MONOCULAR VISUAL ODOMETRY FOR MARS EXPLORATION ROVERS. Geovanni Martinez, Image Processing and Computer Vision Research Laboratory (IPCV-LAB), Escuela de Ingenieria Electrica, Apartado Postal 11501-2060 UCR, Universidad de Costa Rica, San Jose, Costa Rica, email: gmartin@eie.ucr.ac.

This idea belongs to the topical area 3: Mars Surface System Capabilities. It is particularly related to the near-term example 16: long-range navigation of rovers on the surface of Mars, localization, autonomous, and relative (to/from hub) surface navigation.

Abstract: Over the past twenty years Mars surface exploration has been conducted particularly by the following six-wheel rocker-bogie mobile rovers developed at NASA Jet Propulsion Laboratory [1]: the Mars Pathfinder mission rover Sojourner, the Mars Exploration Rovers (MER) Spirit and Opportunity and the Mars Science Laboratory (MSL) rover Curiosity, where the latter is still on his way to Mars and is expected to land on Mars on August 2012 [2].

Because the maximum exploration range of a rover is limited to few tens of kilometers, a Mars Airplane is also currently being developed [3], which will increase the mission coverage to hundreds of Kilometers. As opposite to the Mars Airplane, flapping insect robots (entomopters) are also being investigated due to their potential to fly slow as well as safety land and take off on the rocky Mars terrain [4].

Since the rovers are typically commanded only once per Martian solar day, they must be able to autonomously navigate to science targets and to place instruments precisely against these targets, where any navigation error could cause the loss of the entire day of scientific activity.

For precise autonomous navigation, the rovers must have an onboard system for precise and reliable estimation of its position and orientation. Usually the current rover's position and orientation are estimated by integrating the rover's motion (rover's change of position and orientation) from the time the motion began to the current time, assuming that the initial rover's position and orientation are known or previously estimated. In the MER rovers Spirit and Opportunity the rover's change of orientation (rover's rotation) is estimated from measurements of three-axis angular rate sensors (gyros) provided by an Inertial Measurement Unit (IMU) onboard the rover [5]. The rover's change of position (rover's translation) is estimated from encoder readings of how much the wheels turned (wheel odometry). The initial rover's orientation is estimated from measurements of three-axis accelerometers provided by the IMU, as well as a sun position vector provided by a sun sensor which is also onboard the rover. The initial position is reset by command at the beginning of the rover's motion.

Unfortunately, a limitation to the rocker-bogie mobile rovers as observed on Mars is excessive wheel slippage on steep slopes, which causes large errors particularly on the estimated rover's position from wheel odometry. To correct any position error, the rover's motion is also estimated by using a stereo visual odometry algorithm, which estimates the rover's motion by maximizing the conditional probability of the 3D correspondences between two sets of 3D feature point positions, which were previously obtained from two consecutive stereo image pairs captured by a stereo video camera before and after the rover´s motion, respectively. The conditional probability is computed by modeling the 3D position error at each feature point with Gaussian distributions and using a linearized 3D feature point position transformation, which transforms the 3D position of a feature point before motion into its 3D position after motion given the rover's motion parameters.

This stereo visual odometry algorithm was first proposed by Moravec in [6] and then improved in [7][8]. Afterwards, it evolved to become more robust [9] until it was finally implemented in real time to be used in the Mars Exploration Rover Mission [10]. After evaluating the performance of the above stereo visual odometry algorithm in both MER rovers Spirit and Opportuniy on Mars, it was further improved in [11] resulting in a more robust and at least four time more computationally efficient algorithm, which can also operate with no initial motion estimate from wheel odometry. This last updated version of the stereo visual odometry algorithm is planned to be used in the MSL rover Curiosity.

Our idea is to develop, implement and test in real time and in a real rover test-bed a monocular visual odometry algorithm which will be able to estimate the robot's motion evaluating the intensity differences at different observation points between two intensity frames captured by a monocular video camera before and after the robot's motion, respectively, as an alternative to the traditional stereo visual odometry. The rover´s motion will be estimated by maximizing the conditional probability of the frame to frame intensity differences at the observation points. The conditional probability is computed by expanding the intensity signal by a Taylor series and neglecting the nonlinear terms, resulting the well known optical flow constraint [11][12], as well as using a linearized 3D observation point position transformation, which transforms the 3D position of an observation point before motion into its 3D position after motion given the rover's motion parameters. Perspective projection of the observation points into the image plane and zero-mean Gaussian stochastic intensity errors at the observation points are also assumed.

Similar approaches have been already implemented and tested with very promising results in applications such as video compression [13] and teleoperation of space robots [14].

Our approach differs from traditional optical flow approaches like those described in [15] because we do not follow the typical two-stage algorithm, where the optical flow vector field is first estimated by using the optical flow constraint equation and then the rover´s 3D motion is estimated from the previously estimated optical flow vector field, instead we have developed an one-stage maximum-likelihood estimation algorithm based on the optical flow constraint equation, which is able to directly deliver the 3D rover´s motion parameters. This one stage algorithm is more reliable and accurate because it does not rely on two consecutive estimators to get the rover´s 3D motion.

The motivation of this work is to show that the robot's motion can also be precisely estimated from frame to frame intensity differences using a monocular video camera. We even believe that the proposed algorithm could have a similar error growth than that achieved with the stereo visual odometry algorithm used by the MER rovers and the MSL rover. Additionally, it has the advantage of being able to operate just with a single monocular video camera, which consumes less energy, weight less and needs less space than a stereo video camera. We are also convinced that the proposed algorithm could be computationally more efficient than the stereo visual odometry because it does not depend at all on any correlation based template matching for operation.

This algorihtm could help to improve long-range autonomous navigation of rovers on the surface of Mars because it could be used as an alternative when wheel odometry and traditionally stereo visual odometry have failed, or as a means of validating the stereo visual odometry estimate or to generate a better estimate by statistically combining the wheel odometry estimate, the stereo visual odometry estimate and the estimate of the proposed algorithm using sensor fusion techniques. It is also an excellent candidate for lighter rover systems or entomopters where space, weight and power supply are really very limited.

We are looking for an opportunity to demonstrate the performance of our algorithm comparing it with the traditional stereo visual odometry in a real rover test bed. Our intention is not to replace the stereo visual odometry but to show that monocular visual odometry is another reliable and precise way for odometry estimation that can be merged with other sensors to improve the long rage autonomous navigation of the current and future Mars rovers, Mars Airplanes and Mars flapping insect robots.

This algorithm could also be used to improve planetary landing accuracy (topic area 2, next-term example 7) when merged with acceleration and rotational velocity measurements from an IMU augmented by velocity and altitude information from Doppler radar similar as proposed in [16]. Here the change of attitude and the translation estimates delivers by the algorithm can also be taken into account by the control entry and landing systems to improve landing accuracy.

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