Robust Feature Detection and Matching for Vehicle Localization in Uncharted Environments

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In order for a mobile robot to navigate autonomously over long distances on uneven surfaces, a method for accurately *tracking the pose* of the robot is primarily needed.

**Dead Reckoning**

**Benefits**
- easy to implement;
- good short-term accuracy;
- very high sampling rate.

**Drawbacks**
- not well suited to long-range navigation on rough terrain;
- wheel slippage, sinkage, and sensor drift may cause errors that accumulate without bound over time.
Visual Odometry

Key Idea

Estimating the motion of the robot by visually tracking landmarks, opportently selected in the environment, using an on-board camera

Outlier removal problem

Also robust scale invariant feature detection and matching algorithms (SIFT, SURF), have been shown to produce a number of false matches that significantly affect localization accuracy.

Proposed solutions

- Setting a global threshold on the distance to the closest feature
  This generally does not guarantee good results, since some descriptors are much more discriminative than others.

- Using nearest neighbor-ratio-matching (Lowe, 2004)
  This improves the matching but still does not guarantee correct associations.

- RANSAC (RANdom SAmple Consensus) allows for accurate model estimation
  It may need a high number of samples, thus entailing considerable computational cost.

Purpose of this Work

Development of a visual odometry algorithm for 6DoF ego-motion estimation

• incorporates image intensity information and 3D stereo data to improve outlier rejection in both stereo matching and feature tracking;
• achieves accurate results, using a few interesting points to preserve computational efficiency.

Test of the method

Experiments have been performed, first, indoor and, then, outdoor, proving the approach to be accurate and robust to different environmental conditions, such as irregular soil and lighting variations.
Proposed Approach

Phases

**Feature Detection**
Select significant features in both the image plane and the 3D world

**Feature Tracking**
Track features between two successive frames

**Motion Estimation and Outlier Removal**
*Estimate* the 6DoF motion of the vehicle occurred between two successive image acquisitions
Feature Detection

**LEFT IMAGE**

**RIGHT IMAGE**

**DISPARITY**

**SURF FEATURES**

**3D Points**

**Pixel Points (image features)**
Feature Tracking

Nearest-neighbor-ratio matching & mutual consistency check

Pan Rotation of $-5^\circ$

Tracked Features shown in the 3D space
Motion Estimation and Outlier Removal

Steps:

1) Finding the rotation matrix $R$ and the translational displacement $t$ that minimize the

$$F(R, t) = \frac{1}{N} \sum_{k=1}^{N} \left\| (R\mathbf{p}_k^i + t) - \mathbf{p}_k^{i+1} \right\|^2$$

mean-squares objective function

2) Motion estimation: 3D putative correspondences found in SURF-based features tracking process.

3) Remove Spurious Matches: iterative scheme [similar to the registration stage of ICP];

4) Matches are accepted if the error $e_k$ calculated as

$$e_k = \left\| (R\mathbf{p}_k^i + t) - \mathbf{p}_k^{i+1} \right\|$$

is less than a threshold $T$ (which is computed additively).

5) The estimation of $R$ and $t$ is repeated using the correspondence set without those matches classified as outliers.

The procedure is iterated until the change in motion estimate between two successive iterations is less than 1%. 
Result of Tracking

Right images taken before a pan rotation of 5°

Red lines indicate the matches removed using 3D information

Absolute errors for each of the 6 DoF of the camera
Result of Motion Estimate

Matches in 3D space, before (left) and after (right) registration, \textit{without outlier removal}

Matches in 3D space, before (left) and after (right) registration, \textit{with outlier removal}
Experimental Results

Experiments Setup

- Indoor and an outdoor environments
- In all the experiments, the vehicle was remotely controlled using a joystick, and driven with an average travel speed of about 15 cm/s.

The Robotic Platform

- MobileRobots Pioneer P3-AT;
- Point Grey Bumblebee2 stereo camera;
- SICK LMS 200 Laser Rangefinder for localization and mapping in indoor tests;
- Control architecture based on an Open source robotic development framework, named MARIE;
- Stereo processing is performed using the Triclops library;
- The robot navigation toolkit CARMEN is used for laser-based Monte Carlo Localization (MCL) in indoor environments.
Indoor Environment

Travel distance $D = 18.0$ m

$$E = \sqrt{x_e^2 + y_e^2}$$

$$E\% = \frac{E}{D} \times 100$$

<table>
<thead>
<tr>
<th></th>
<th>Laser-based MCL</th>
<th>Odometry</th>
<th>Visual Odometry (VO)</th>
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<tbody>
<tr>
<td>$x_e$ [m]</td>
<td>0.081</td>
<td>0.023</td>
<td>0.241</td>
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<tr>
<td>$y_e$ [m]</td>
<td>-0.230</td>
<td>1.103</td>
<td>-0.368</td>
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<tr>
<td>$E%$</td>
<td>1.35</td>
<td>6.13</td>
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Outdoor Environment

- non-homogenous road
- closed path
- total travel distance $D$ of 34.0 m
- total of 360 degrees of turning

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<tr>
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<th>Odometry</th>
<th>Visual Odometry (VO)</th>
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<tr>
<td>$E%$</td>
<td>13.5</td>
<td>2.0</td>
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Conclusion

• In this paper, a **visual odometry algorithm** for 6-DoF egomotion estimation of an autonomous vehicle was presented.

• The method integrates **image intensity** and **3D stereo information**, and uses an iterative procedure to remove 3D outliers.

• **Preliminary tests** were performed in both an **indoor** and an **outdoor environment**, showing the good performance of the approach in terms of accuracy and robustness to external disturbances.

• These results suggest that the proposed method may be also successfully employed to support autonomous navigation functions in **intelligent transportation systems**.

• Following this direction, our **future research** will are currently performing experimentation on **road vehicles** for long range navigation applications.