Absolute map-based localization for a planetary rover

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Work developed within the ESA founded Startiger activity “Seeker”
• On the importance of localization
• Absolute map-based localization
• Outlook
On the importance of localization

“Reach that goal”, “Map this area”…
→ Missions are defined in terms of localization

Environment models are required
→ Spatial consistency ensured by localization

Safe execution of the planned trajectories
→ Robust locomotion control and diagnosis ensured by localization

“If you are not localized, you are lost!”
Which localization?

Localization: “estimates one’s position”
(possibly with an associated confidence / accuracy)

Essential questions to answer to define a localization process:

1. With what precision? From $cm$ to $meters$
2. In which frame? Absolute vs. local
3. At what frequency? From $kHz$ to “sometimes”
Trajectories are defined by geometric primitives: a precise localization estimate is required.

50% slip ➔ visual odometry (Spirit in 2004)

Required localization: cm accuracy, local frame, frequency function of speed
Locomotion diagnosis

Opportunity traverse

April 26th, 2005

Required localization: $cm$ accuracy, local frame, high frequency
Locomotion diagnosis

Monitoring the terrain profile

Predicted vs. observed robot pitch angle

Required localization: \( cm \) accuracy, local frame, high frequency
State of the art (http://rtslam.openrobots.org): 12 state parameters @ 200 Hz, errors of the order of 1% over hundreds of meters
Environment models spatial consistency
Environment models spatial consistency

- Velodyne lidar provides chunks of 64 points @ 3.5 kHz:
  1° error on pitch yields a 17 cm elevation error @ 10 m

2 m/s, GPS RTK @ 20 Hz
+ Xsens AHRS @ 50 Hz
+ FOG gyro @ 50 Hz

2 m/s, RT-SLAM @ 100 Hz

Required localization: cm accuracy, local (or global) frame, frequency defined by the range data acquisition rate (often high)
Ensuring long range missions

- Odometry, VO, INS, SLAM (without loop closures) localisation solutions eventually drift
  - No way to ensure the achievement of global mission plans

⇒ Need to rely on “absolutely localized” features: georeferenced maps
Required localization: \( m \) accuracy, global \textit{absolute} frame, very low frequency
Which localization?

Essential questions to answer to define a localization process:

1. With what precision? From \( \text{cm} \) to \( \text{meters} \)
2. In which frame? Absolute vs. local
3. At what frequency? From \( \text{kHz} \) to “sometimes”

- \( \text{cm} \) accuracy, 10 to 100 \( \text{Hz} \), local frame
  - Ensure the lowest level (locomotion) controls
  - Ensure the proper execution of paths / trajectories
  - Ensure the spatial consistency of the built models

- \( \text{m} \) accuracy, “sometimes”, global frame
  - Ensure the achievement of the missions, most often defined in localization terms (“\( \text{goto} \ (\text{goal}) \)”,”\( \text{explore} \ / \text{monitor} \ (\text{area}) \)”, ...)
• On the importance of localization

• Absolute map-based localization
  • Related work
  • Approach
  • Results

• Outlook
The essence of the problem

- **Given**
  - A map  
    *(various maps)*

- Local data

⇒ Where am I?
(Matching aerial and terrestrial data on earth)

- A very relevant problem for modern mapping systems
  - 3D points registration
  - Using landmarks
Available maps on Mars

HIRISE Mars orbiter images
0.25m/pixel (here 0.5/pixel)

DTM of Holden Crater
(1m/pixel)

+ descent imagery
(cf MSL)
Map-based localization solutions (1)

- Skyline matching [Cozman 2000]

1. Extract Skyline Signature for each orbiter DTM cell

2. Compare robot perceived skyline with DTM skylines
Map-based localization solutions (2)

- Surface feature matching [Hwangbo 2009]

1. Extract rocks from orbital data (e.g. using shadows)

2. Extract rocks from rover stereo data

3. Match rock patterns between rover and orbital data
Map-based localization solutions (3)

- DTM peaks matching [Carle 2010]
Map-based localization solutions (4)

- DTM feature matching [Vandapel 2006]
Map-based localization solutions: summary

- Two processes involved:
  1. Matching rover and orbiter data (“perception” process)
  2. Assessing the position (“estimation” process)

- Skyline matching
- Surface feature matching
- DTM peaks matching
- DTM feature matching

⇒ Proposal: exploit for the matching process the rover DTM build for path planning
Proposed solution: overview

• Two processes involved:

1. Matching rover and orbiter data ("perception" data association process)
   ⇒ Comparison between the rover DTM and the orbiter DTM (fast to compute)

2. Assessing the position ("estimation" process)
   ⇒ Particle filter
   • The robot pos uncertainty is represented by a population of position hypotheses (the particles)
   • Prediction step: the particle positions evolved according to the motion estimation (with associated error model)
   • Observation step: the likelihood of each particle to represent the true position is estimated (with the perception process), particles are weighted accordingly
   • Resampling: “light” particles are killed, “heavy” ones are “multiplied”
Proposed solution: optimizations

• Particles management
  ⇒ “discretized particles” on the orbital DTM

- One \((x,y)\) particle per DTM cell
- Orientation (heading) angle is also discretized: \(\beta = k\alpha\)
- Particle uncertainty is assumed to be Gaussian

- Conventional particles
- Discretized particles
Getting the orbiter map

With a UAV, using a camera to build a high resolution DTM
Up-to-date commercial bundle adjustment techniques

• Down-sampled to 1m/cell
Getting the orbiter map

With a UAV, using a camera to build a high resolution DTM
Up-to-date commercial bundle adjustment techniques
Proposed solution: illustration

- On the quarry test field

- “Full” initial position uncertainty (worst possible case)
Proposed solution: illustration

• On the quarry test field

• “Full” initial position uncertainty (worst possible case)

Full search with heading information
Proposed solution: illustration

• On the quarry test field

• “Full” initial position uncertainty (worst possible case)

![Graph showing Evolution of the error of the (x,y,θ) position](image-url)
Proposed solution: illustration

• On a parking lot

• “Full” initial position uncertainty (worst possible case)
Outline

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  • Related work
  • Approach
  • Results

• Outlook
Summary and outlook (1/2)

• Showed good performances on the quarry test site
• Need for “signal” in the orbiter DTM

Further extensions:
• Need to assess “localisability” in initial orbiter maps
• Exploit this information to plan long range traverses
• Integrate other absolute localisation processes
  (this work is pursued at LAAS, and extended to terrestrial areas)
More generally on localization:

- A variety of needs
- A variety of solutions

Need to develop an overall framework that integrates the solutions and allows their control (in a distributed multi-robot context)

SLAM processes are at the heart of such a framework