digital moon rover are integrated into model integration/publish interface for experimental field, simulation analysis and virtual scene.

A. Modeling lunar rover

Simulation provides an effective method to secure space robots such as lunar rover. Simulation can verify the physical models, the planning-path for robots, and so on. Using the modeling software of Multigen Creator on SGI graphics workstation, three-dimensional solid model of the rover is created, and shown in Figure 1[8], it is used to the model simulation for path planning.

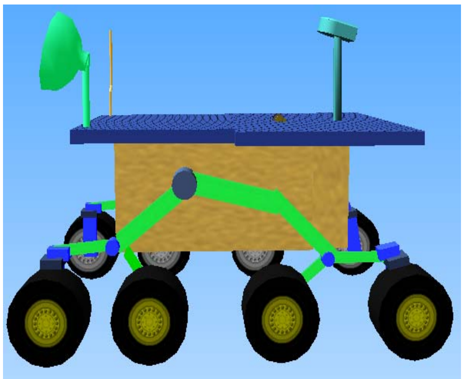

Figure 1 solid model of the rover

B. Modelling terrain

Digital lunar terrain is the basis of virtual simulation. The surface of lunar is the continuous ups and downs of craters and valleys. Therefore, the digital lunar terrain should include these basic elements such as slopes, craters and stones, meanwhile in order to achieve a better simulation result, it should be in accord with the real lunar surface as much as possible. As a natural terrain, the lunar surface has very obvious fractal characteristics. It is reasonable to use the fractal technology to form the lunar base terrain. First it uses the fractal technology to form the lunar base terrain and stone upon the lunar surface,then adds lunar craters and stones to the terrain according to the real statistical data, then joint hill model around it, forming a realistic parameterized virtual lunar surface for lunar rover simulation, as Fig. 1.

In a digital simulation, not only a basic lifelike lunar terrain is necessary, while in an autonomous navigation simulation, the geometric properties and location information are also required, besides, the feature of the terrain in this lunar rover simulation platform needs to be expressed as well. The files of terrain attribute and geometric properties together constitute a complete full-digital lunar terrain. In this paper, we describe geometric properties and position attribute by means of XML. XML (eXtensible Markup Language) is a general-purpose specification for creating custom markup languages, which is a powerful tool to deal with structured documents. XML supports custom tag and provides a powerful expansion mechanism. So XML is very suitable for expression of the attributes of geographic information. Lunar terrain can be categorized into base terrain, pits, stones, soil properties. First of all, create a terrain tree for lunar terrain, and then describe base terrain, pits, stones, soil properties as branch of the tree respectively.

Lunar rover terrain environment modeling is a key technology to achieve one of the navigation task, which is the basis for the rover path planning.

Using shot of the lunar surface using satellite photos, digital elevation model (DEM) of the terrain data is achieved, a three-dimensional terrain for the lunar rover is modeled to provide the navigation environment.

DEM data is the discrete data points, and to represent the actual terrain surface, is about to converse discrete point set into TIN (Triangulated Irregular Network-TIN) model. The most common method is to Delaunay triangulation subdivision algorithm. This paper employs the incremental insertion algorithm used commonly in Delaunay triangulation algorithm for establishing TIN model .

Incremental insertion algorithm of the basic steps are:

(1) Define an initial polygon to contain all the data points;

(2) Create the initial triangulation in the initial polygon, and then iterate the following steps until all the data points are processed;

(3) Insert a data point P, find the triangle t containing P in the triangulated net, and connect P with the three vertices of t to generate a new triangle;

(4) Optimize triangle using local optimization of (LOP) algorithm.

With the rapid development of modeling techniques, three-dimensional terrain models often contain tens of thousands, hundreds of thousands or even millions of triangular facets, storaging, rendering and transmission terrain model of such a huge amount of data brought great inconvenience for lunar rover navigation, and made a great challenge in real time. Therefore, a three-dimensional terrain model must be simplified.

This paper uses the terrain simplification method proposed in literature[8]. Main steps of the algorithm are as follows:

Step 1: pretreatment (PREPROCESSING operation).
Step 2: Data read (READ operation).
Step 3: simplify (DECIMATE operation).
Step 4: Data output (WRITE operation).

C. *Kinematics and dynamics*

In the traditional understanding, we considered that lunar rover move so slowly that we could ignore the dynamic influence. Additionally, it will waste a lot of computing resource to take dynamics into account. Therefore, most of the similar systems entirely ignored the dynamic influence. However, too many assumptions will eventually lead to the result of "distortion simulation" which makes the less reliability for the lunar rover of the real world. This has been proved by lunar rover single-wheel bench test results. Based on the domestic related papers published, recently many domestic research institutes have been focused on dynamics simulation and its relative domains. We believed that it will take long for comparing the simulation with the test result.

The motion control module in this system using Vortex software to complete the following tasks: the initialization of lunar rover geometric property parameters and physical attributes, the definition and solution of constraints, collision detection and collision response, control signal processing interface. Dynamics module mainly complete with establishing and solving kinetic model, among which the interaction between wheels and lunar soft soil is the focus content.

D. *Visualization module*

Visualization module is an interface between simulation system and operators, the main function of which is to import the file of terrain and lunar rover, building up a scene tree, using three-dimensional graphics rendering methods (scene model management, texture mapping, lighting, real-time shadow, three-dimensional text and so on) to display the virtual lunar environment and analyze real-time status of the rover, including 3-D full-digital lunar terrain, dynamic lunar rover and some relative parameters display. First, import lunar rover model and terrain data; convert them into an OpenGL Performer scene graphics. A view into the scene graphics is described by a channel. This view is rendered by an OpenGL Performer software pipeline, then display into a window, on a selected screen.

E. *Visual navigation*

This module simulates lunar rover autonomous navigation. It captures the front image of the vehicle in real-time, analyzes the captured image, distinguishes obstacles and make decisions for path planning and autonomous navigation control. There will be frequent interactions between visual navigation modules and other modules, so interface and information exchange work turn out to be very important during integrating process.

III. KNOWLEDGE BASED GENETIC ALGORITHM

A. *Coding*

Lunar environment is expressed by the triangular mesh model. Planning path, an undirected weighted graph is built, in which each node represents a triangle in the triangle mesh model, and edges represents connection lines between the two triangles. Each node is identified by an order number, the node's coordinates is the center coordinates for each triangle. Here

$$p = x + 10 \times y \tag{1}$$

Sequence identity number of path points is as the path encoding. We assume that there is not duplicated serial identification number in each path. For example, a path can be expressed as 0-24-36-66-74-84-99, where 0 is the starting point, 99 for the target point, and 36,66,74 and 84 for the intermediate nodes.

B. *Adaptive parameter*

We assume that in the initial population $P(0)$ the path length of the individual a_n is $L(a_n)$.The path of "0-36-66-74-84-99" can be expressed as:

$$L(a_n) = \sum_{i=1}^{N} d_i + \beta_i C \tag{2}$$

here di expresses the distance between the path point i and the path point j. N is the number of segments in the path of an. For example, in the path "0-36-66-74-84-99" the number of segments N is equal to 5; βi is the coefficient of the depth of that node, which is defined as follows:

$$\beta_i = \begin{cases} 0 & -h_0 \le z \le h_0 \quad feasiblepath \\ \sum_{j=1}^{M} a_j & other \end{cases} \tag{3}$$

here, M is the number of edges which the segment contains, and the depth value of edge nodes is outside the range of $-h_0 \le z \le h_0$

$$\sum_{j=1}^{M} a_j = \begin{cases} |z| & -h_{\max} \le z \le -h_0 \; or \; h_0 \le z \le h_{\max} \\ & feasiblepath, butdificult \\ |z| & h_{\max} \le z \; or \quad z \le -h_{\max} \\ & notfeasible \end{cases} \tag{4}$$

Here, h0 is equal to 0.05m, hmaxis equal to 0.15m. z is the larger absolute value of the depth of the edge node. The length of each path is its fitness value $f(a_n)$. That is $f(a_n) = L(a_n)$

C. *Genetic operators*

This paper designs the five genetic operators. As shown in Figure 1, the black part of the figure for the barrier area, gray area is passable, but there are difficulties, colorless part for passable area.

Crossover operator: from two parent individuals we randomly select two nodes ,and exchange the back section of the two node points, as shown in Fig. (a) of Figure 1

Mutation operator: randomly select a node from a path which is replaced with the non-path node. Mutation operators increase population diversity, therefore, individuals after mutation do not have to be more excellent than the individual before mutation, as shown in fig.(b) of Figure 1.

Repair operator: this operator can be applied to a feasible path and non-feasible path. Randomly select a node, the local search technology is applied to move the node to the best place in adjacent area ,as shown in Fig. (c)of Figure 1

Delete operator: this operator can be applied to a feasible path and non-feasible path. Randomly select a node, check its two adjacent nodes, and connect the two nodes. Remove it if it is useful that the selected node is deleted, as shown in Fig. (d) of Figure 1

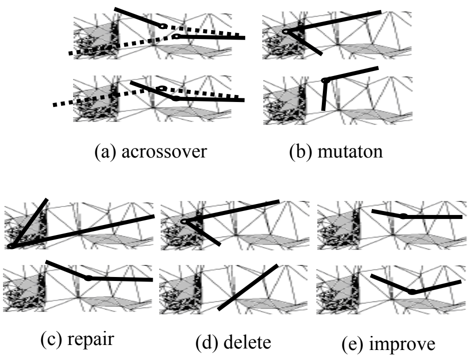

Fig.1 five genetic operators

Improved Operator: this operator can be applied to a feasible path. Select a node from the path, insert a new node, respectively, from the two line segments connected with the node, connect the two new nodes, if this path is feasible, then delete the selected node, as shown in figure (f) of figure 2.

VI. SYSTEM UNCERTAINTY

In practice, in order to effectively detect the lunar environment and accomplish a given task, the lunar rover may have to rely on a variety of sensors (such as OD, visual sensors, etc.) to perceive the lunar surface environments, and thus build environment model, then plan motion and make decision. However, due to the limitations brought about by the sensor, the information obtained by the perception of these sensors there are information uncertainty in different degrees. Perceived uncertainty of the information will inevitably lead to uncertainty of model, accordingly, planning and decision-making based on models and perception, planning and decision-making will also be containing uncertainty.

A. Uncertainty model

Probability method is an effective means by which uncertainty is described. For uncertainties in above analysis, because the ultimate result is collision which possibly come into in movement process between lunar rover and obstacles, the system certainty can be described by the relative spatial relationship of the obstacle with the rover. As specifically shown in Figure 2.

The probability density of Obstacle Center CΩ(Oj) is two-dimensional normal distribution as shown in formula (5).

$$\rho(x,y)=\rho'(r)=\frac{1}{2\pi\sigma^2}e^{-\frac{r^2}{2\sigma^2}} \qquad (5)$$

In formula (5), $r=\sqrt{(x-x_\eta)^2+(y-y_\eta)^2}$.

For a more detailed description, see literature [9].

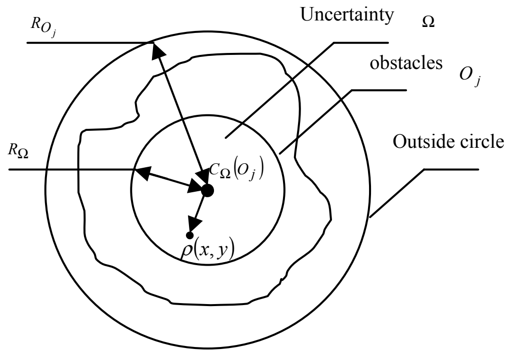

Fig.2 uncertainty model

B. Uncertainty Measure

To reflect the uncertainty of the system to the path planning model, and accordingly plan a safe path away from obstacles as possible, the paper proposes the concept of potentially dangerous areas, and describes the danger information which the uncertainty lead to by the introduction of risk measurement functions.

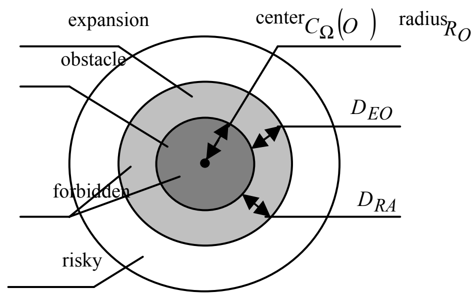

Figure 3 obstacle area relationship diagram

Figure 3 shows the relationship diagram between Obstacle Area, Expanded Obstacle Area,

Forbidden Area,and Risky Area

The risk measurement functions $f_{G_{FD}}^{risky}$ can be defined as follows:

$$f_{G_{FD}}^{risky}=255\cdot\left[1-\prod_{j=1}^{N}\left(1-\Gamma\left(d\left(Fbd_j,G_{FD}\right)\right)\right)\right] \qquad (6)$$

which，

$$\Gamma\left(d\left(Fbd_j,G_{FD}\right)\right)=\begin{cases}\iint_{G_{FD}}\rho'\left(d\left(Fbd_j,G_{FD}\right)\right)dxdy & d\left(Fbd_j,G_{FD}\right)\le D_{RA}\\ 0 & d\left(Fbd_j,G_{FD}\right)>D_{RA}\end{cases} \qquad (7)$$

$$d\left(Fbd_j,G_{FD}\right)=\min_{E_n\in\partial Fbd_j}d\left(E_n,G_{FD}\right)=\min_{E_n\in\partial Fbd_j}\sqrt{\left(x_{E_n}-x_{G_{FD}}\right)^2+\left(y_{E_n}-y_{G_{FD}}\right)^2} \qquad (8)$$

For a more detailed description, see literature [9].

V. PATH PLANNING

Step1. Environment modeling. Do environmental modeling using TIN (Triangulated Irregular Network-TIN).

Step2. Coding and initialization. To encode possible paths, set the counter of evolution algebra $t \leftarrow 0$; set the maximum evolution algebra T; generated n individuals randomly as initial population $P(0)$.

Step3. Individual evaluation. Using the equation

$$L(a_n) = \sum_{i=1}^{N}(d_i + f_i) + \beta_i C$$

to calculate each individual's fitness value in population $P(t)$.

Step4. Determine whether the environment changes. If the environment changes, then run step 5. Otherwise, go to step 6.

Step5. Re-evaluation for population $P(t)$.

Step6. Selection operation. To retain the best individual in parent population, run tournament selection in parent groups,.

Step7. Crossover operation. Use the single-point adaptive crossover operator on the group.

Step8. Mutation operation. Use the mutation operator on the group with each individual gene by probability p_m.

Step9. Other operations. Use other operator on group $P(t)$. After these sessions of selections, we finally get the next generation $P(t+1)$.

Step10. To determine whether it is in the dynamic environment. If it is, then go to step 4. Otherwise, run step 11.

Step11. To check if the final condition is meet If $t \le T$, then $t \leftarrow t+1$ is right, go to step 3; if $t > T$, we can consider the minimum fitness value of the individual as the optimal solution, output it and stop computing.

VI. SIMULATION EXPERIMENT

To demonstrate the effectiveness of the algorithm, we have conducted the simulation test on PC. The main experimental parameter are set as follows:

the environment is a 24 m× 24m for the lunar terrain, population size M = 40, k1 = 0.8, k2 = 0.05, k3 = 0.75, k4 = 0.5. the maximum evolution generation T = 500. Set start and end point coordinates are (4.125,7.125), end (14.125,16.125).

To simplify the experiment, assuming no slipping,at the same time, in order to model the uncertainty of the environment, the path planning algorithm can be incorporated into the uncertainty of the risk measure, and as long as one condition is not satisfied, it is thought as forbidden area to ensure a more reasonable path planning.

Typical simulation results is shown in Figure 4.

VII. CONCLUSION

This paper presents an navigation approach to lunar rover based on virtual reality.It uses real terrain data to build virtual terrain model,in the meantime, knowledge based genetic algorithm is used to plan path in a virtual three-dimensional terrain. The path planning method is not only fast, but considering the slip, uncertainties of modeling and sensing data, the system and other factors. Thus practicality of the navigation of lunar rover is enhanced. The simulation results show the feasibility and effectiveness of this method in navigation for lunar rover.

This next step work will focus on the main physical parameters estimation of of the terrain and the estimation of contact angle between terrain and wheel.

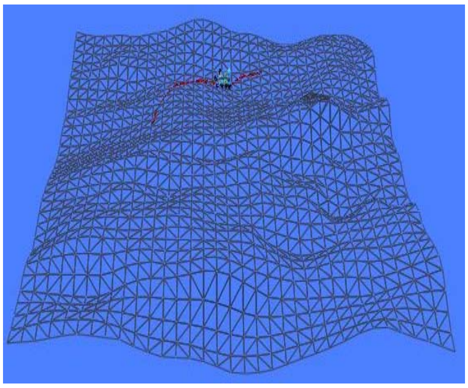

Figure 4 typical simulation results

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