AUTOMATION OF GROUND IMAGE BASED MARS ROVER LOCALIZATION

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In Mars rover missions, localization of the rover with a high degree of accuracy is of fundamental importance both for safe rover navigation and for achievement of scientific and engineerin g goals. D uring the Mars Exploration rover (MER) 2003 mission, wheel odometry, sun positioning using rover images, and IMU are used to estimate rover positions and orientation. The onboard visual odometry (VO) technique is applied when the rover travels on slopes o r across loose soils in order to correct errors caused by wheel slippage. The Ohio State University (OSU) team, in collaboration with the Jet Propulsion Laboratory (JPL), has been performing ground image -based rover localization using an increment al bundle adjustment (BA) method to achieve improved localization accuracy at rover locations over the entire traverse. Key to the success of the bundle adjustment is selection of a sufficient number of well-distributed tie points to link the ground images into an image network. During MER mission operations, tie points linking panoramic images taken at one rover position were selected automatically, while cross -site tie points were selected manually. It is highly desirable to automate the cross -site tie po int selection process so that rover localization can be performed onboard autonomously.

We are currently developing an innovative method for object modeling and matching from multi -view ground (rover) images for automated Mars rover localization. Since ro cks are one of the major features/objects found in rover images of the Martian terrain, our method focuses on extracting, modeling and matching of rocks as the first stage.

Rocks are extracted from dense 3D ground points generated from stereo image match ing. Given the input of dense 3D ground points, the rock extraction process consists of two steps: rock peak extraction and rock surface point extraction. Rock peaks are extracted from 3D ground points using the following criteria: 1) they are the local he ight maxima within a window of 50 x 50 cm, for example; 2) the maximum height difference within the window is greater than a threshold of 10 cm, for example; and 3) there are at least a set of ground points within the window.

In order to extract rock sur face points so that we can model the shape of that rock, we first fit a local plane using all the 3D points within a window centered at the extracted peak. Then, the height of a rock is calculated as the perpendicular distance from the peak to the plane. C onsequently, the above -ground points are identified. Note that these above -ground points may belong to different rocks in the window. The surface points belonging to one particular rock are selected by a local search from the peak. Based on ground-truth me asurements of width/height ratios from the images taken at the Spirit landing site, the search radius is set from 0.3h to 1.7h (h is the height of the specific r ock). Within the lower and upper limits, the search radius is adaptively changed during iterations. The search process proceeds as follows: 1) starting from the peak, a search is made for the points around the rock peak using the lower limit of the search radius (0.3h), and the distance of each such point to its closest neighbor is calculated and th e maximum (maxD) of these distances is obtained; 2) starting from each of the points that have been extracted from the last step, search for the all the points within the above obtained maxD distance and update the overall search radius by adding maxD. Thi s step iterates until the overall search radius reaches the upper limit, 1.7h, or there are no new points added. Extensiv e experiments using Spirit rover's Navcam (Navigation Camera) images have verified that the rock peaks and rock surface points for most of the rocks within 30 m of the camera can be extracted correctly.

The extracted rocks are modeled using analytical surfaces such as hemispheroids, semi -ellipsoids, cones, and tetrahedrons. The parameters of the models for each individual rock are estima ted by a least-squares fitting using the rock surface points. Points that are far from the analytical surface model are eliminated during iterations. The resultant RMS (Root Mean Square) error of the fitting for each rock reflects the accuracy with which e ach model fits that particular rock. In the end, the model with the minimum RMS error is used to represent a particular rock. Our experiments have demonstrated that most of the extracted rocks can be modeled with reasonable accuracy; typical RMS errors are 1 cm to 4 cm for rocks with heights over 20 cm.

Using the panoramic (partial or full) stereo images taken at two adjacent rover sites (stops), we are able to obtain two sets of rocks with their analytical models. The next critical step is to match the ro cks from the two different sites so that the matched rocks can be used as tie points in the bundle adjustment for rover localization. Obviously, the shape of the same rock may look very different when seen from different sites (because of different viewing directions). In general, if a rock is roughly symmetrical and it is not too far from either s ite, the derived analytical models from two different sites should be comparable.

Currently, we are developing and testing two methods for rock matching. The fir st method is matching of individual rock models, i.e., comparison of rock model parameters and other metrics such as volume and surface area. Mismatches may exist when two different rocks have a similar size or when the rock is not modeled very accurately.   The second method is matching of rock distribution patterns, or the geometric configurations of the rocks. Preliminary test results show that this method is generally reliable and is able to match the rock patterns between sites that are 26 m apart or clo ser. Using this method, mismatches may also hap pen when one small rock is extracted from one site and another small rock (which is very similar to it) is extracted from the second site. By combining these two rock -matching methods, we expect to have an enh anced rock-matching method that can robustly match rocks extracted from two adjacent sites to support fully automat ed rover localization.