Guided Descent to Mars

Vision-based Navigation System for a Mars Probe

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Background

The Vision-based Navigation System designed aims to provide a better navigation feedback to the control systems and increase the landing precision of the probes. The mission frame is the Mars Minor project of ISAE TAS-ASTRO Master, a low cost and low weight lander mission to Mars [1].

This navigation system will start operating at around 15 km altitude, once the speed is reduced after the re-entry phase; when a small aperture is opened (see Figure 1) to allow the camera to start taking images of the surface.

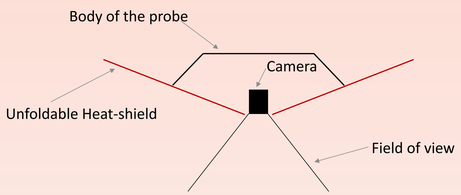

Figure 1. Probe design

System design

The system has as inputs a database of Mars images and the images taken by the probe. Performing several functions (see following section), the system is able to obtain the ground position, altitude, heading, speed and track of the probe.

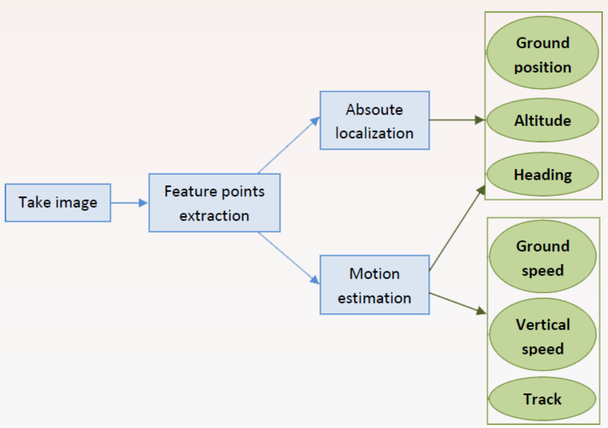

Figure 2. System design. In blue, the functions. In green, the outputs.

Functions

Feature points extraction. *A set of characteristic points is obtained from the image taken by the probe by using VLFeat-SIFT (Scale-Invariant Feature Transform) [2].*

Feature points database. *A database of feature points is previously extracted from database images of the surface coming from orbiters such as MRO [3]. This process reduces computational time and size of the database.*

Absolute localization. *The database is filtered according to a first estimation of position and time of landing (figure 3). Then, the selected feature points (f.p.) are matched with the ones obtained from the surface image coming from the probe's camera, providing the latitude, longitude and altitude of the probe.*

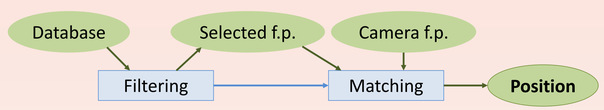

Figure 3. Absolute localization algorithm diagram. In blue, the functions. In green, the inputs and outputs.

Motion estimation. *A first initial position, coming either from the IMU or the absolute localization algorithm is required. This algorithm compares the feature points extracted from two successive camera images. The purpose of the motion estimation is to reduce computation time once a first position fix is obtained, as it uses a single image instead of the whole database.*

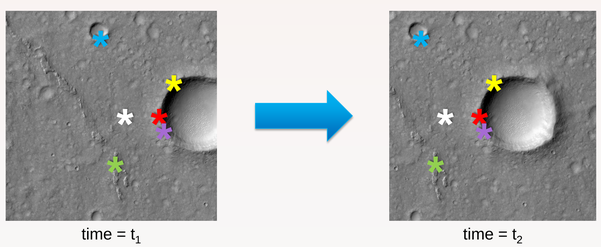

Figure 4. Motion estimation matching process between SIFT feature points obtained from two consecutive camera images. The pairs of points with the same color represent matched points. The grey points at right represent the position of old points of the first image. The arrows show the displacement of the points.

Implementation and simulation

*The **system**, comprised by the absolute localization and motion estimation algorithm, has been implemented in Matlab.*

*The **simulation visualization** has been designed in order to provide an easy-to-use interface for every potential user. The result (figure 5) is freely available at www.marslanding.tk. With this web-based interface, you can select a simulation depending on the EDL profile, characteristics of the probe and landing site. Then, the position and velocity computed by the system can be analyzed through a variety of plots and a 3D visualization of the descent [4].*

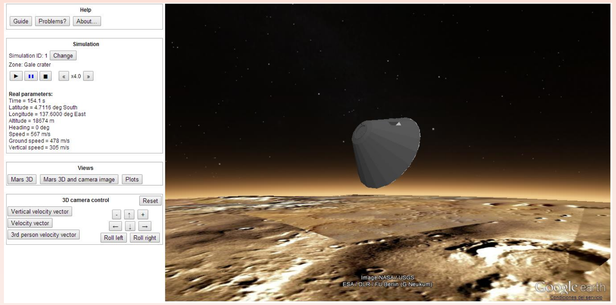

Figure 5. Simulation visualization. Left, the simulation controls, view selection and camera control. Right, main window of the interface, where the 3D visualizations and the plots are loaded.

Results

The system has been tested with a database of 2 million feature points. After the filtering, the number of points is reduced to 1000 with an uncertainty cube of 2x2x2km. The results are shown in table 1.

Estimation error and system performance	
Absolute localization error	13.4 px (75 m on ground)
Motion estimation drift	< 2px / estimation
Abs. loc. computing time	0.6 seconds
Motion est. computing time	0.07 seconds

Table 1. Estimation error and system performance. The tests have been performed with a standard PC with Matlab.

Conclusions

According to the results described above, the system has shown positive results during simulations. The performance of localization determination and movement estimation is satisfactory.

Compromises. *An estimation of the landing site prior to the launch of the probe is required in order to reduce the size of the database.*
There is also a restriction regarding the availability of database images. The system needs images taken over a wide range of solar hours and of at least 5 m/px of the zone; however, the HiRISE database usually has images of a small range of hours, restricting the landing time.

Versatility. *As long as there is an image database and the surface does not change much in time, the system can work in any illuminated surface of any celestial body, including the Moon or other moons of Mars. In addition, the web-based simulation has been designed to facilitate the manage of data and the configuration change between celestial bodies.*

References

1. D. Hernandez, *Mars Minor*. Concepts and Approaches for Mars Exploration, 2012
2. *VL Feat-SIFT,* VLFeat.org
3. *HiRISE Image Explorer*, University of Arizona http://hirise.lpl.arizona.edu
4. *Google Earth API,* Google Inc.

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