FOR THE MARSOKHOD ROVER PROJECT

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ABSTRACT

This paper presents a general overview over Marsokhod rover mission . The autonomous navigation for a Mars exploration rover is controlled by a vision system which has been developed on the basis of two CCD cameras, stereovision and path planning algorithms. Its performances have been tested on a Mars-like experimentation site.

INTRODUCTION

This study has been performed in the frame of the Russian-French project Marsokhod : Marsokhod is a small rover (less than 100 kg) designed for Mars exploration ; its launching is foreseen in 1998. This six-wheeled vehicle was tested 1992 in Death Valley and has shown a remarkable locomotion capacity ; it was foreseen to run it on the surface of Mars, being teleoperated from the Earth. However, due to important delays for data transmission, its operational range in such a mode is very limited. In order to improve this situation, an autonomous navigation facility is under study in CNES (French space agency),

and in close cooperation with the Russian Marsokhod team. This should increase drastically the operational range of the rover and its scientific return, allowing movements of several tens of meters per days, only limited by available on board energy. Furthermore, this system enables a short range perception, thus a safer obstacles detection with an increase of the rover's security.

The goal of the work in progress is to prove the feasibility and to develop an autonomous path generation sub-system. This includes mainly a pair of stereo cameras and the necessary software to implement on-board 3D reconstruction and path-planning. The basic idea is to acquire and process a pair of stereo images after a stop of the rover every 5 to 10 meters.

A series of tests has been achieved since 1993 to assess precision, robustness and performances of algorithms as well as to define the specifications of the vision hardware, in particular the focal length and the stereo basis. This paper presents results of the studies and experiments performed.

The constraints of the project and the poor knowledge on the Martian environment make it an interesting challenge to improve the rover's autonomy. It is also a preparation for future projects with stronger requirements, presently being carried out by CNES [1].

CONSTRAINTS ON THE VISION HARDWARE

The autonomous navigation system is confronted with important constraints in the area of available resources, some of them are highlighted hereafter :

- use of a fixed stereovision device (2 CCD cameras) set at 1 meter high; CCD devices will be TH7861 matrix (300x400 pixels of 23x23 microns),
- no specific calibration facility,
- use of one Transputer based board to process pictures, with restricted memory size,
- hostile environment in which the device has to operate (low temperature with large variations and dust are major threats for mechanical stability and electronics).

The impossibility to move the cameras has some impacts on the stereovision device:

- a wide field of view is required to reduce the invisible area just in front of the rover, to get a fair optical range (5 to 10 meters) and to have a good probability of finding a path in the common field of view of both cameras. This leads to chose small focal lengths and to deal with optical distortions.

- no target can be seen by the cameras, so that no in-flight calibration can be performed. We need to fix rigidly the cameras and to know exactly their position and orientation to apply on-board stereovision.

AUTONOMOUS NAVIGATION

The general scheme of the process to be applied on Marsokhod images involves two main steps for each cycle :

- Stereovision and 3D reconstruction of the relief of the terrain surface,
- Detection of obstacles from the disparity map and path planning minimising

risks for the rover.

The main algorithms have already been described in [2], so that we will focus here on 3D reconstruction accuracy tests, which enabled us to select the two basic parameters of the device : the length of the stereo basis and the focal length.

The 3D reconstruction of the points of the terrain surface is done without calibration, by using the camera's geometry and intrinsic characteristics.

3D reconstruction accuracy

As it is not necessary for the reconstruction error to be much less than the error on the knowledge of the rover's motion, the specification for 3D reconstruction accuracy has been defined as follows : up to 4 meter, the error shall be less than 4% of the distance; between 4 and 10 meters, the error shall be less than n%, n being the distance in meters.

An error model has been defined, with the following elements :
- uncertainty on the size of pixels and focal length,
- distortion residue,
- quantization on x and y,
- uncertainty on disparities.

Although this model is a worst case model (sum of absolute values of each error), the results are close enough of the error specification (see Figure 1).

To assess real errors, measurements have been done on a set of structured objects with specific marks. The distances between the marks have been measured (measurement accuracy : 1 mm) and compared with the values given by 3D reconstruction algorithms. This has been done on a set of about 20 distances in various conditions :

- distances from the cameras: 1.5, 3.4 and 6.7m
- stereo bases : 150 , 300 and 450 mm
- different resolutions : full resolution (i.e. 2 milliradians per pixel), resolution reduced to 1/2 (pixels merged by 4) and resolution reduced to 1/3 (pixels merged by 9).

Maximum and quadratic errors have been calculated for all these configurations. We found that the specified 3D reconstruction accuracy can be reached easily with a relatively short stereo basis (less than 300 mm) and low resolution (4 milliradians for pixel resolution); with a TH7861 matrix, this leads to a focal length of 5.7 mm. Results corresponding to this choice are shown in Figure 1.

Obstacle mapping and path planning

Several tens of image pairs have been acquired on a specific Mars like test area made up at CNES. The robustness of the process has been evaluated for various lightening conditions and terrain configurations . One example is presented here from two 512*512 CCD cameras, with 4.8 mm focal length optics and a 30 cm stereo basis. The top view of the obstacles mapping presents holes corresponding to areas occulted by rocks, but it has been possible to find a path large enough for the rover (Figures 2 and 3).

Performances

The performances given in Table 1 are not fully representative for the final software because the present release has not yet been fully optimised. A rough performance estimate for the in-flight hardware (384x288 CCD and T800 transputer) has also been performed .

CONCLUSION

The goal was to prove the feasibility of an autonomous and safe motion of Marsokhod

on the surface of Mars, allowing the rover to get rid of teleoperation constraints, and thus to reach a range fitting with its locomotion capacity.

The results of the studies and experimentation done in CNES in the frame of Marsokhod project have shown that it is possible to reconstruct 3D points and to find trajectories on a non structured Mars like landscape with a sufficient accuracy for the requirements of a sub-system of autonomous navigation . According to these results, a prototype of stereovision device is presently under development and will be used in the coming months to test the complete sub-system , in terms of hardware as well as the implemented algorithms.

The new acquisition campaign scheduled for 1994 foresees real time processing of the images taken at each position, and moving the cameras in order to fulfil the planned path ; this will enable us to check the elementary paths given by the algorithms and also to see if it is possible to reach a given target by connecting consecutive trajectories. After this, we plan to make tests on board of the Russian rover at the end of 1994 to analyse the interface with the control of the rover and to define the exact use of vision in the Marsokhod mission.

REFERENCES

[1] L. Boissier, B. Hotz, C. Proy, O. Faugeras, P. Fua , 1992. Autonomous planetary rover (VAP): onboard perception system concept and stereovision by correlation. In *Proceedings of IEEE International Conference on Robotics and Automation.*

[2] C. Proy, M. Lamboley, I.Sitenko, T.N.Guyen , 1993. Improving Autonomy of Marsokhod 96 . In *Proceedings of 44th Congress of the International Astronautical Federation.*

Performances	256 x 256 images	512 x 512 images	384 x 288 images
Time	3.6 sec on Sparc10	40 sec on Sparc 10	90 sec estimated on T800
Memory (code + data)	65O Kbytes	2 Mbytes	1 Mbyte

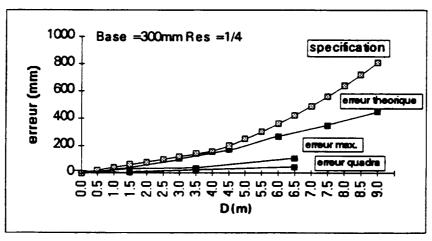Table 1 : Performances of the complete processing sequence
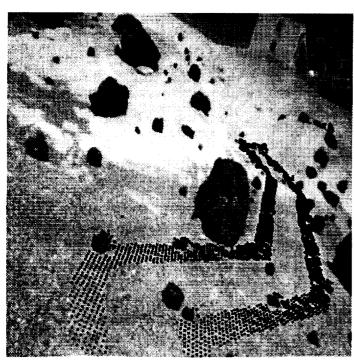

Figure 1 : Example of 3D reconstruction accuracy

Figure 2 : Image from Geroms Site
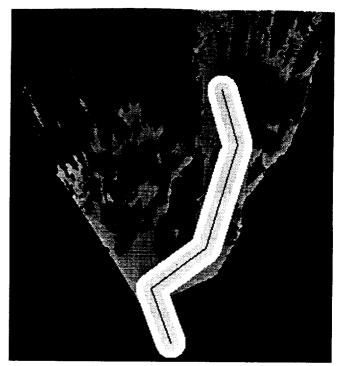The path found for rover
has been traced in black

Figure 3 : Top view of the obstacle map
black: unknown areas, dark grey:
obstacles, white: path of the rover

A Unified Control Architecture for Planetary Rovers

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THIS PAPER WAS NOT SUBMITTED IN TIME FOR PUBLICATION.