Field Tests on Flat Ground of an Intensity-Difference Based Monocular Visual Odometry Algorithm for Planetary Rovers

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Abstract
In this contribution, the experimental results of testing a monocular visual odometry algorithm in a real rover platform over flat terrain for localization in outdoor sunlit conditions are presented. The algorithm computes the three-dimensional (3D) position of the rover by integrating its motion over time. The motion is directly estimated by maximizing a likelihood function that is the natural logarithm of the conditional probability of intensity differences measured at different observation points between consecutive images. It does not require an intermediate step to determine the optical flow or establish correspondences. The images are captured by a monocular video camera that has been mounted on the rover looking to one side tilted downwards to the planet's surface. Most of the experiments were conducted under severe global illumination changes. Comparisons with ground truth data have shown an average absolute position error of 0.15% of distance traveled with an average processing time per image of 0.06 seconds.

Intensity-Difference Based Monocular Visual Odometry Algorithm

• Alternative algorithm: It was proposed in [1] as an alternative to the long-established feature-based stereo visual odometry algorithms [2, 3, 4, 5].
• Positioning computation: The rover’s 3D position is computed by integrating the frame-to-frame rover’s 3D motion over time.
• Type of sensor: The frames are taken by a single video camera rigidly attached to the rover (see Fig. 1 and Fig. 2a).
• Direct motion estimation: The frame-to-frame rover’s 3D motion δR is directly estimated by maximizing the likelihood function of intensity differences at the N key observation points, without establishing correspondences between features or solving the optical flow as an intermediate step, just directly evaluating the frame-to-frame intensity differences measured at the N key observation points. The key observation points are image points with high linear intensity gradients.
• Compact solution: The resulted frame-to-frame 3D motion estimates have the following compact form:

\[
\Delta \mathbf{R} = \mathbf{O} \mathbf{O}^{-1} \mathbf{F} \mathbf{O}
\]

(1)

where \( \mathbf{O} \) is the observation matrix and \( \mathbf{F} \) is a vector with the intensity differences measured at the N observation points.
• Iterative algorithm: Since the observation matrix \( \mathbf{O} \) resulted from several truncated Taylor series expansions (i.e. approximations), the Eq. (1) needs to be applied iteratively to improve the reliability and accuracy of the estimation.

Problem Statement

• Field tests missing: Despite that in [1] the above intensity-difference based monocular visual odometry algorithm has been extensively tested with synthetic data, an experimental validation of the algorithm in a real rover platform in outdoor sunlit conditions is still missing.

Main Contribution

• To provide first field test results: This paper’s main contribution is to provide the first of the outdoor experiments towards validation of the algorithm, which was obtained for now on surfaces of little geometrical complexity such as flat ground, to help to clarify whether the algorithm really does what is intended to do in real outdoors conditions under severe global illumination changes.

Results

The intensity-difference based monocular visual odometry algorithm has been implemented in the programming language C and tested in a Clearpath Husky A200™ rover platform (see Fig. 1). In total 343 experiments were carried out over flat paved sidewalks only, under severe global illumination changes due to cumulus clouds passing fast across the sun. Special care was taken to avoid the rover’s own shadow in the scene. During the experiments towards validation of the algorithm, which was obtained for now in the presence of shadows, and comparing the results with the corresponding ground truth data, we concluded that the algorithm is able to deliver the rover’s position in average of 0.06 seconds after an image has been captured and with an average absolute position error of 0.15% of distance traveled.

So far so good: Although the experiments so far have been only on flat ground, these results closely resemble those achieved by known traditional feature based stereo visual odometry algorithms, whose absolute position errors of distance traveled are within the range of 0.15% and 2.8% [2, 3, 4, 5].

Forthcoming field tests

• Field tests on rough terrain: In the future, the algorithm will be tested over different types of terrain and geometries, and also it will be made robust to shadows.

References


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