Real-Time Robot 3D Pose Computation from NIR Imagery and ToF Depth Maps for Space Applications

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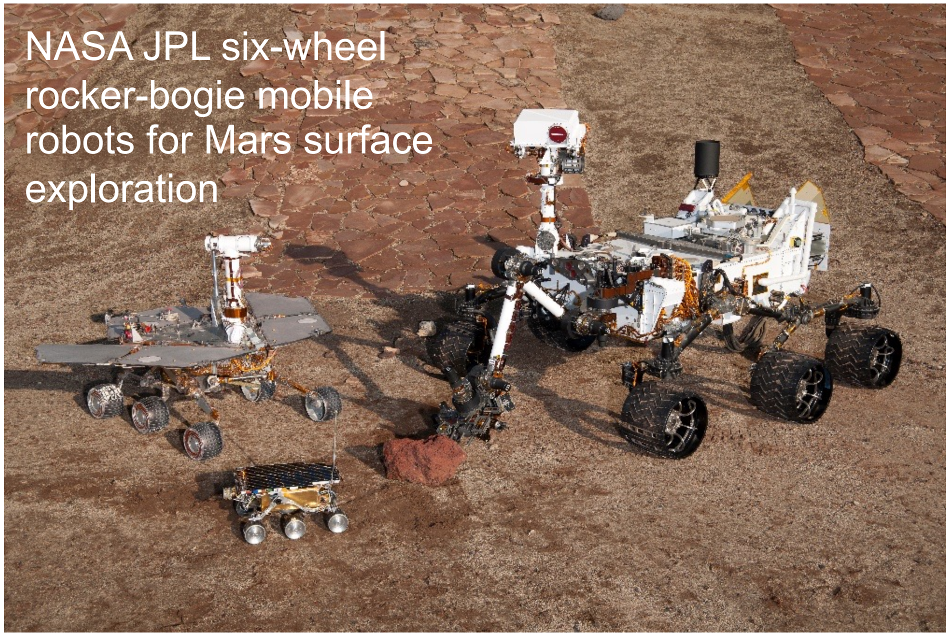
Overview

- Introduction
- Approach
- Algorithm
- Results
- Summary

Introduction

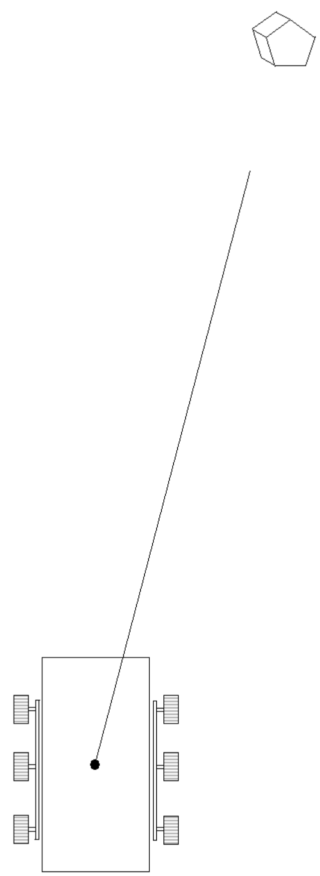
- One important feature of these planetary exploration robots is their ability to navigate autonomosly



Courtesy NASA/JPL-Caltech

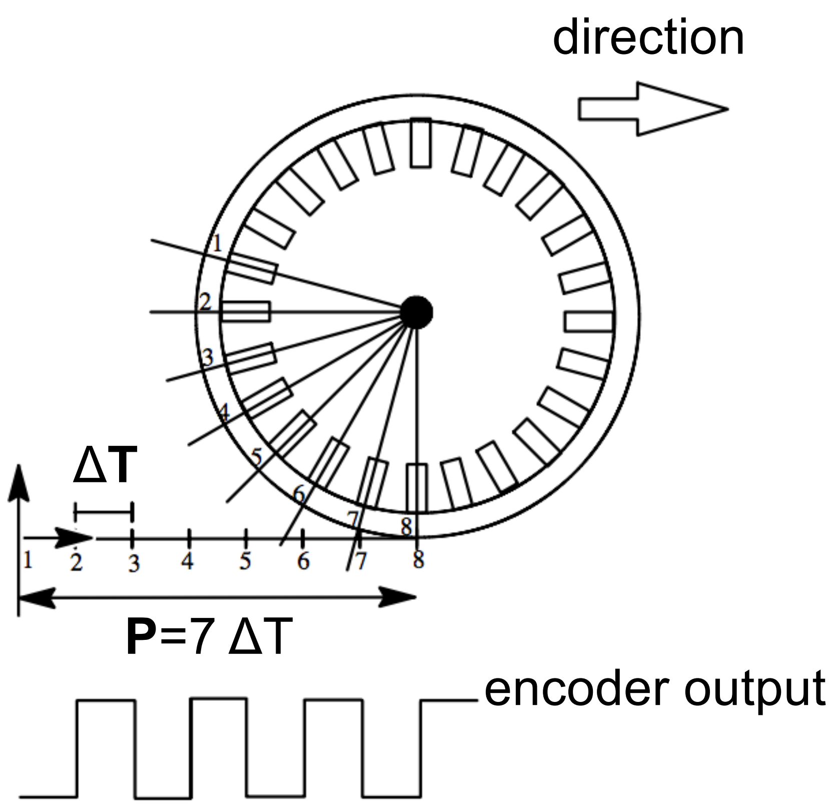
Introduction

- If you want a rover to navigate autonomously in a precise way, then the rover must know its position and orientation at any discrete time



Introduction

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



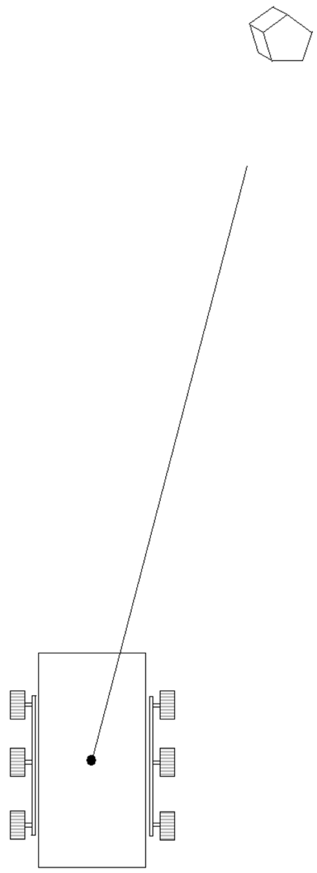
Introduction

- Wheel odometry fails on slippery environments, such as sandy terrain, due to the loss of traction

Courtesy NASA/JPL-Caltech

Introduction

- This could cause the rover to deviate from its desired path



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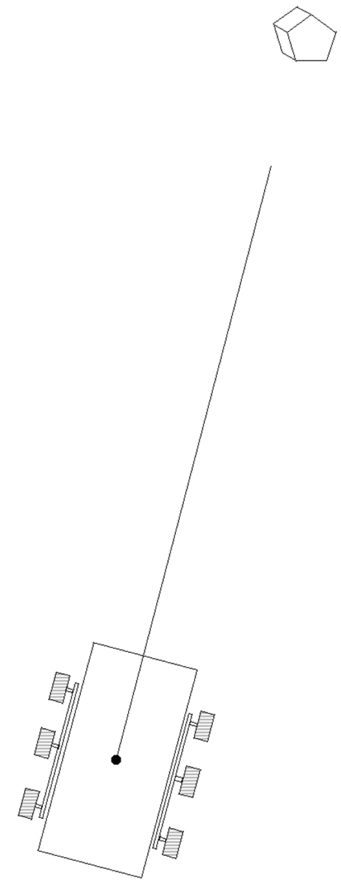

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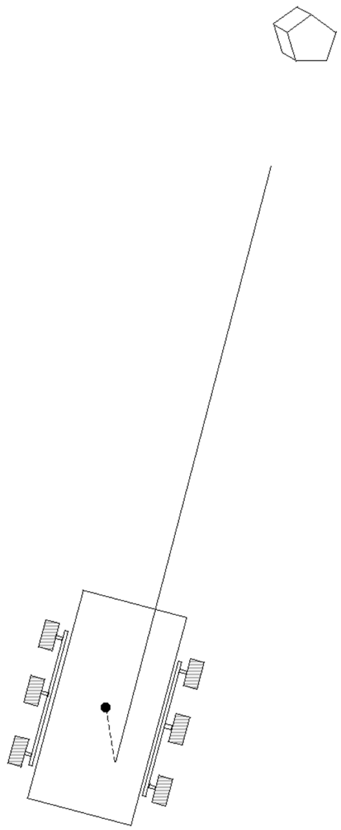

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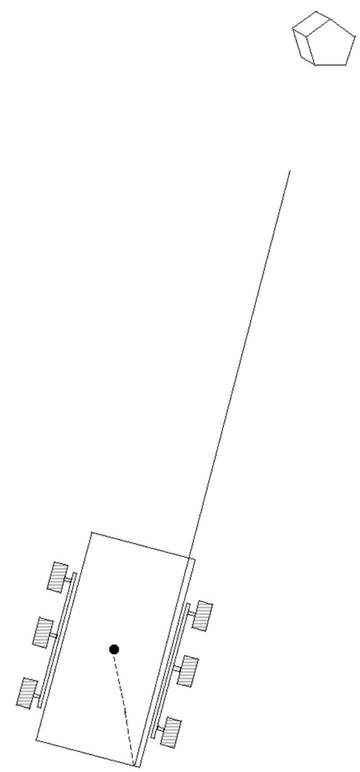

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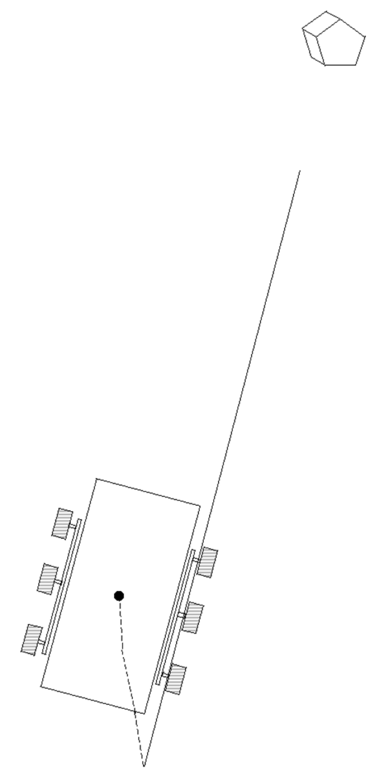

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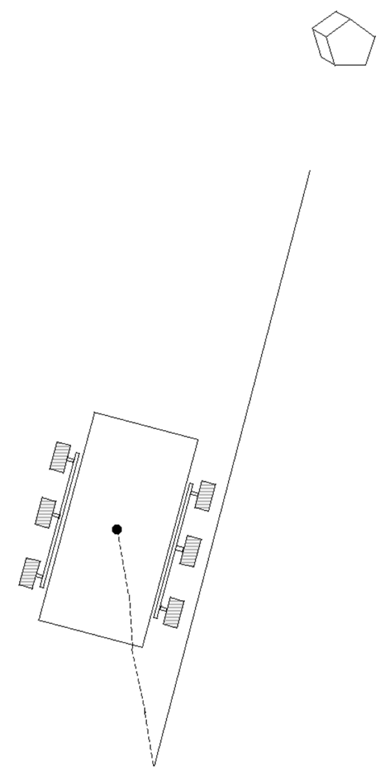

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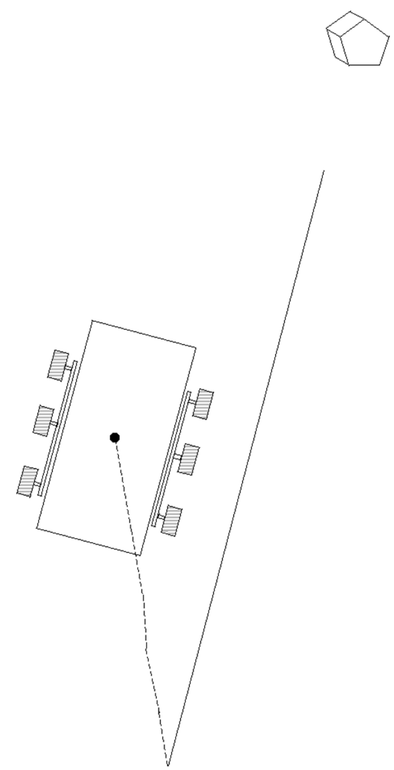

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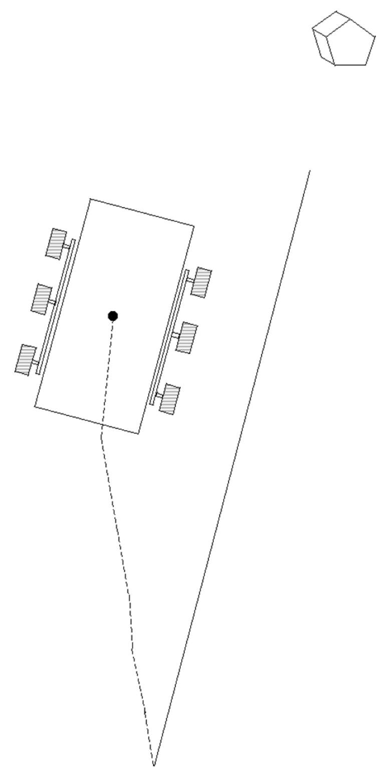

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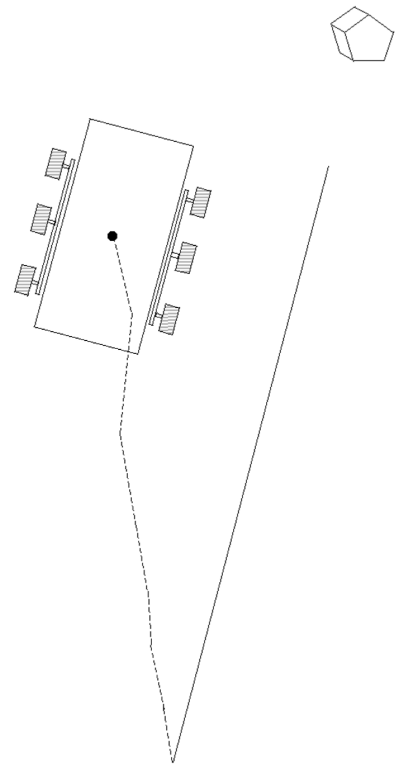

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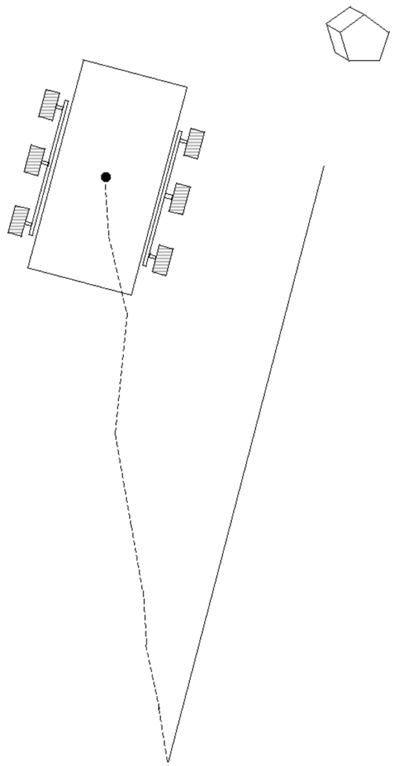

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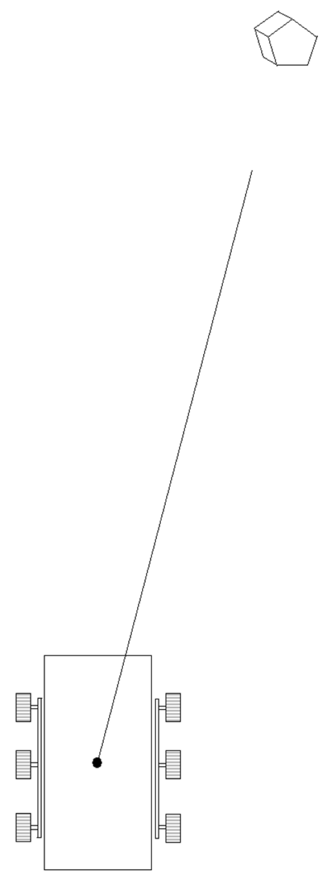

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  - a stereo camera used
  - feature point correspondences required
- Knowing the rover 3D pose, detect and compensate any slip that may occur

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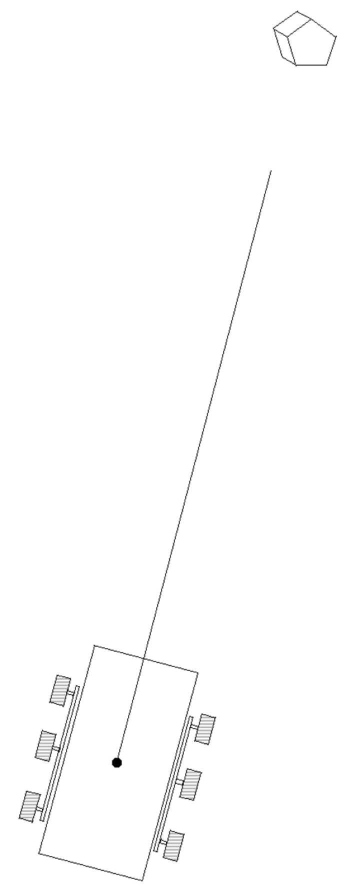

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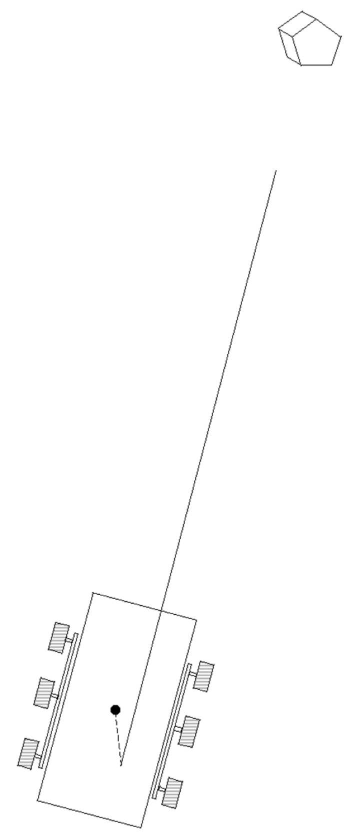

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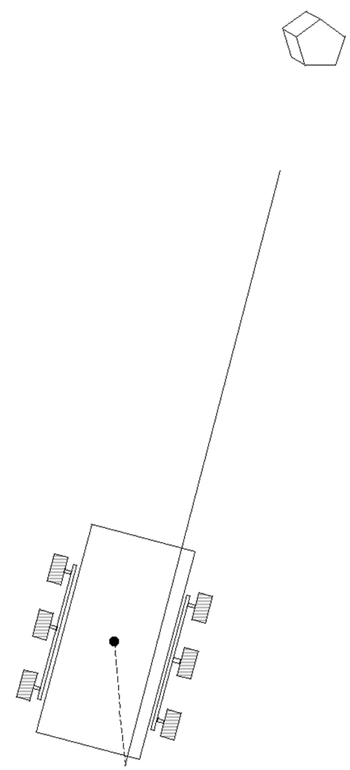

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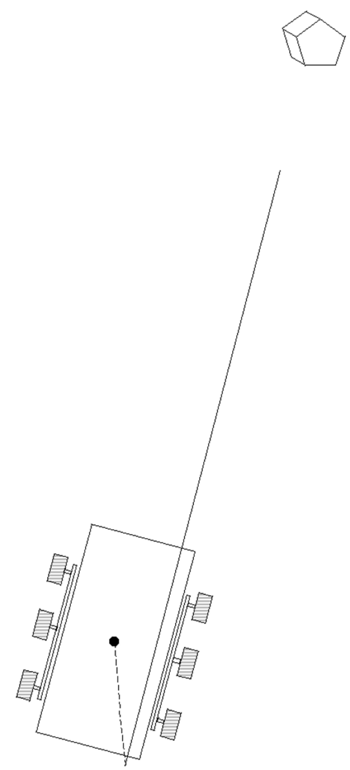

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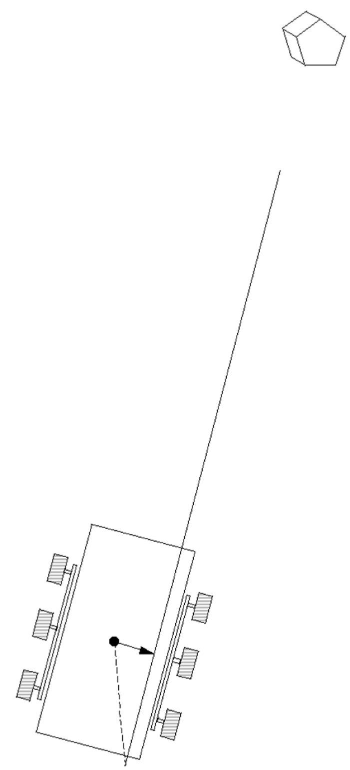

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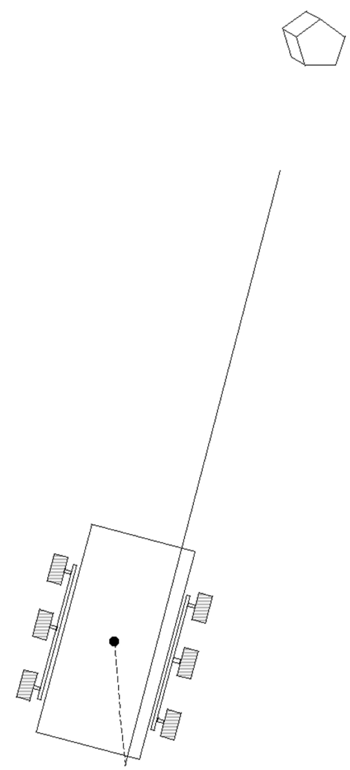

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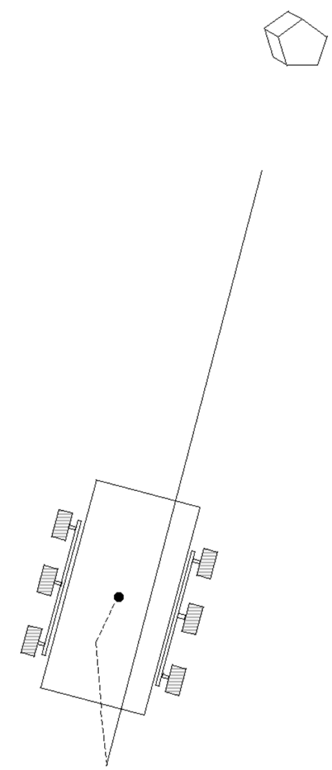

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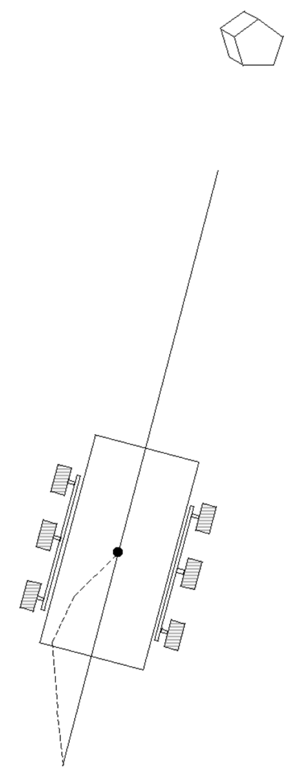

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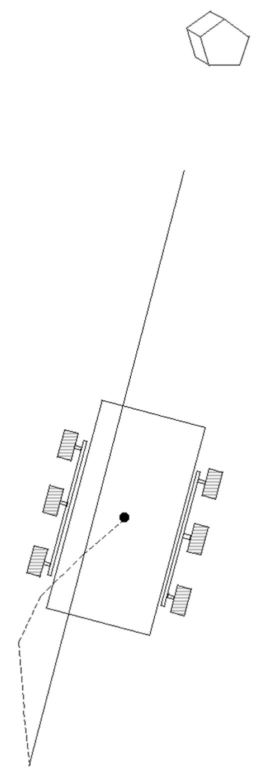

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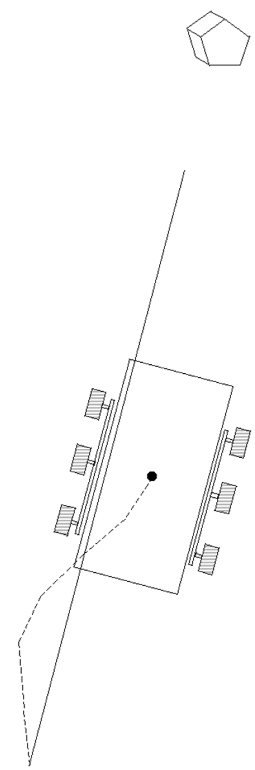

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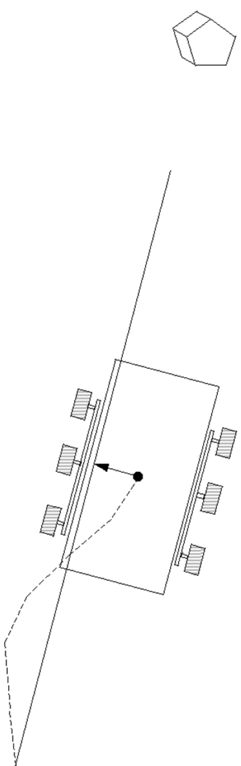

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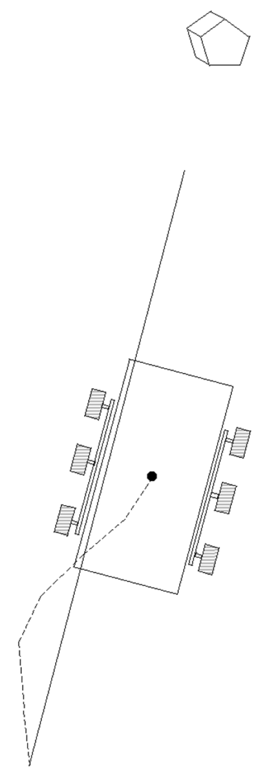

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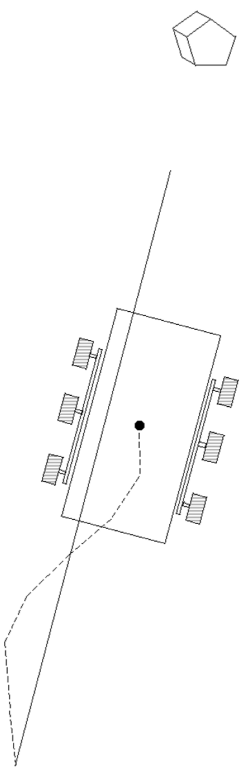

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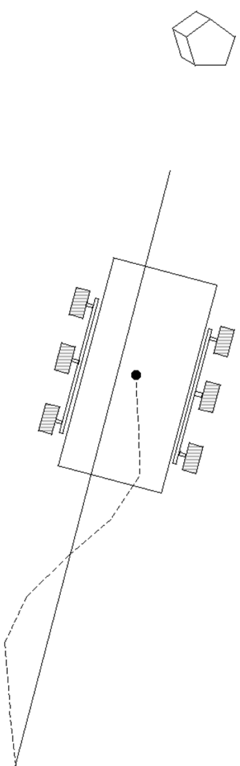

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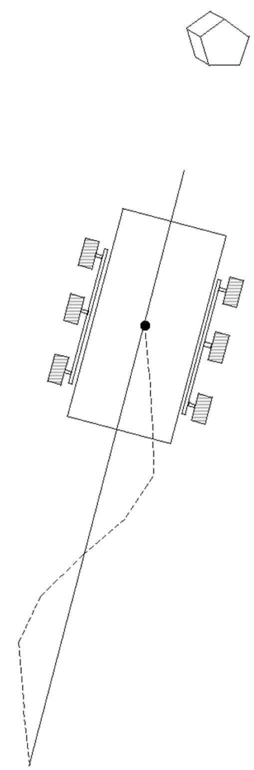

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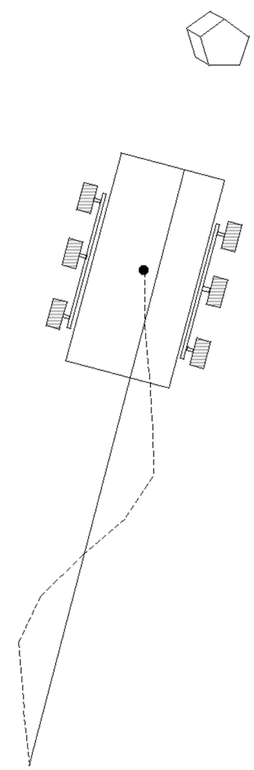

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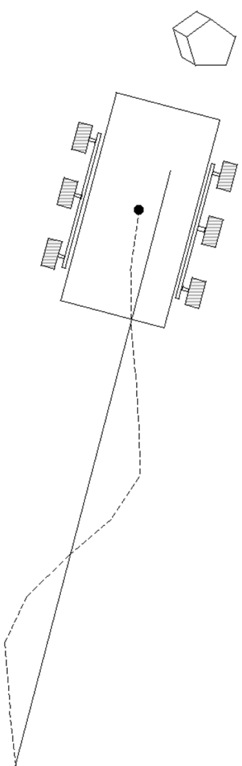

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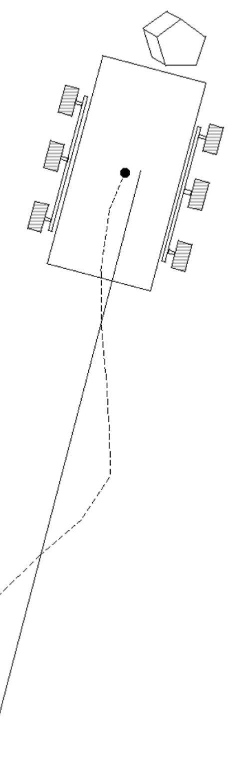
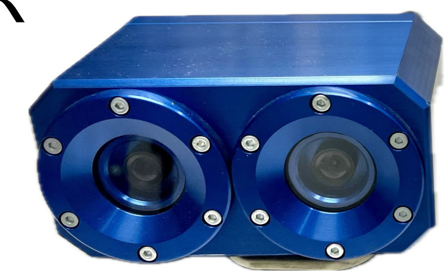


Approach

Sensor: instead of using a stereo camera, we propose to use a NIR ToF camera

- Monocular
- Faster depth signal calculation
- More accurate depth signal
- Easier to calibrate
- Works also at night
- Smaller
- Lower energy comsumption (?)

X



Stereo camera

✅

NIR ToF camera

Approach

Algorithm: instead of minimization the reprojection error at feature points, we propose the minimization of the photometric error at observation points

- no correspondences required
- faster

Two steps for getting the robot 3D pose:

(1) Frame to frame robot 3D motion estimation
(2) Integration of the estimated frame to frame robot 3D motion over time

Algorithm

Basler
640 20gm_850nm
NIR ToF camera

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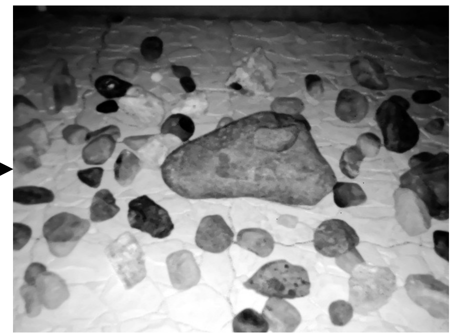
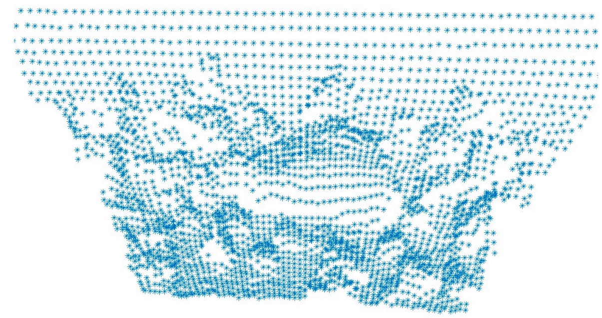
Algorithm

Basler
640 20gm_850nm
NIR ToF camera

NIR video signal (VGA 15 fps)



ToF depth signal (15 pcps)



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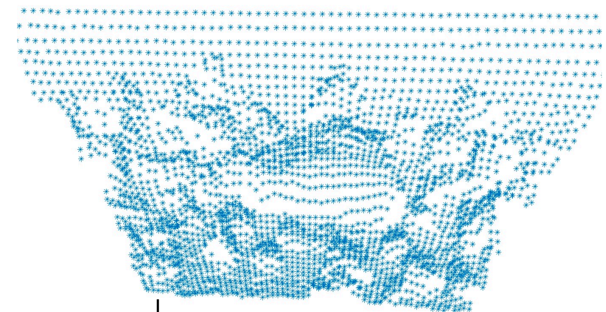

Frame to frame robot 3D motion estimation

Robot 3D motion

Algorithm

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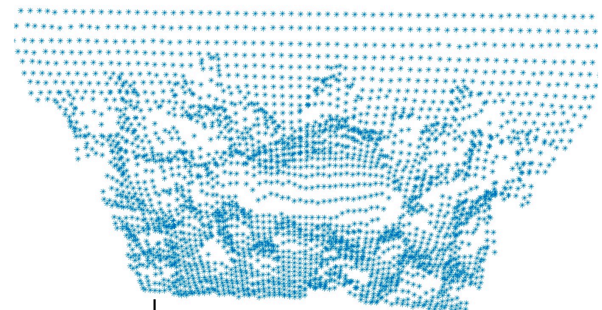

Frame to frame robot 3D motion estimation

Minimizing photometric error at observation points (iterative Maximim-Likelihood estimator)

Robot 3D motion

Algorithm

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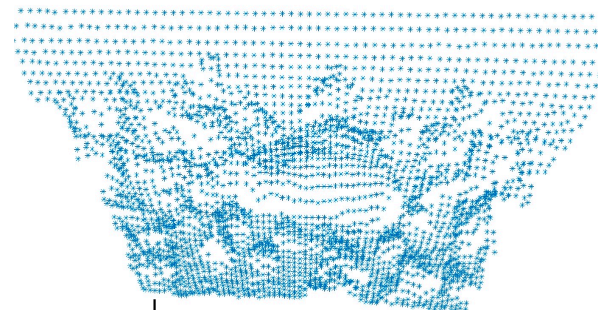
NIR video signal (VGA 15 fps)

ToF depth signal (15 pcps)



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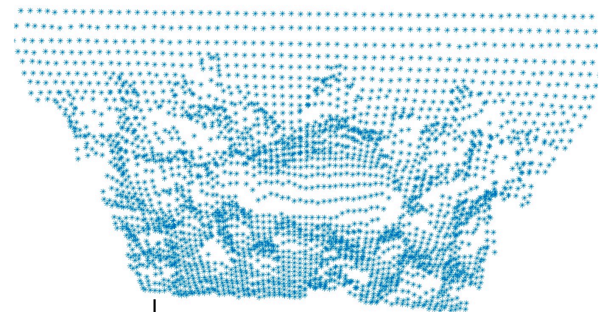

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Minimizing photometric error at observation points (iterative Maximim-Likelihood estimator)

Composition rules Σ

Robot 3D motion

Robot 3D Pose

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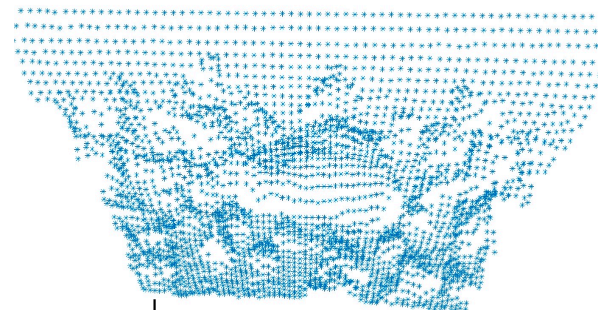


No inertial or wheel odometry aid used so far

No correspondences required

Frame to frame robot 3D motion estimation

Minimizing photometric error at observation points (iterative Maximim-Likelihood estimator)

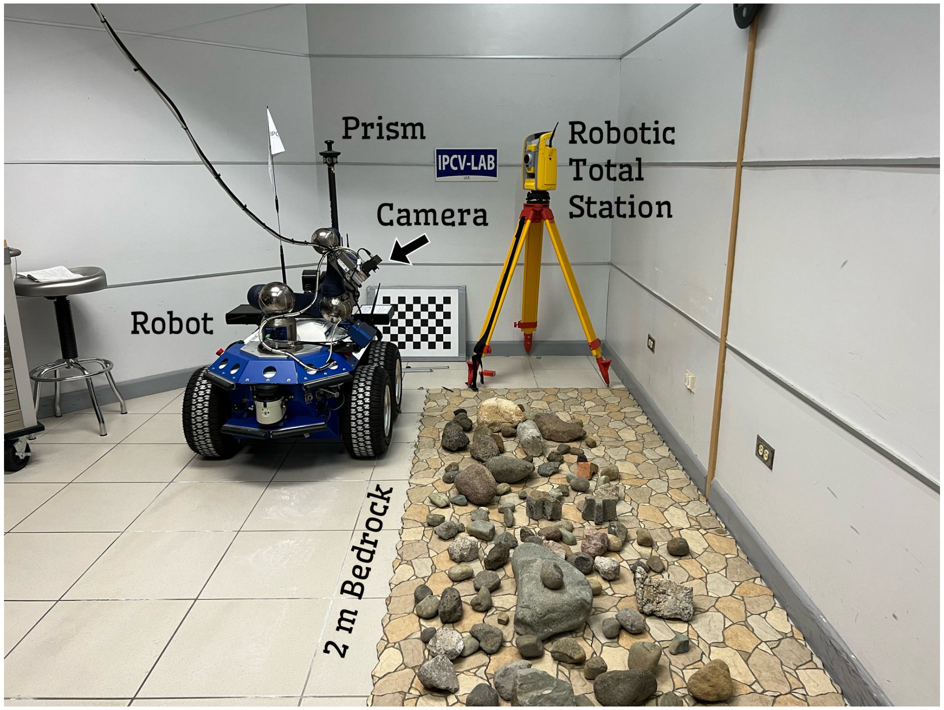
Composition rules Σ

Robot 3D motion

Robot 3D Pose

Experimental Results

- Implemented in C
  - under Ubuntu/ROS
- Tested in real rover
  - Seekur Jr.
- NIR ToF Camera
  - 80 cm above the ground
  - Looking to the left side of the rover tilted downwards 37°
- Ground truth
  - Robotic total station
- 180 over rough terrain



Experiment setup.

Experimental Results

- **First set**
  - Straight paths
  - 0.5, 1.0, 1.5 and 2.0 m
  - 3 cm/s
- **Mean of the absolute position error**
  - 0.47% ±0.32% of the distance traveled

- **Second set**
  - rotation on its own axis
  - 0.0° to 20.0°, 0.0° to 45.0° and 0.0° to 60.0°
  - 1.0°/s
- **Mean of the absolute orientation error**
  - 0.43% ±0.34% of the angle traveled

- **Real time operation**
  - 50 ±7 fps

Intel Core i9-9980HK CPU @ 2.40GHz and
8GB Memory under 64bit Ubuntu 14.04 LTS.

Summary

- NIR ToF Odometry algorithm proposed
  - Robot 3D pose computed by integrating frame-to-frame robot 3D motion over time
  - Robot 3D motion estimated by minimizing photometric error at observation points
  - No correspondences required
- Less 1% of the distance and angle traveled
- Real time operation
- Operation in the dark possible
- No inertial or wheel odometry aid used so far

Future work

- Improve robustness
- Adapt to fast moving robots
- Extent to SLAM
- More experiments in the dark