Intensity-Difference Based Monocular Visual Odometry for Planetary Rovers: A Case Study

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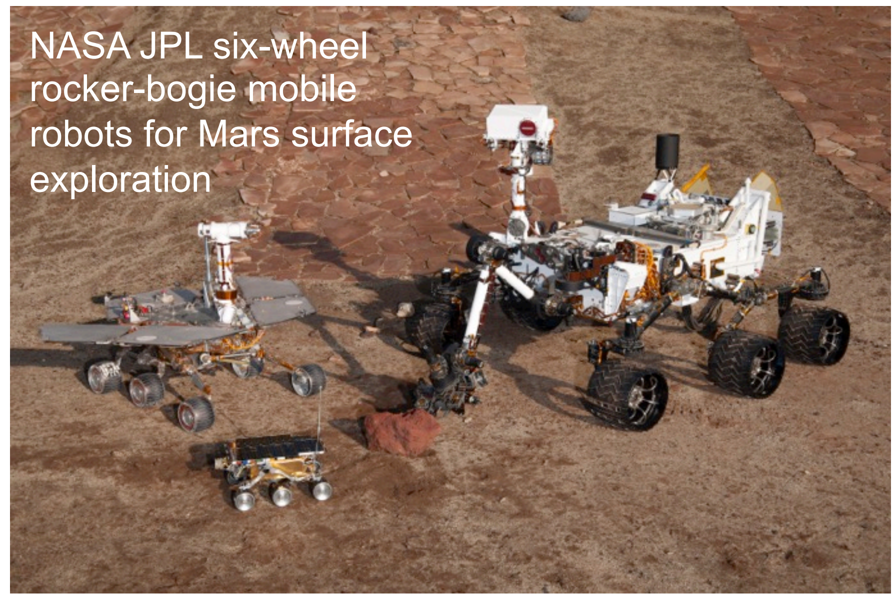
Overview

- Introduction
- Problem
- Current approach
- Our approach
- Results
- Summary

Introduction

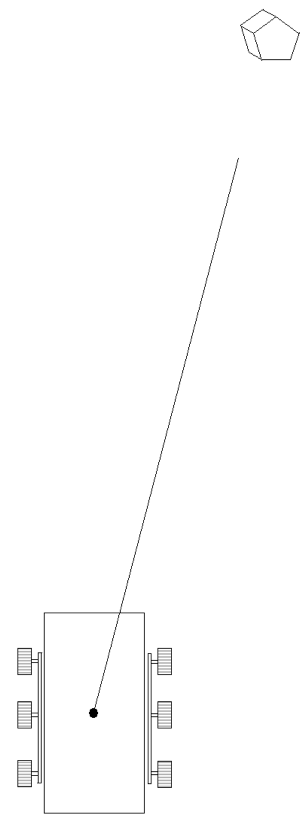
- These rovers have proven to be very powerful and long lasting tools for Mars exploration due to their ability to navigate and perform activities autonomosly



Courtesy NASA/JPL-Caltech

Introduction

- For safe and precise autonomous navigation, the rover must know its exact position and orientation at any time



Introduction

- The rover´s position is obtained by integrating its translation Δ**T** over time
- Δ**T** is estimated from encoder readings of how much the wheels turned (wheel odometry)

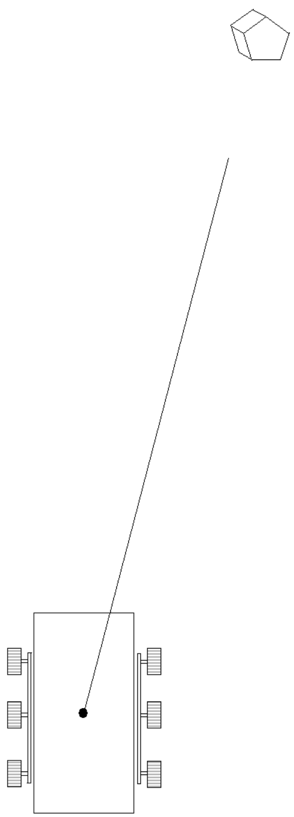
Problem

- Wheel odometry fails on slippery environments, such as steep slopes and sandy terrain, because the wheels slip due to the loss of traction

Courtesy NASA/JPL-Caltech

Problem

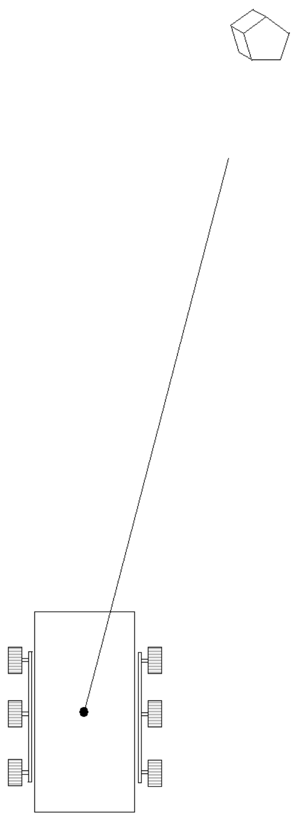
- This could cause the rover to deviate from its desired path and this in turn could cause the loss of an entire day of scientific activity, trap the vehicle in hazardous terrain, or even damage the hardware



Current Approach

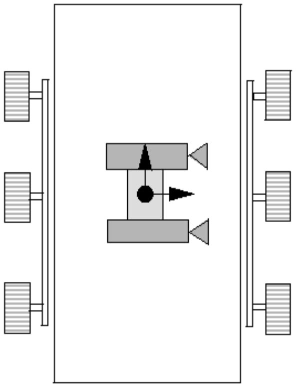
Slip detection and compensation

- Estimate the rover´s motion **B** from two video signals delivered by a stereo video camera mounted on the rover by applying a **feature based stereo visual odometry algorithm**
- Compute the rover's position by accumulating the motion estimates $\hat{\mathbf{B}}$ over time
- Detect and compensate any slip that may occur by using the computed rover's position



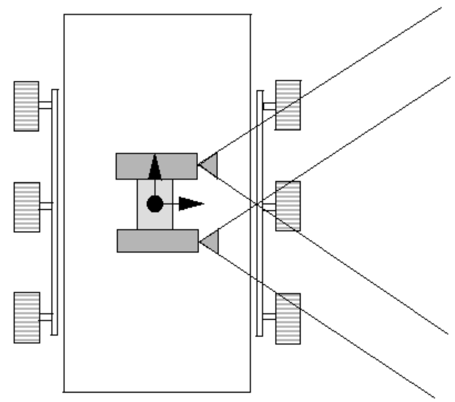
Stereo Visual Odometry

Algorithm



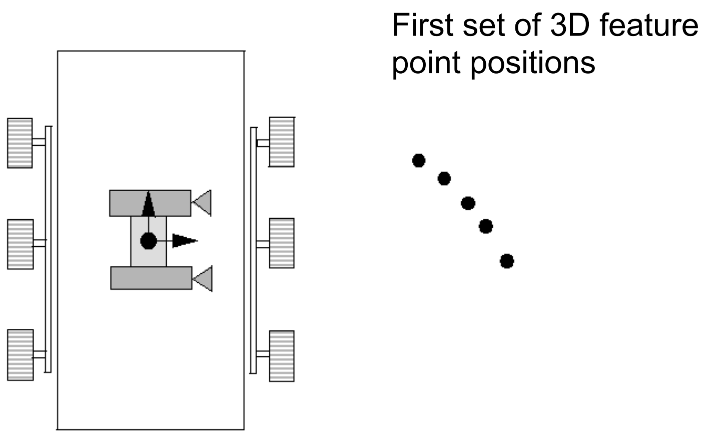
Stereo Visual Odometry

1. Capture a first stereo image pair before the rover's motion



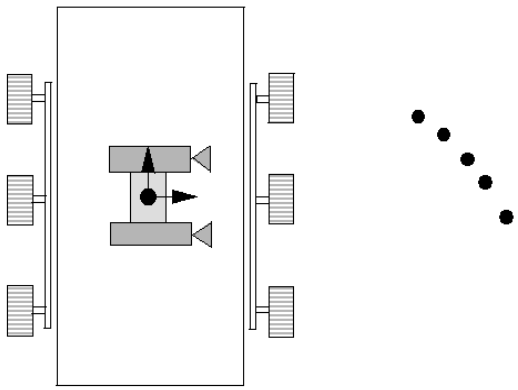
Stereo Visual Odometry

2. Estimate the 3D positions of a first set of feature points from the first stereo image pair by using stereo triangulation



Stereo Visual Odometry

3. Allow the rover to move



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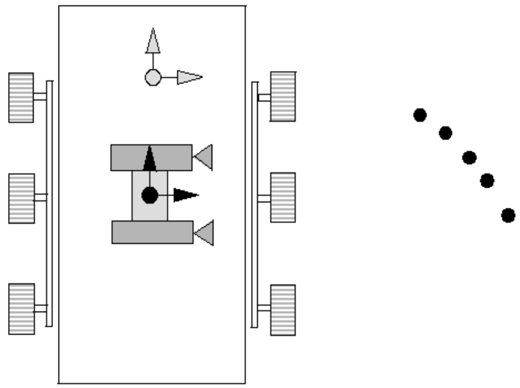
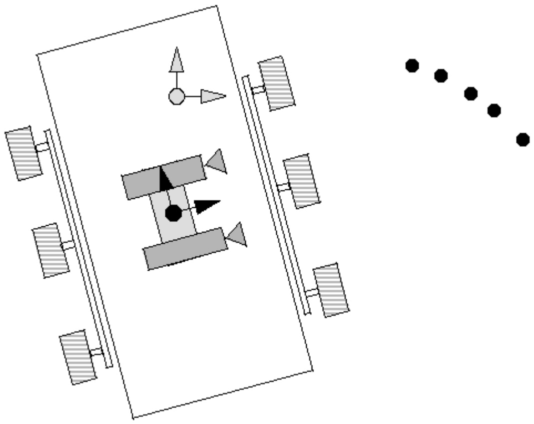


Stereo Visual Odometry

3. Allow the rover to move



Stereo Visual Odometry

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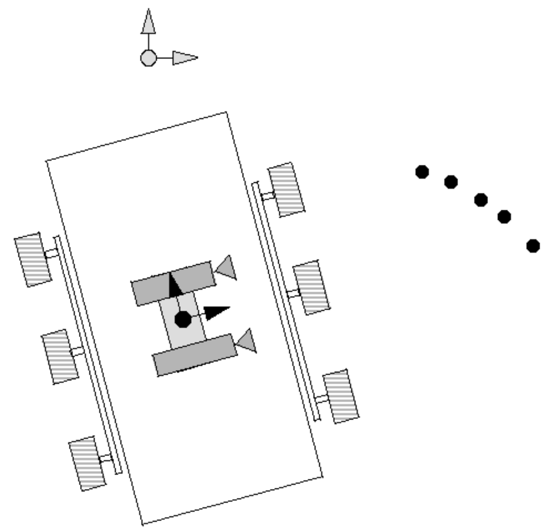

Stereo Visual Odometry

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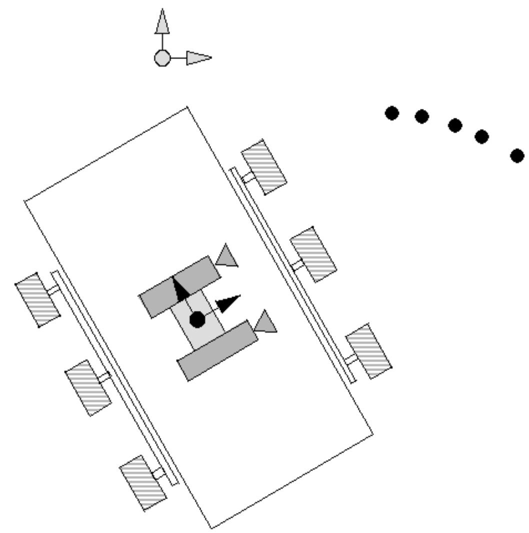

Stereo Visual Odometry

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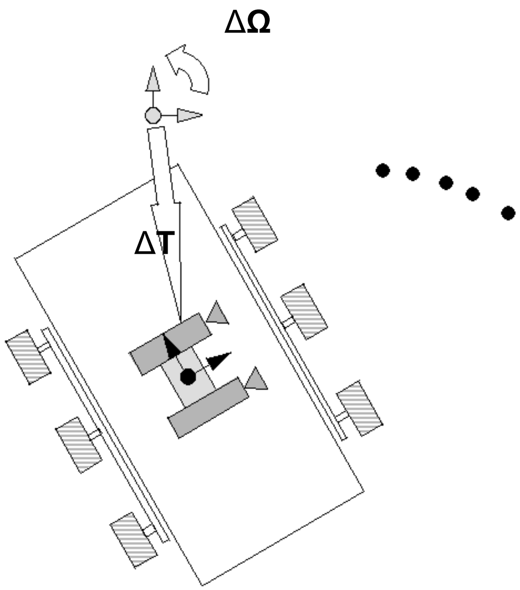
3. Allow the rover to move

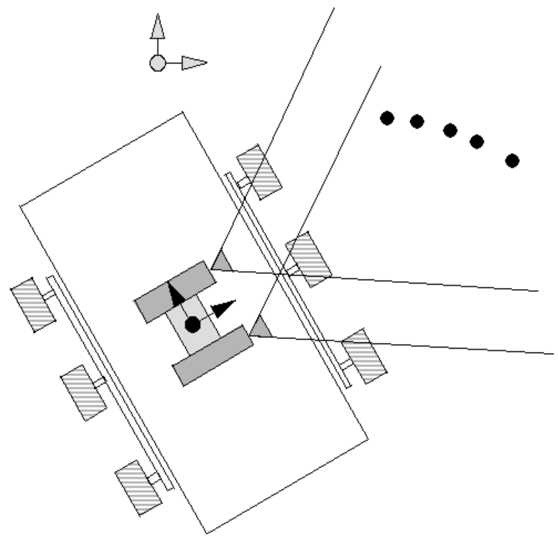
6 motion parameters:

B=(**ΔT**, **ΔΩ**)^T



Stereo Visual Odometry

4. Capture a second stereo image pair after rover´s motion



Stereo Visual Odometry

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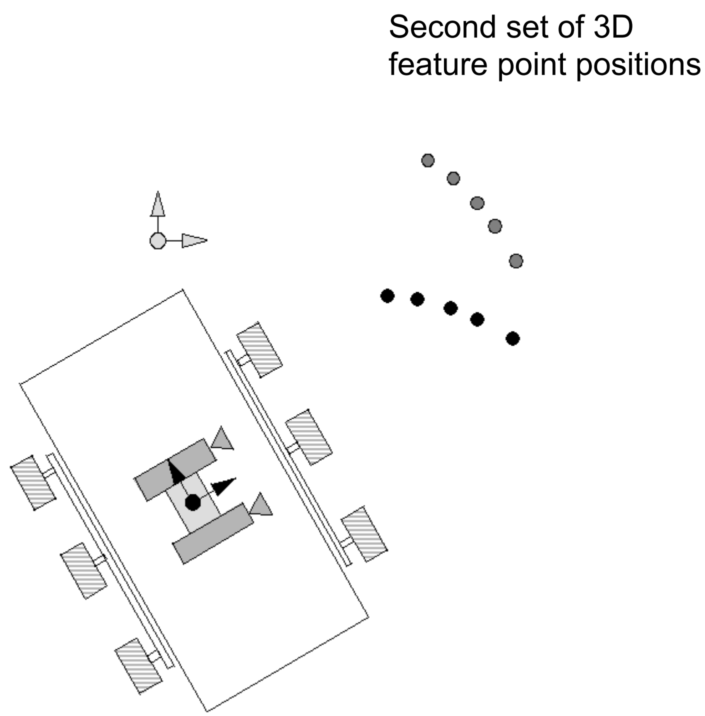
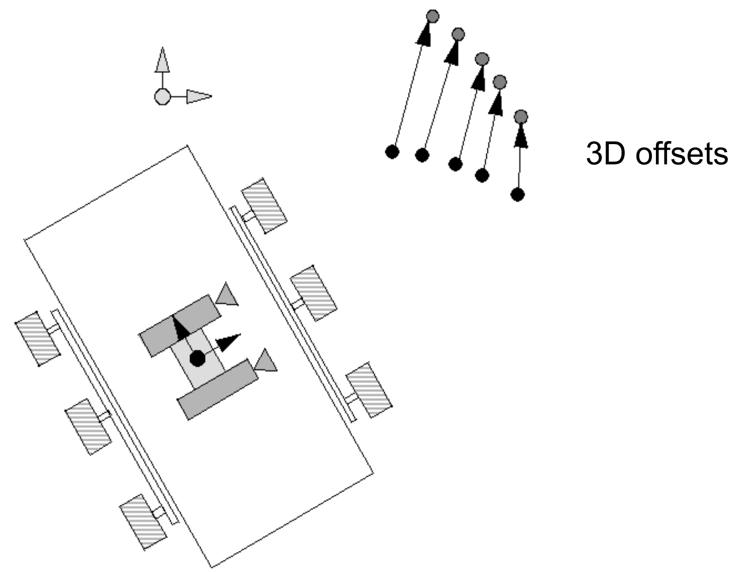
5. Estimate the 3D positions of a second set of feature points from the second stereo image pair by using stereo triangulation



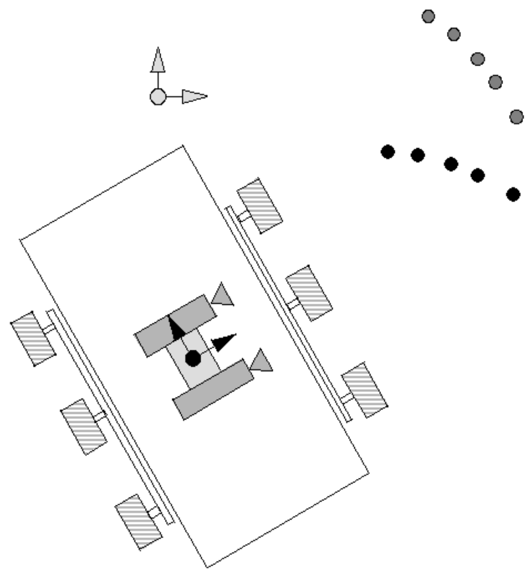
Stereo Visual Odometry

6. Establish the 3D correspondences (3D offsets) between the two sets of 3D feature point positions before and after the rover's motion



Stereo Visual Odometry

7. Search for those motion parameters **B'** that move rigidly the first set of 3D features point positions (before rover´s motion) to that place where the 3D offsets become as small as possible



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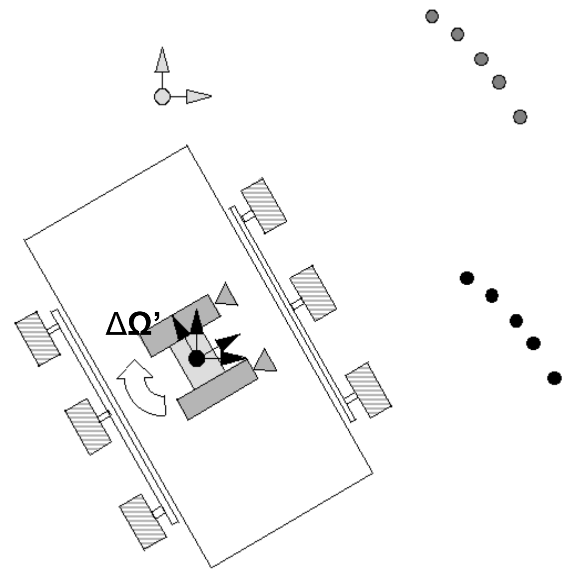

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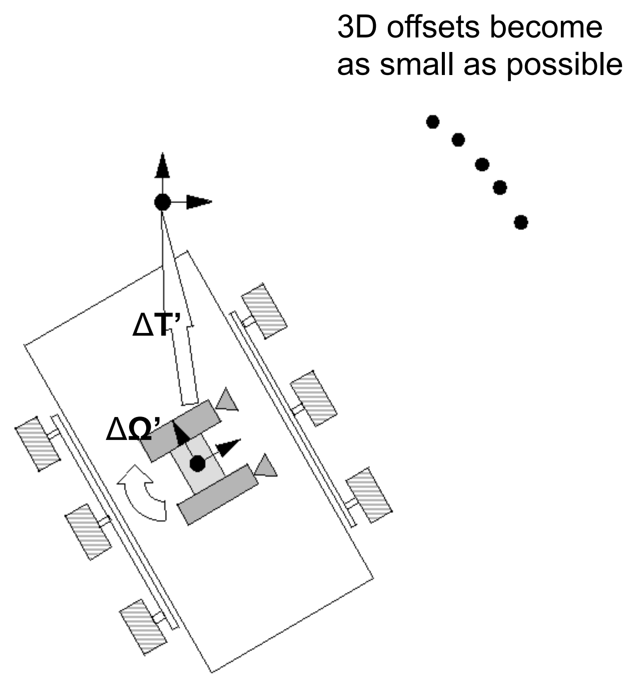

The parameters **B'** are searched by maximizing a likelihood function of the established 3D correspondences

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Stereo Visual Odometry

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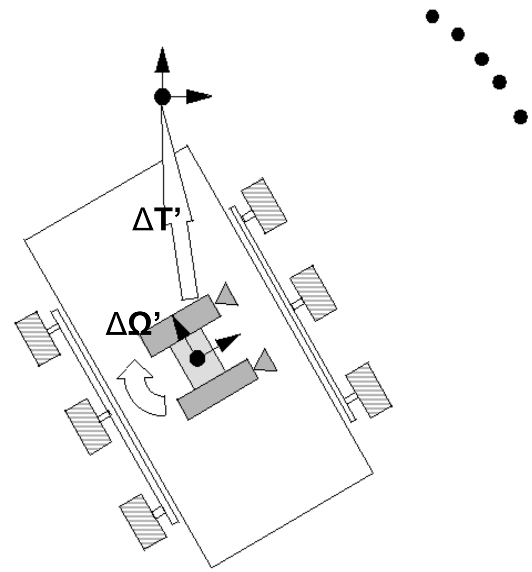
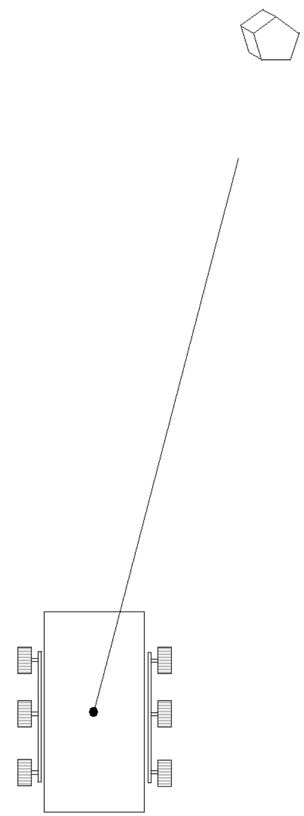


The rover’s motion estimates are $\hat{\mathbf{B}}$=-**B’**

Our Approach

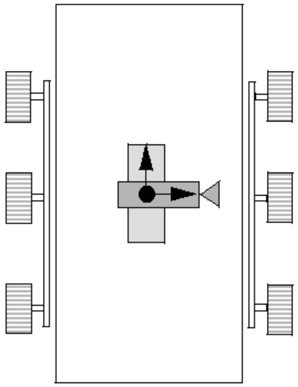
Slip detection and compensation

- Estimate the rover´s motion **B** from the video signal delivered by a single camera mounted on the rover by applying an **intensity-difference based monocular visual odometry algorithm**
- Compute the rover's position by accumulating the motion estimates $\hat{\mathbf{B}}$ over time
- Detect and compensate any slip that may occur by using the computed rover's position



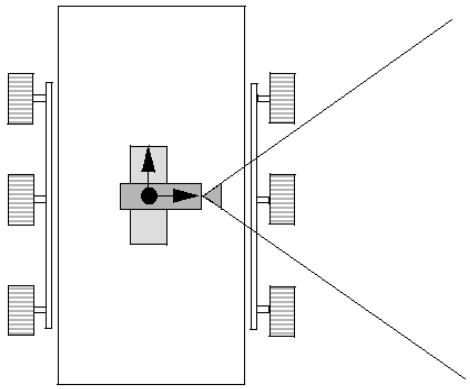
Monocular Visual Odometry

Algorithm



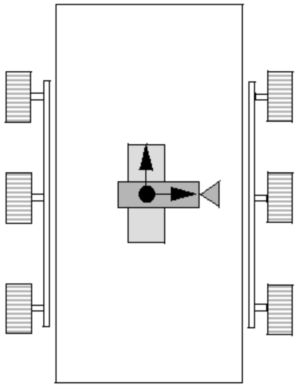
Monocular Visual Odometry

1. Capture a first intensity image before the rover's motion

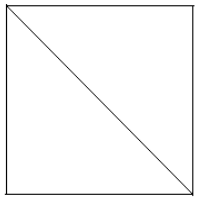


Monocular Visual Odometry

2. Adapt the size, position and orientation of a generic surface model to the content of the first intensity image



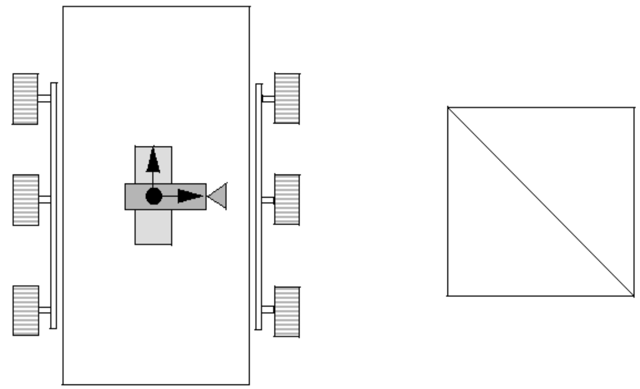
Adapted surface model



In this contribution the generic surface model is a rigid and flat mesh of triangles consisting of only two triangles

Monocular Visual Odometry

3. Select as observation points those image points in the first intensity image with high linear intensity gradients



Monocular Visual Odometry

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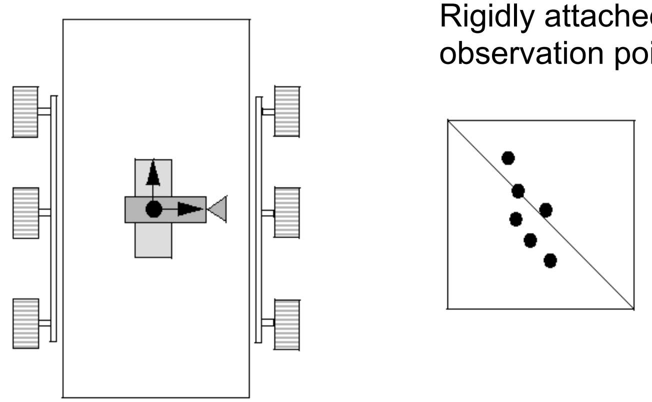
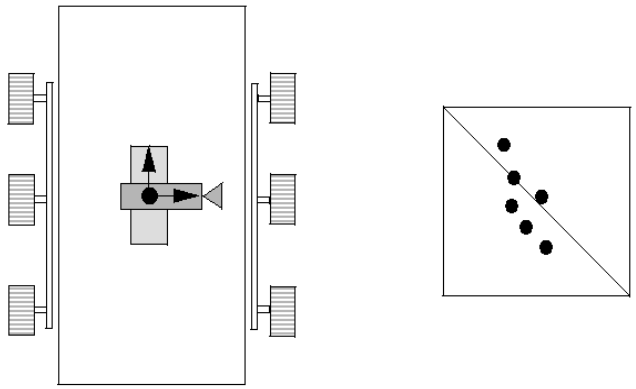
3. Select as observation points those image points in the first intensity image with high linear intensity gradients and attach them (together with their intensity values) rigidly to the surface model



Monocular Visual Odometry

4. Allow the rover to move



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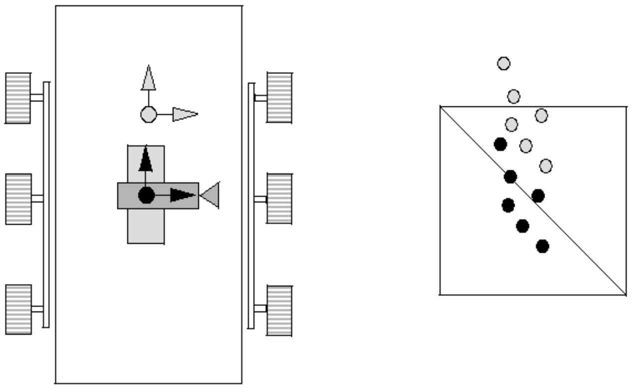

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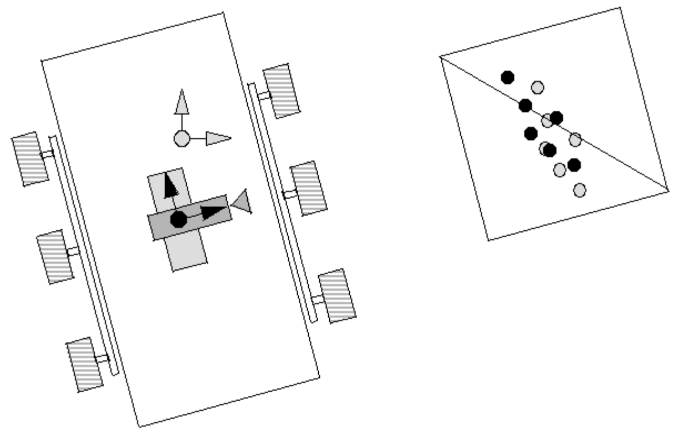

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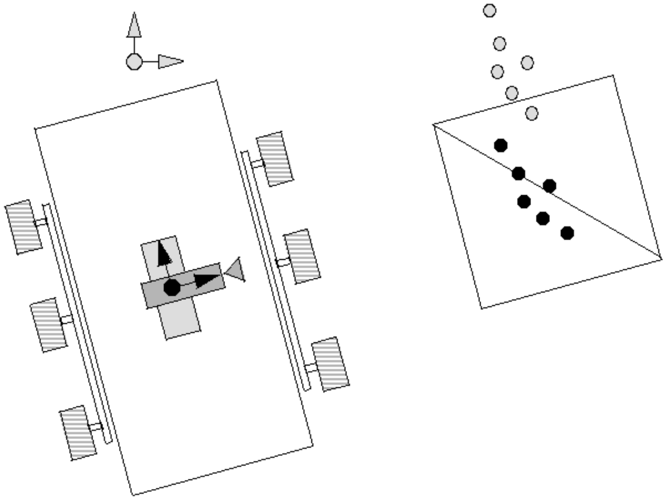

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Monocular Visual Odometry

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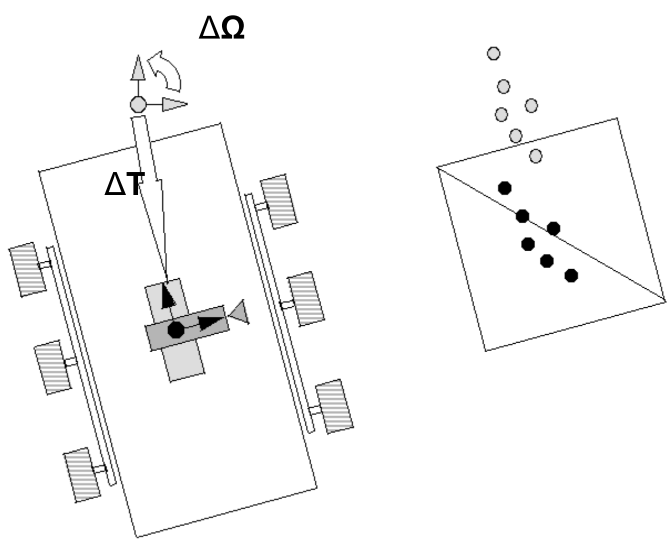
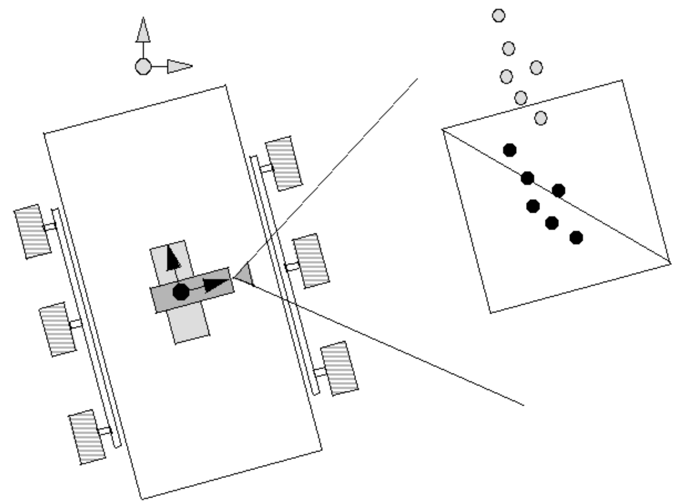


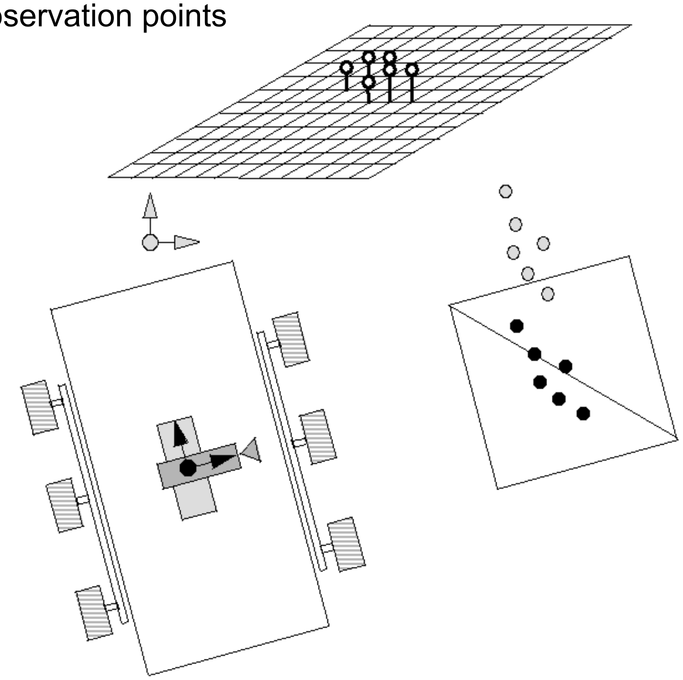
Monocular Visual Odometry

5. Capture a second intensity image after rover´s motion



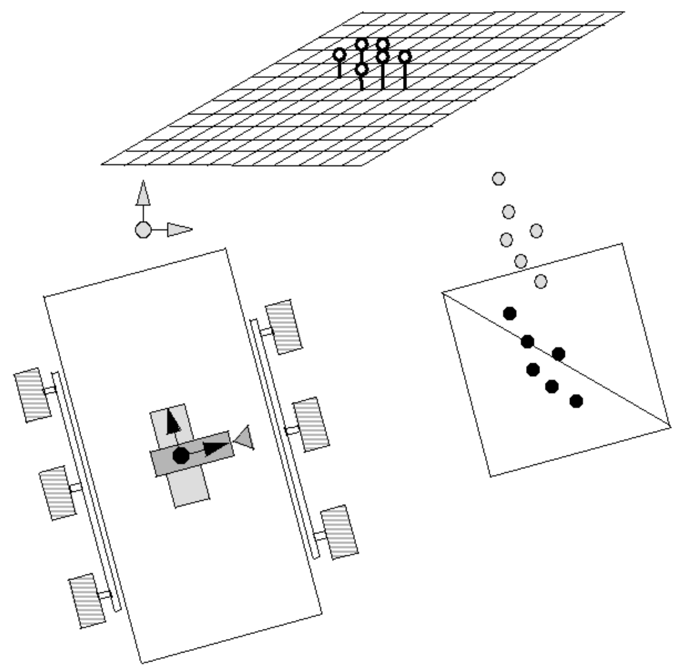
Monocular Visual Odometry

6. Project the observation points into the image plane and compute the intensity differences between their intensity values and the second intensity image



Monocular Visual Odometry

7. Search for those parameters **B'** that move the surface model (and therefore the rigidly attached observation points) to that place where the intensity differences become as small as possible



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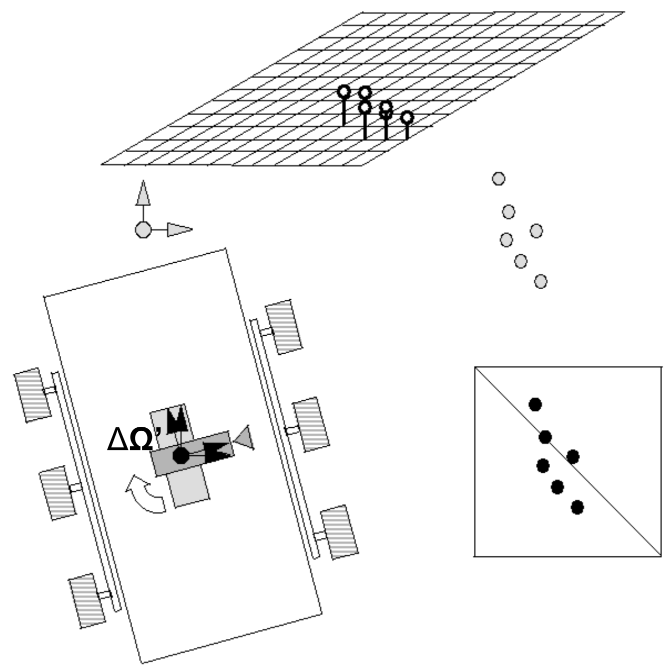

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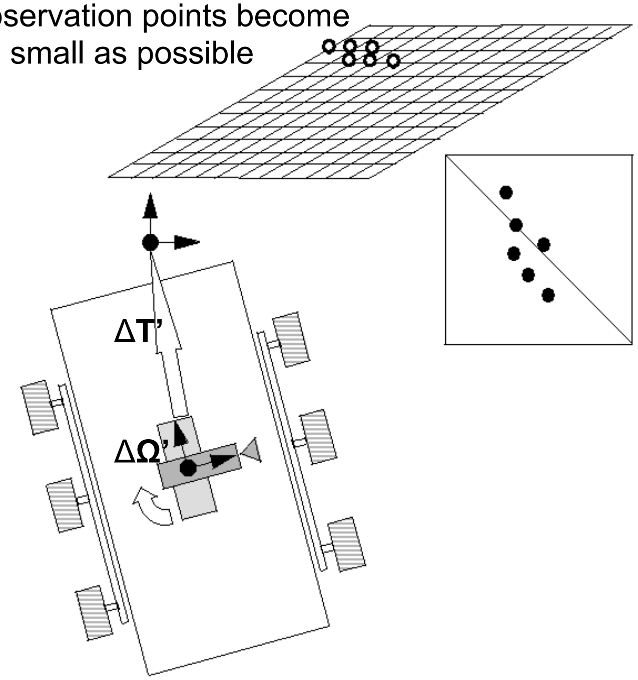

The parameters **B’** are searched by maximizing a likelihood function of the intensity differences at the observation points

Monocular Visual Odometry

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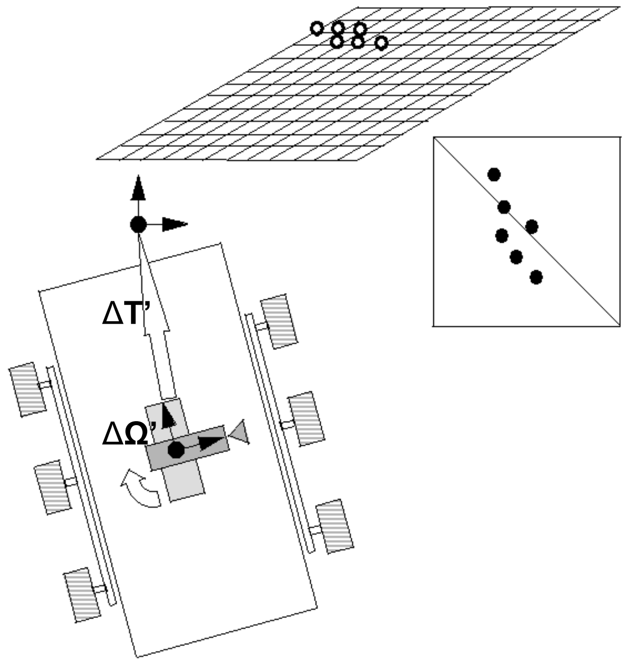

The rover’s motion estimates are $\hat{\mathbf{B}}$**=-B’**

Monocular Visual Odometry

Innovations

- A single camera used instead a stereo camera
- Evaluation of intensity differences instead of feature point correspondences
- Direct estimation method, no intermediate steps required

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Experimental Results

- Implemented in C
- Tested in a real rover platform (Husky A200)
- Outdoor sunlit conditions
  - Even under severe global illumination changes
- 343 experiments
  - Over flat paver sidewalks
- Performance measure
  - Absolute position error of distance traveled

Experimental Results

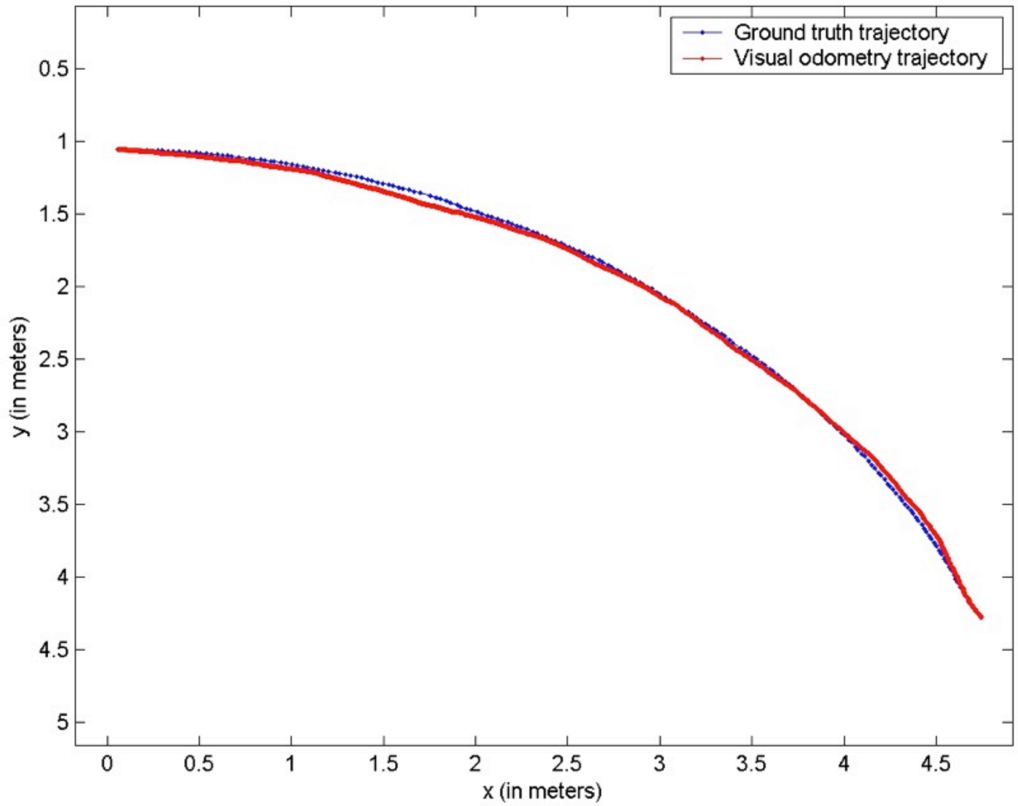
- Paths and velocity
  - Straight or semicircular paths
  - 3 cm/sec constant velocity
- Video Camera
  - Rigidly attached to the rover
  - 15 fps
  - 77 cm above the ground
  - Looking to the left side of the rover tilted downwards 37°
  - 640x480 pixel^2, 43° FOV

Captured intensity image

Experimental Results

- Ground truth
  - Robotic total station
  - Tracks a prism rigidly attached to the rover
  - Delivers its 3D position with high precision (<5 mm) every second
- Comparison of ground truth trajectory and visual odometry trajectory

Experimental Results



Experiment No. 337

Experimental Results

- The absolute position error was 0.9% of the distance traveled on average
- The processing time was 0.06 seconds per image on average
- These results are very similar to those achieved by traditional feature based stereo visual odometry algorithms which are within the range of 0.15% and 2.5% of distance traveled

Future work

- The outdoor tests will continue
- The algorithm will be tested over different types of terrain geometries and weather conditions
- We will use an Adept Mobilerobots Seekur Jr all-terrain rover platform, which is able to operate outdoors in any weather

Summary

- Monocular visual odometry proposed
  - Alternative algorithm
  - Use of a single camera
  - Evaluation of intensity differences for motion estimation
  - Direct estimation method

- Until now it has been tested in a real rover platform in outdoor sunlit conditions, under severe global illumination changes, over flat terrain
  - Very encouraging results

Thanks!

Any question?