Absolute map-based localization for a planetary rover

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Work developed within
the ESA founded Startiger activity “Seeker”

Outline

- 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)

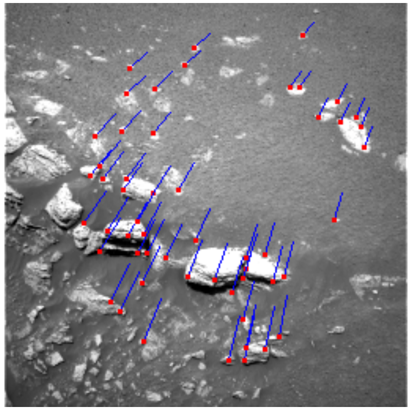
Essential questions to answer to define a localization process :

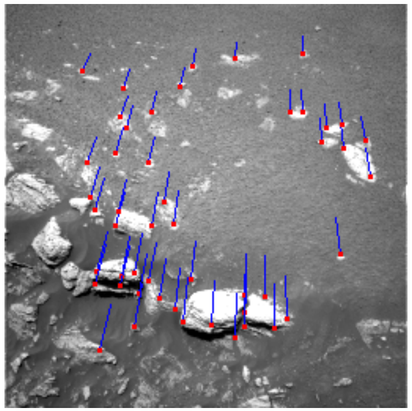
1. With what precision ?	From *cm* to *meters*
2. In which frame ?	Absolute vs. local
3. At what frequency?	From *kHz* to “sometimes”

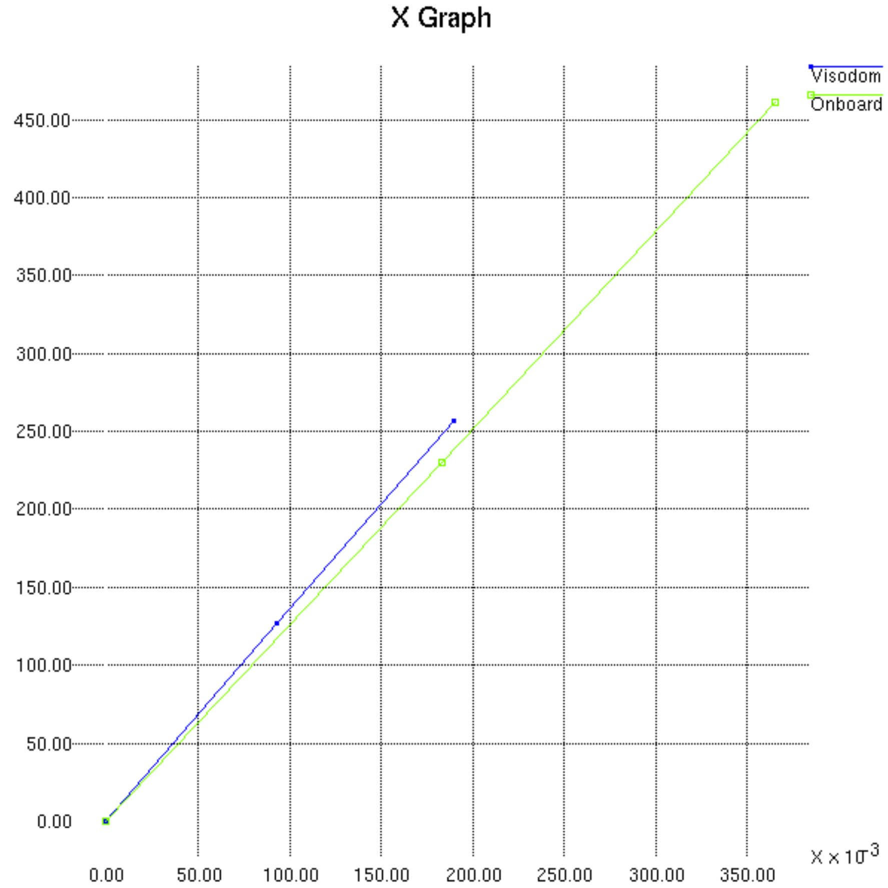
Trajectory following

Trajectories are defined by geometric primitives : a precise localization estimate is required

50% slip
→ visual odometry (Spirit in 2004)



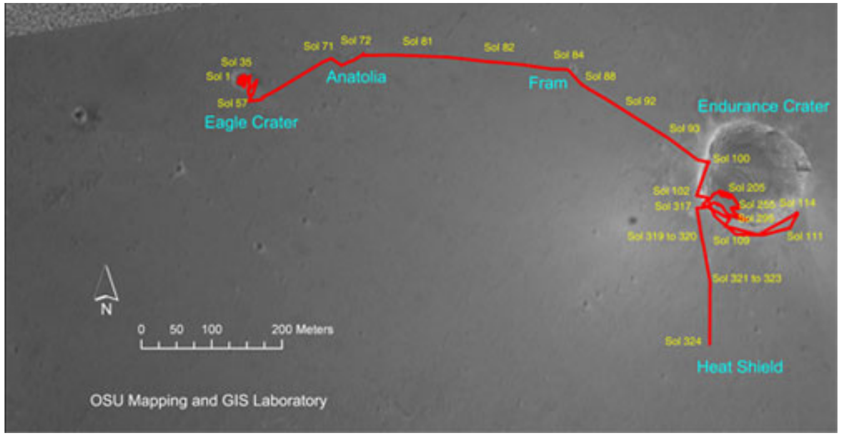




Required localization : *cm* accuracy, local frame, frequency function of speed

Locomotion diagnosis

Opportunity traverse

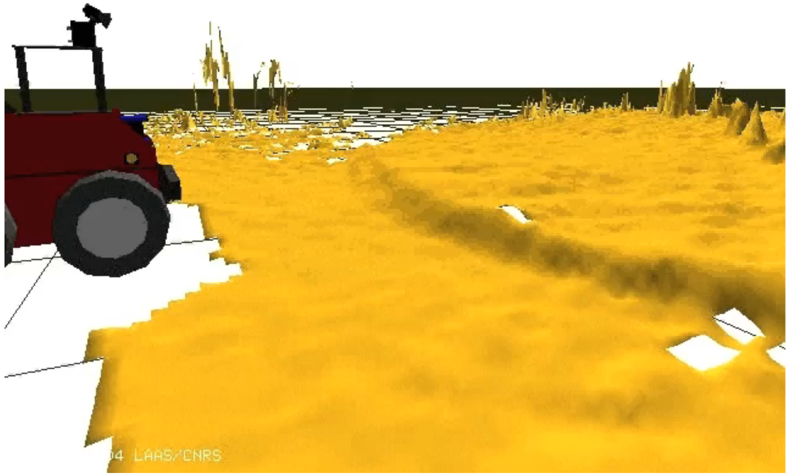


April 26th, 2005

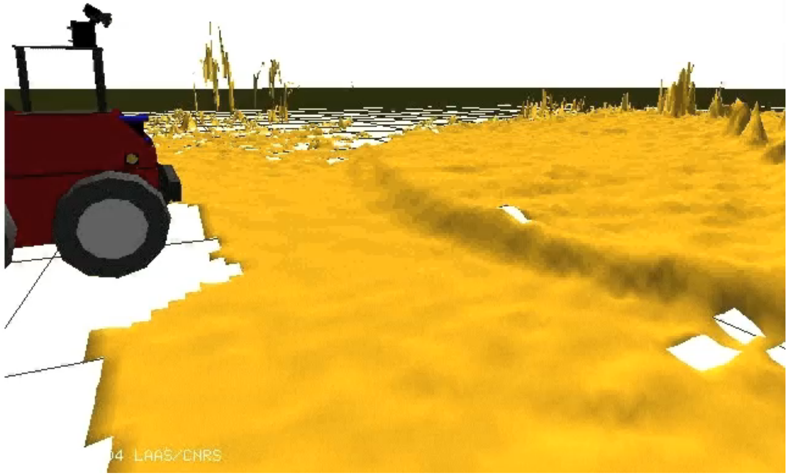
Required localization : *cm* accuracy, local frame, <u>high</u> frequency

Locomotion diagnosis

Monitoring the terrain profile

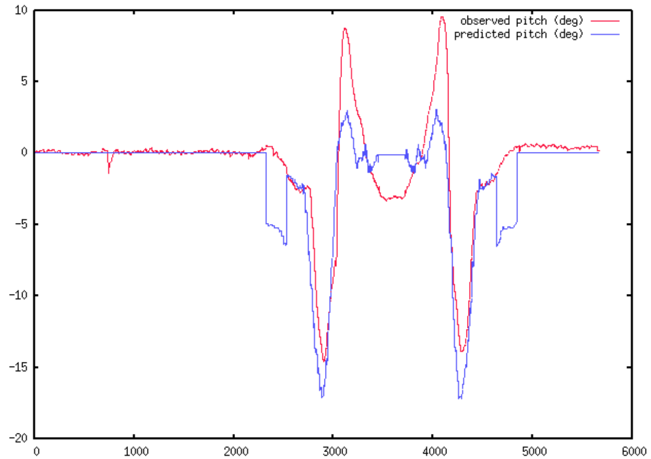


predicted



measured

Predicted vs. observed robot pitch angle



Required localization : *cm* accuracy, local frame, <u>high</u> frequency

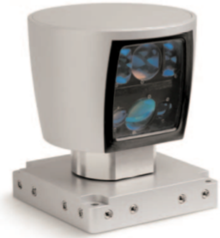
(From visual odometry to INS/visual SLAM)

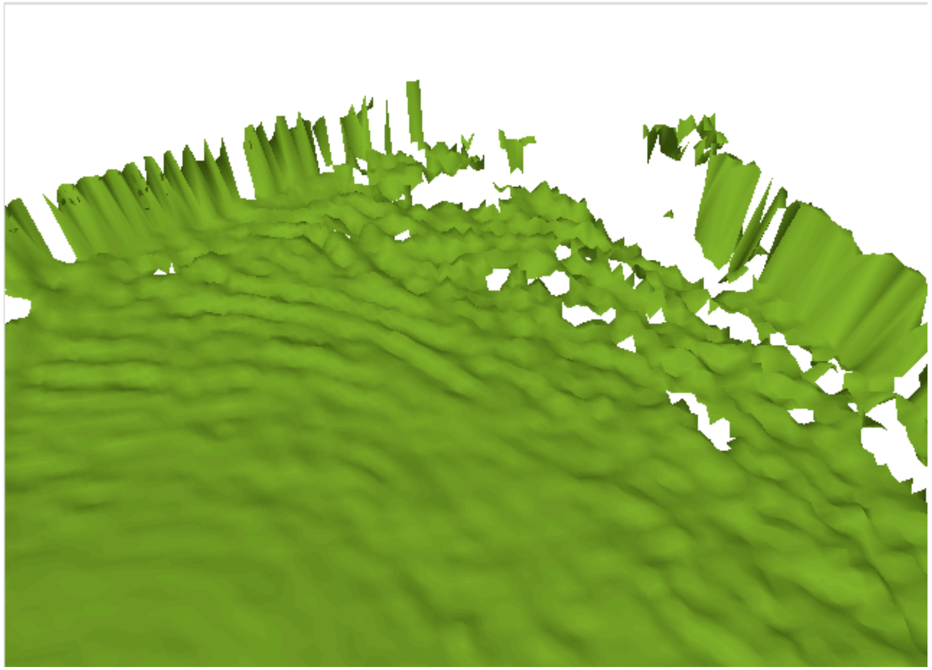
State of the art (http://rtslam.openrobots.org) : 12 state parameters @ 200 Hz, errors of the order of 1% over hundreds of meters

Environment models spatial consistency

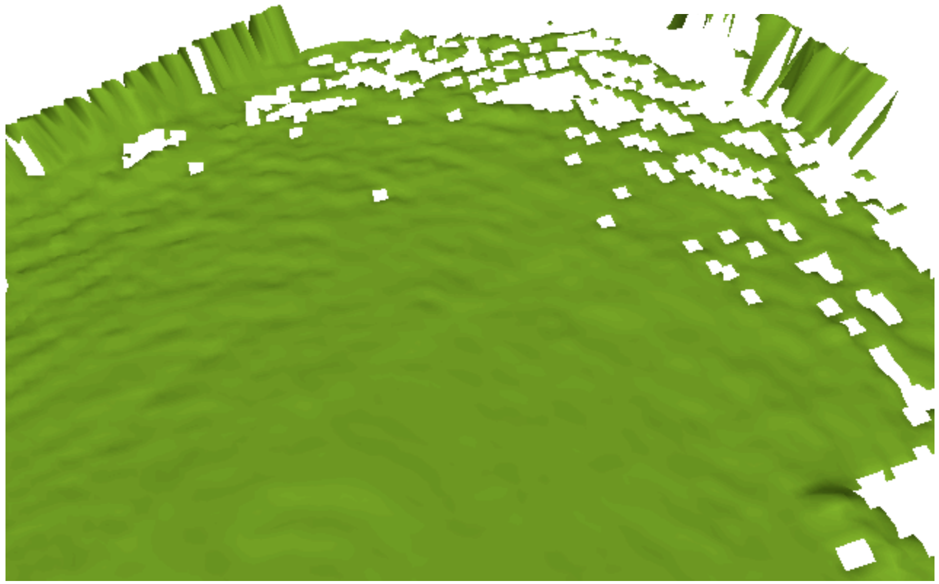
Environment models spatial consistency

- 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*



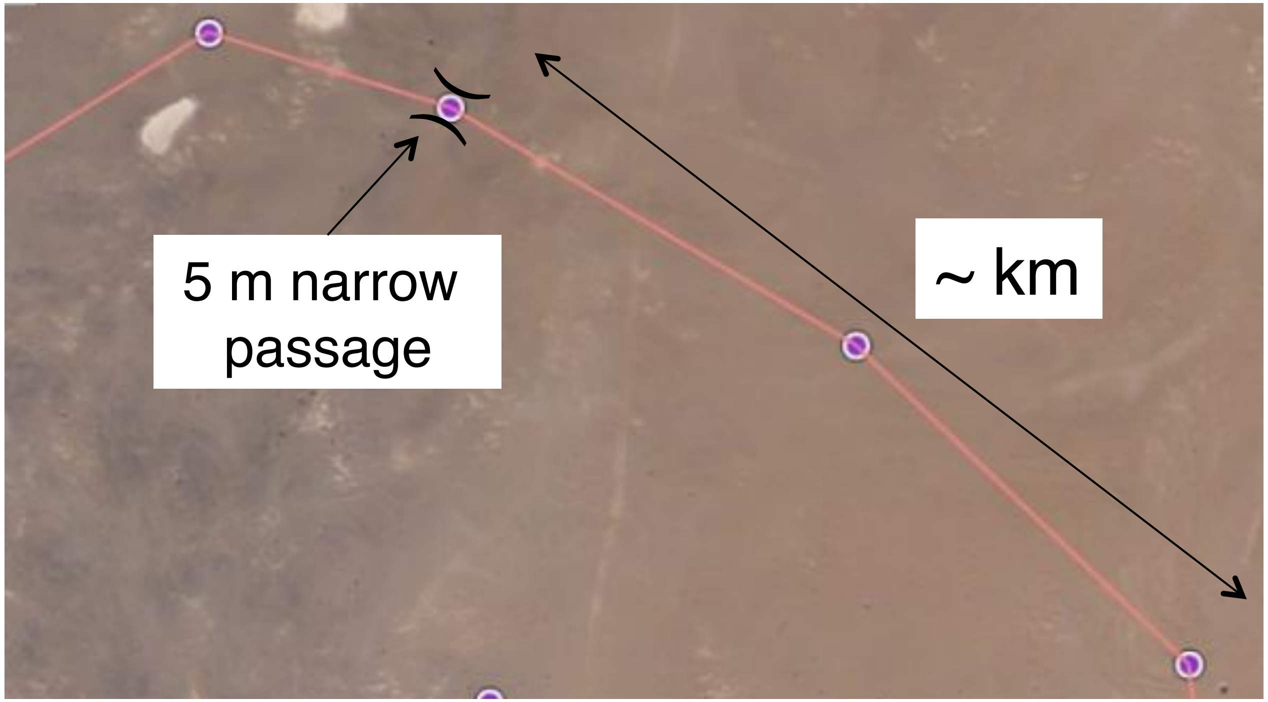
2*m/s*, RT-SLAM @ 100*Hz*

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 : geo-referenced maps

Required localization : *m* accuracy, global *absolute* frame, very low frequency

Which localization?

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”

cm accuracy, 10 to 100 *Hz*, local frame

- Ensure the lowest level (locomotion) controls
- Ensure the proper execution of paths / trajectories
- Ensure the spatial consistency of the built models

~*m* accuracy, “sometimes”, global frame

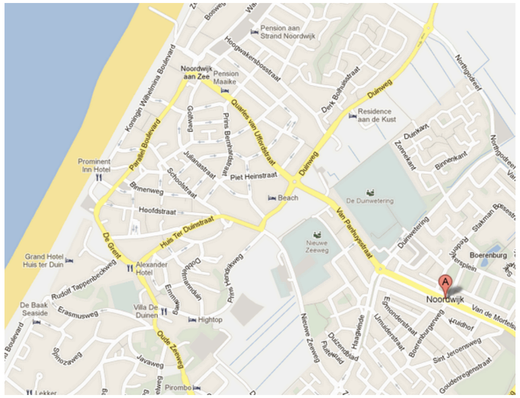
- Ensure the achievement of the missions, most often defined in localization terms (“`goto` *`(goal)`*”, “`explore / monitor` *`(area)`*”, …)

Outline

- On the importance of localization
- Absolute map-based localization
    - Related work
    - Approach
    - Results
- Outlook

The essence of the problem

- Given
  - A map (*various* maps)

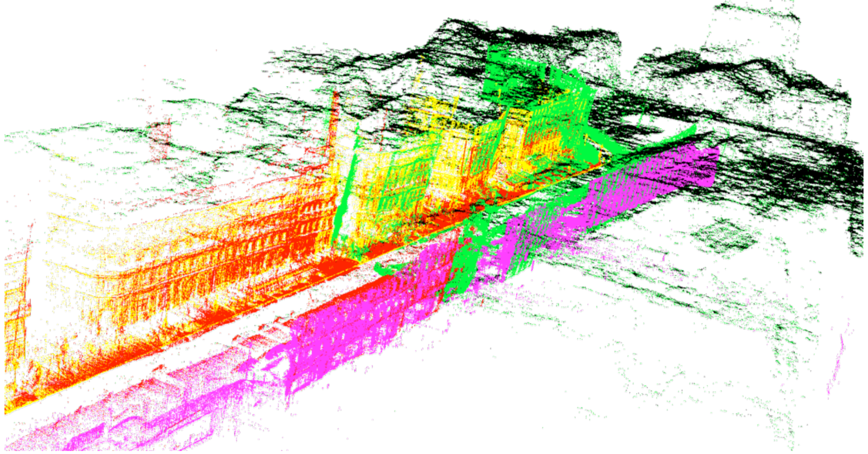


  - Local data

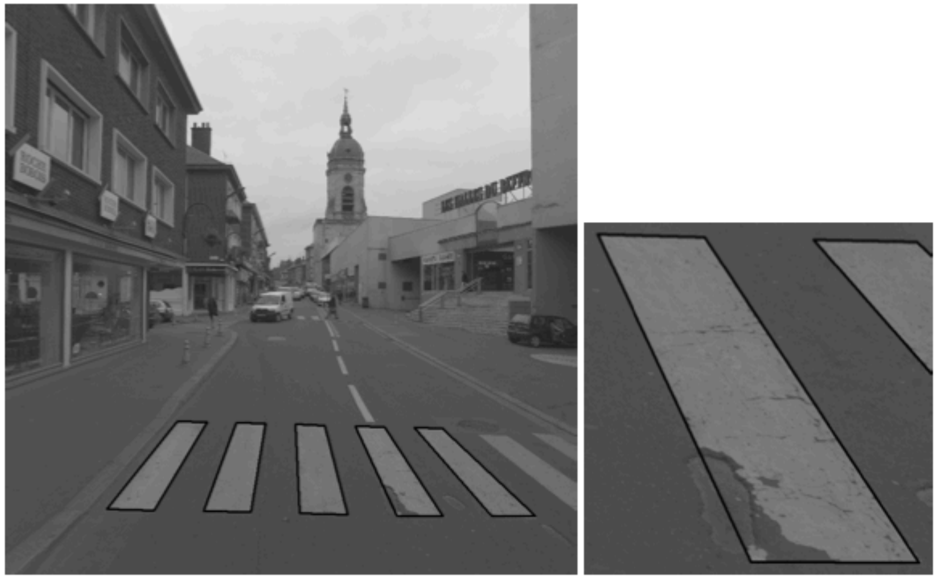
⇒ Where am I ?

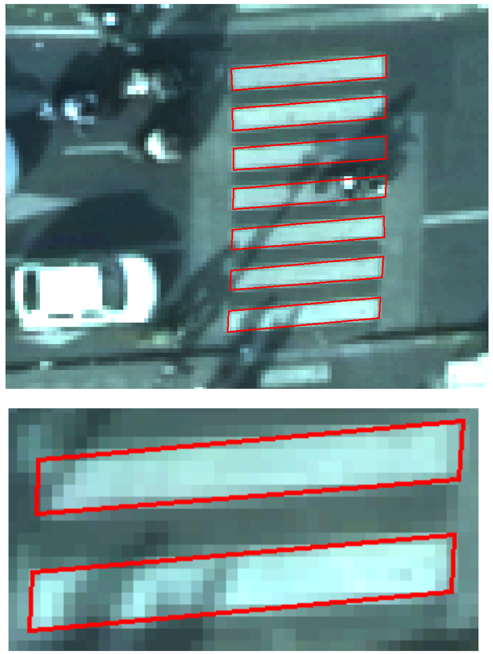
(Matching aerial and terrestrial data on earth)

- A very relevant problem for modern mapping systems
  - 3D points registration



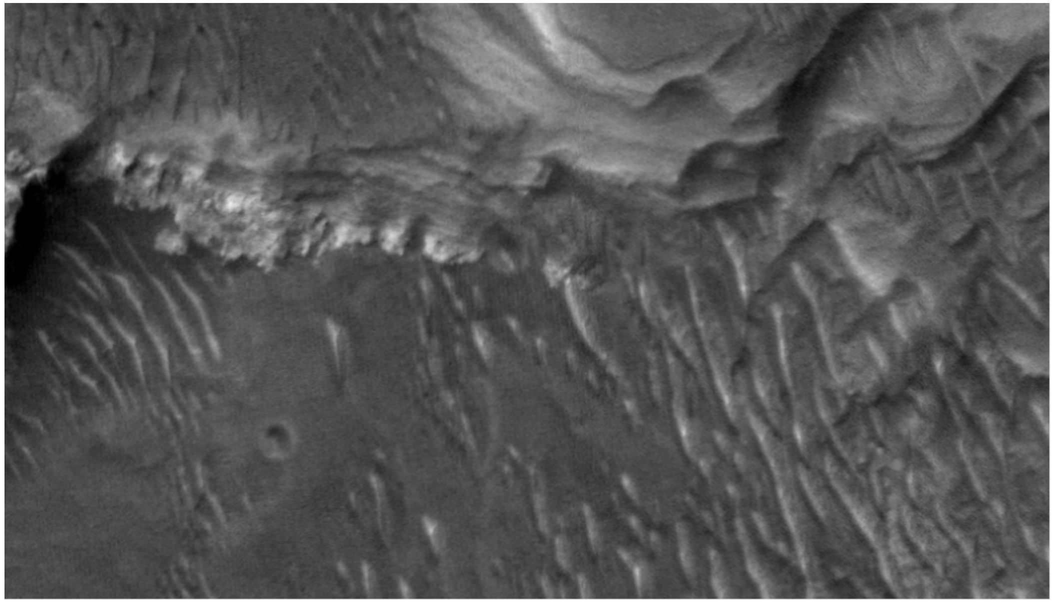
  - Using landmarks



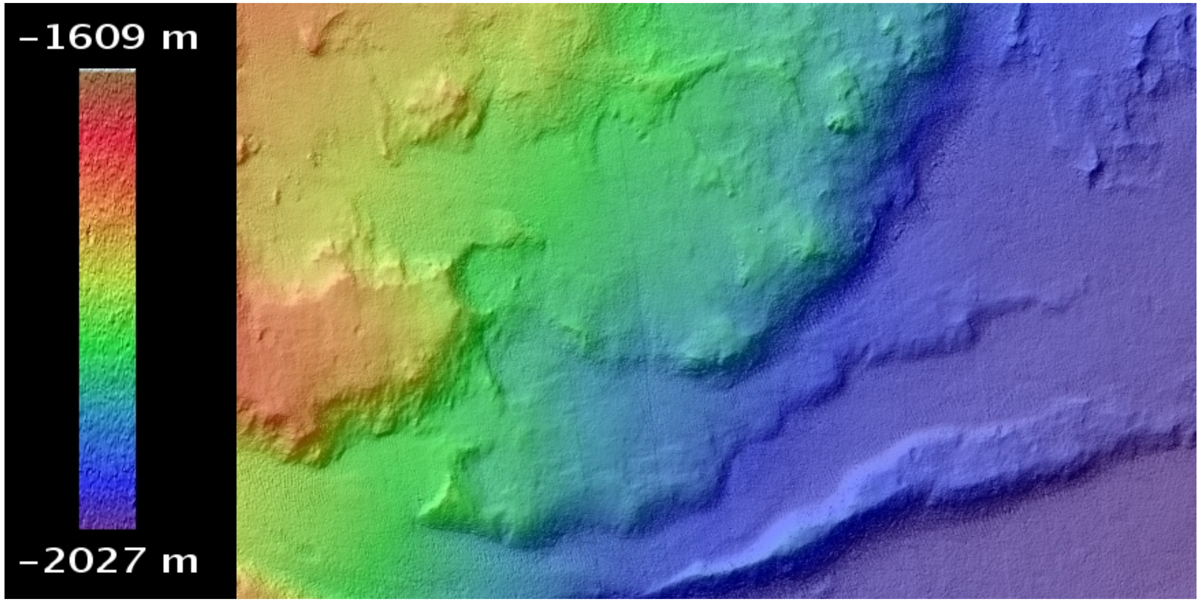


Available maps on Mars

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



DTM of Holden Crater
(1m/pixel)

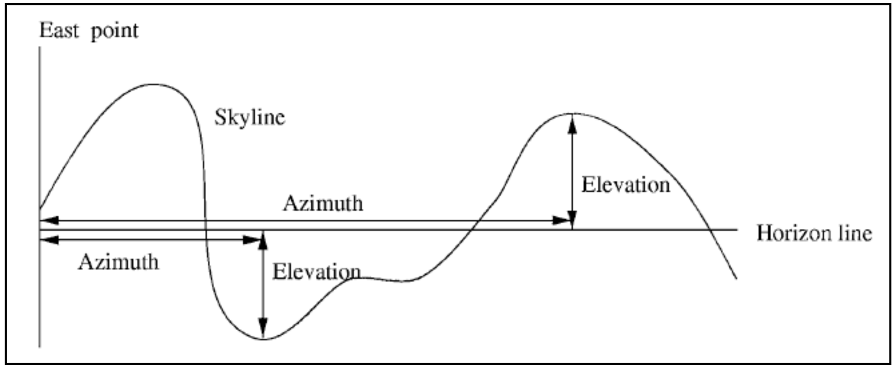


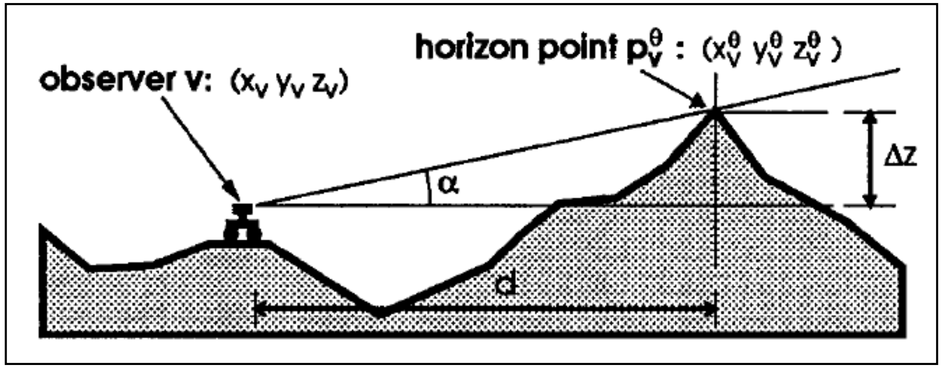
+ descent imagery
(cf MSL)

Map-based localization solutions (1)

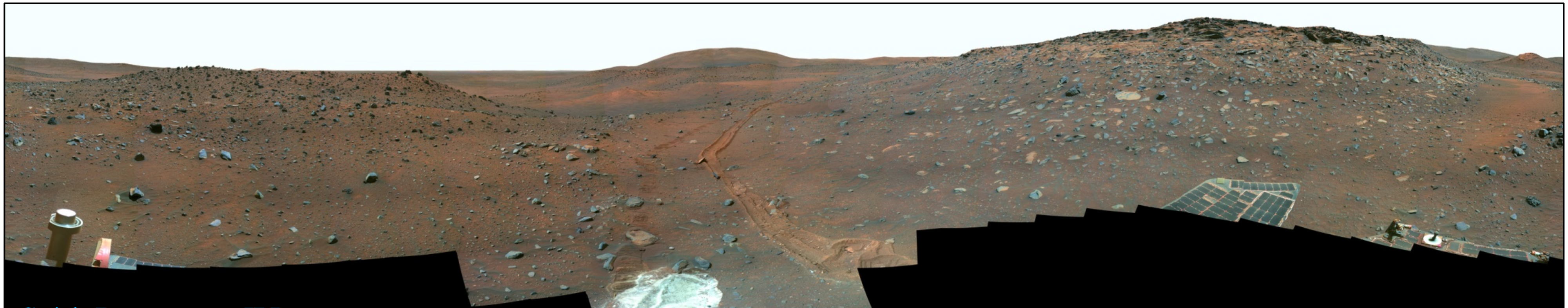
- Skyline matching [Cozman 2000]

1. Extract Skyline Signature for each orbiter DTM cell





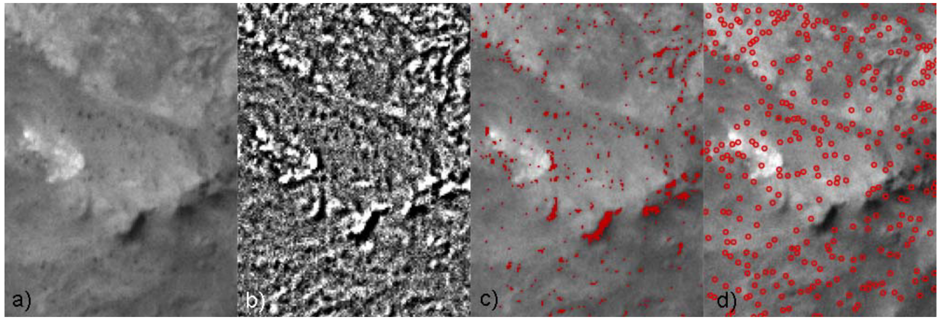
2. Compare robot perceived skyline with DTM skylines


Spirit Panorama - JPL

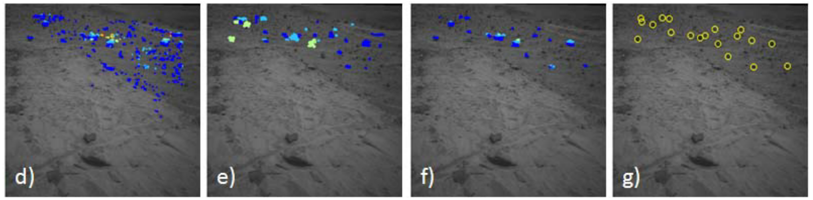
Map-based localization solutions (2)

- Surface feature matching [Hwangbo 2009]

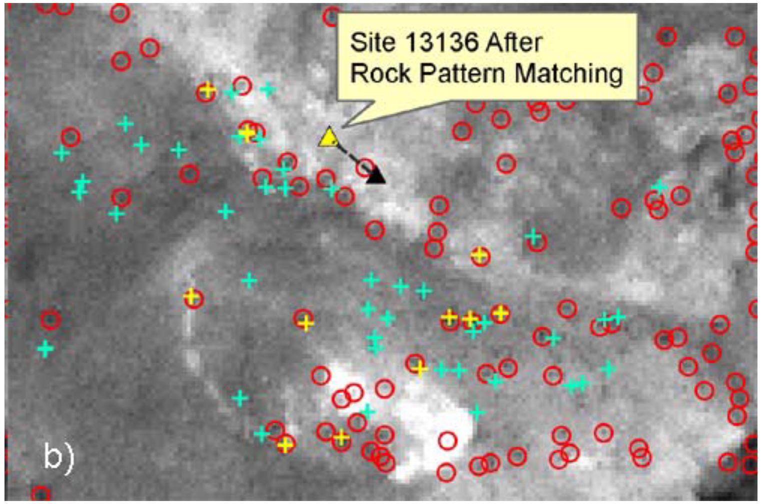
1. Extract rocks from orbital data (e.g. using shadows)



2. Extract rocks from rover stereo data

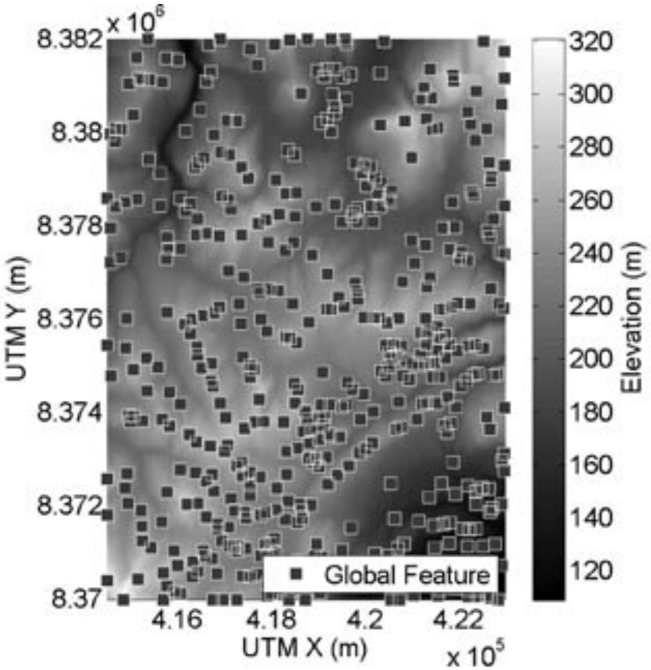


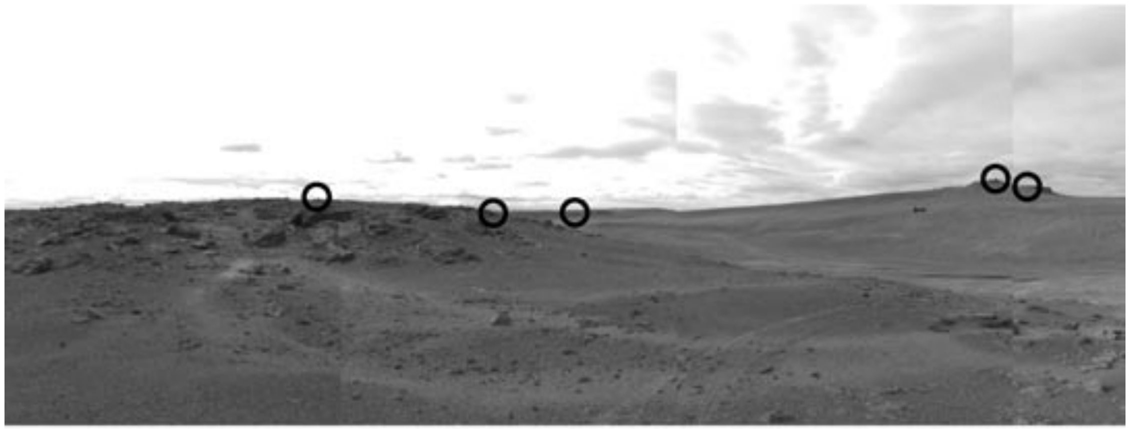
3. Match rock patterns between rover and orbital data



Map-based localization solutions (3)

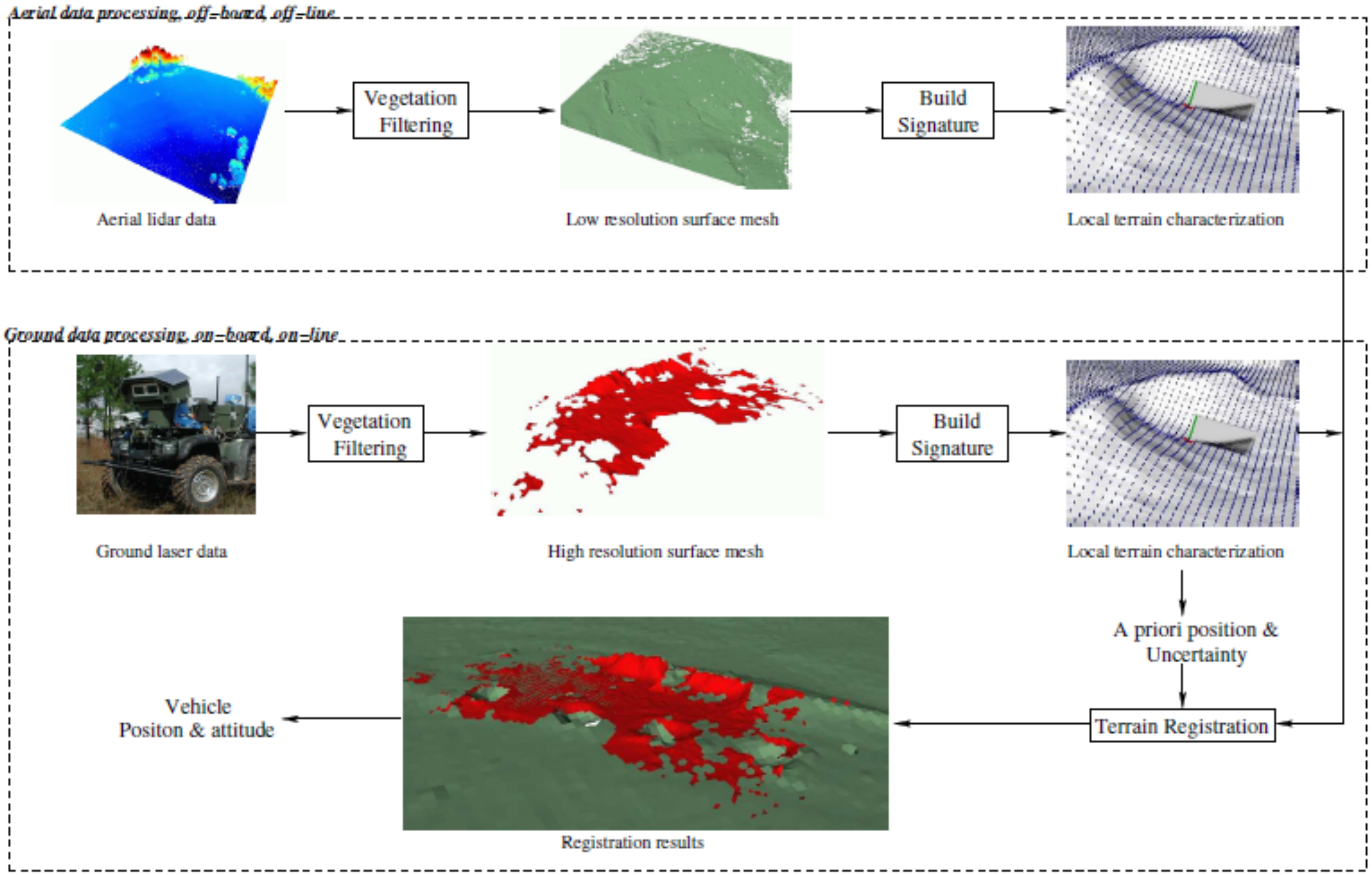
- DTM peaks matching [Carle 2010]





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

All the matching processes involve additional computations

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

Proposed solution: overview

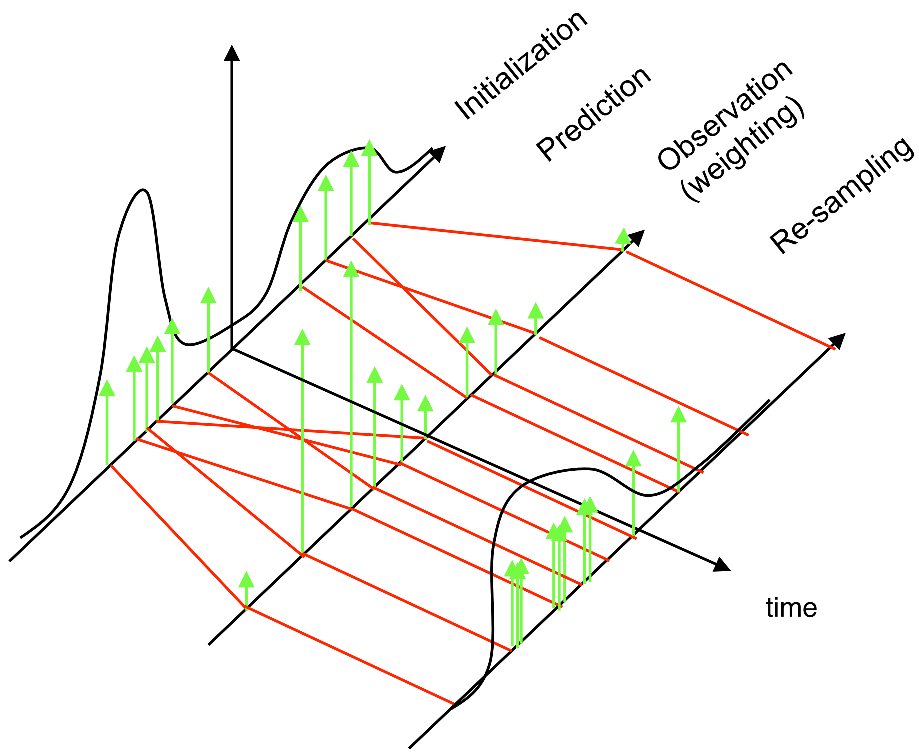
• Two processes involved:

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

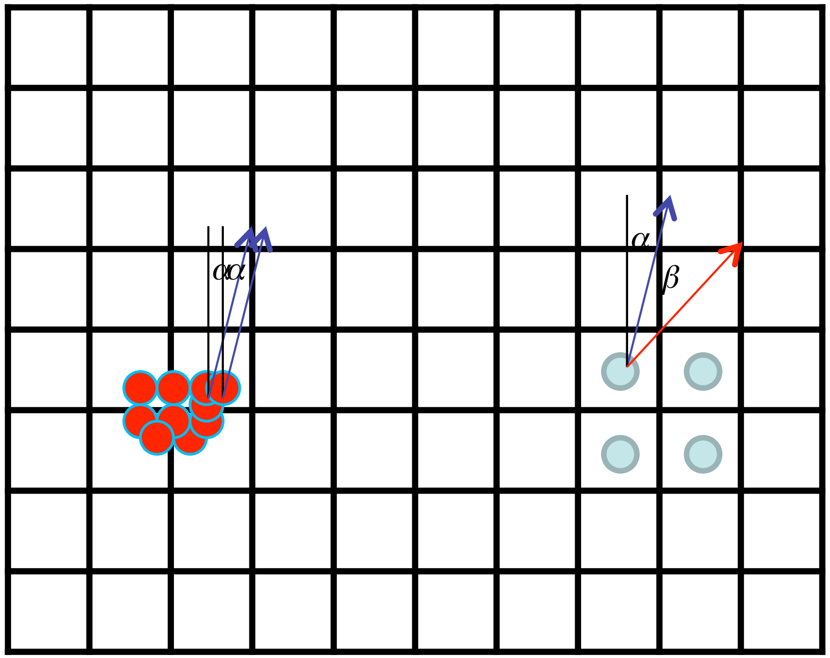
- The robot pos uncertainty is represented by a population of position hypotheses (the particles)
- Prediction step: the particle positions evolved according to the motion estimation (with associated error model)
- Observation step: the likelihood of each particle to represent the true position is estimated (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

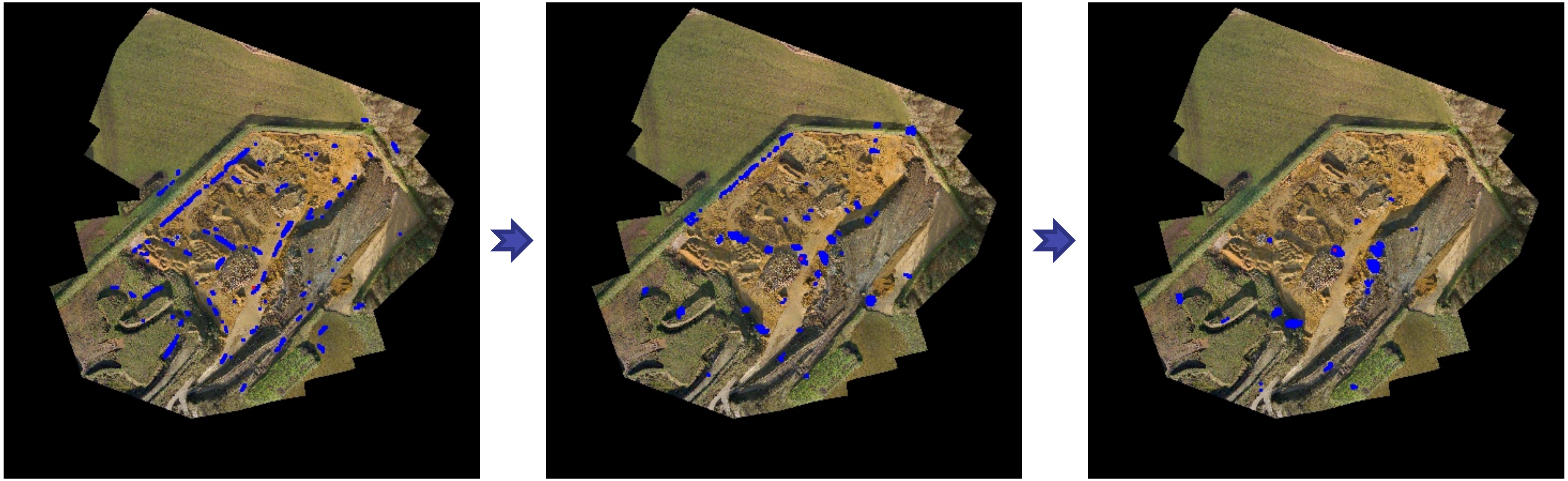
With a UAV, using a camera to build a high resolution DTM

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

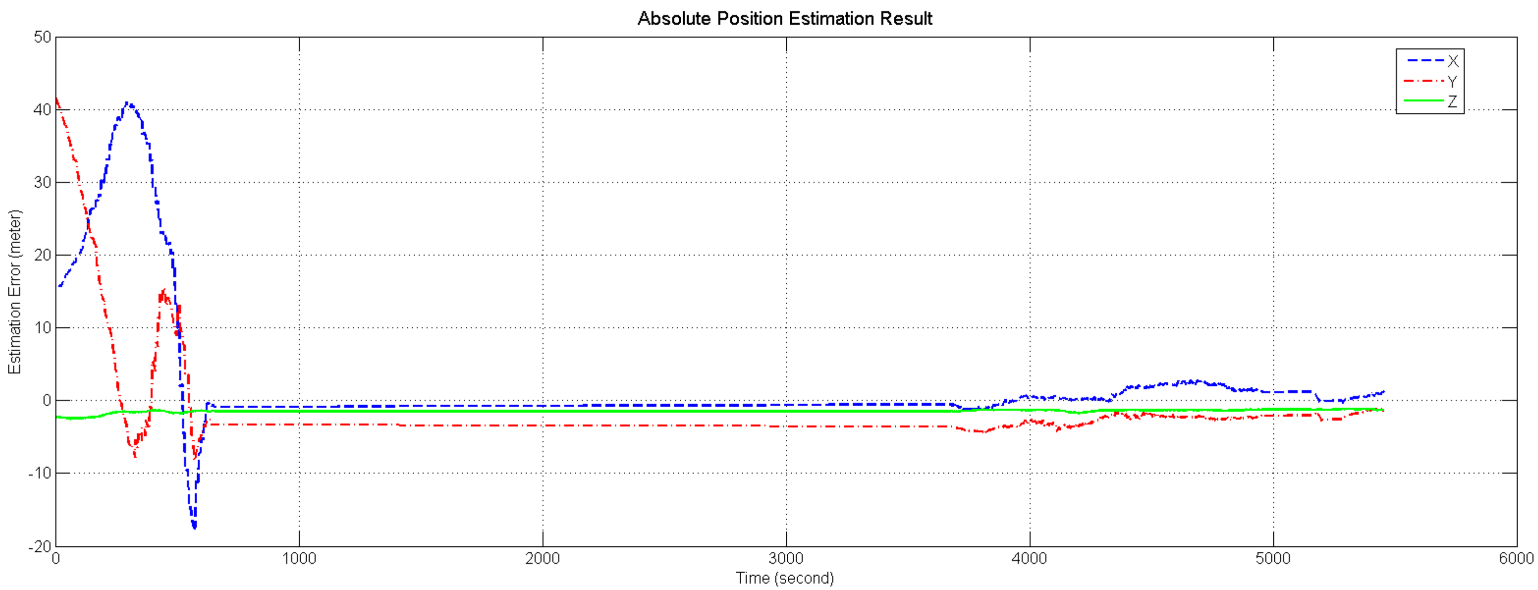
- “Full” initial position uncertainty (worst possible case)

Full search with heading information

Proposed solution: illustration

- On the quarry test field

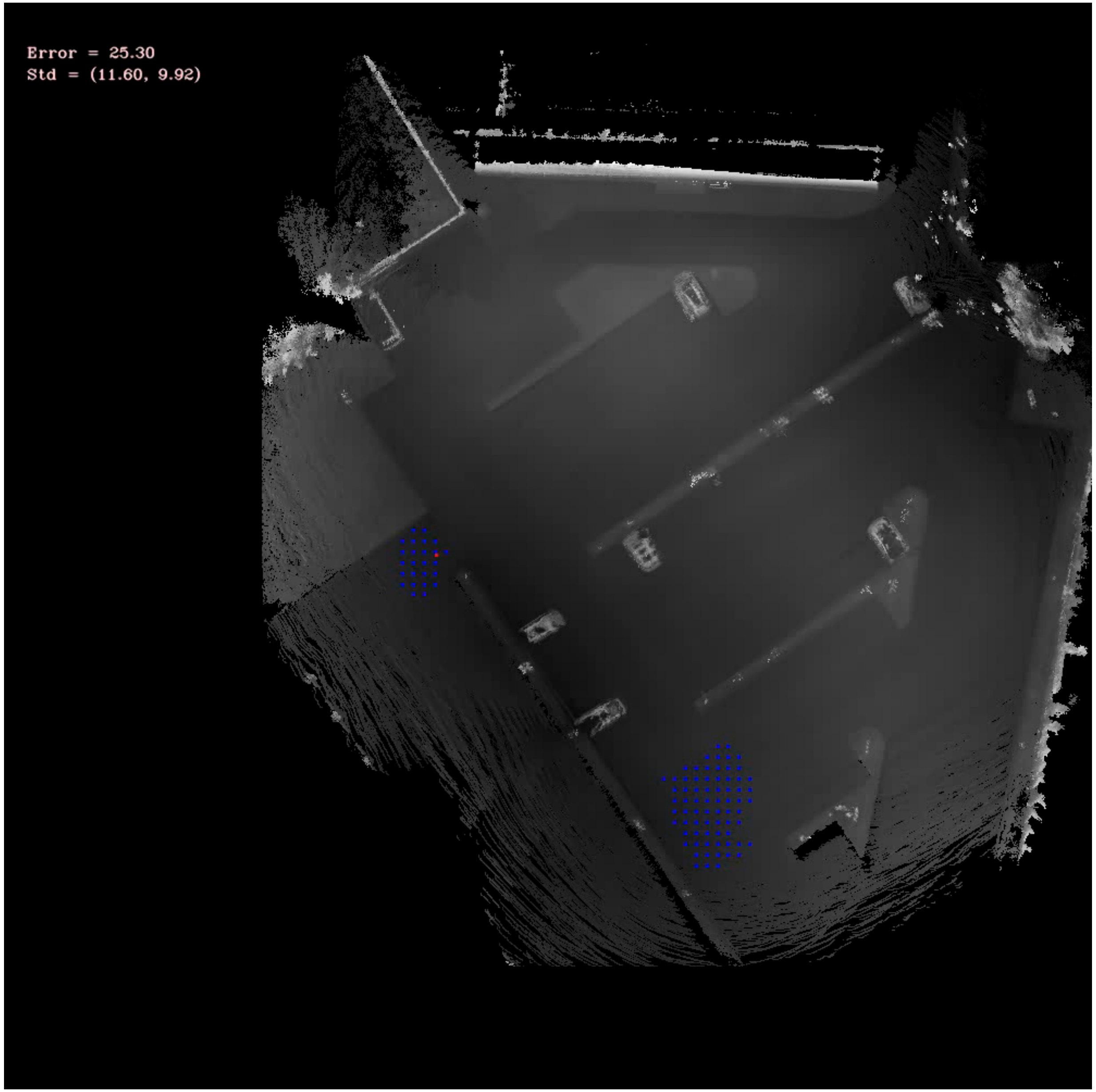
- “Full” initial position uncertainty (worst possible case)



Evolution of the error of the (x,y,θ) position

Proposed solution: illustration

- On a parking lot
- “Full” initial position uncertainty (worst possible case)



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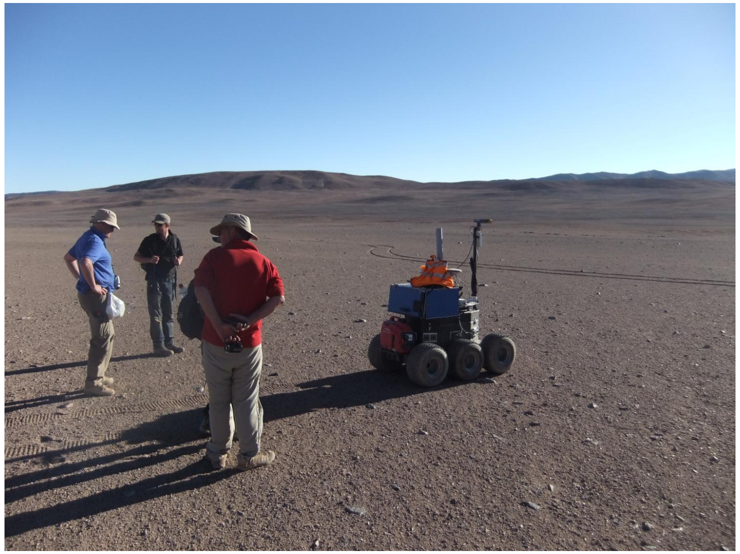
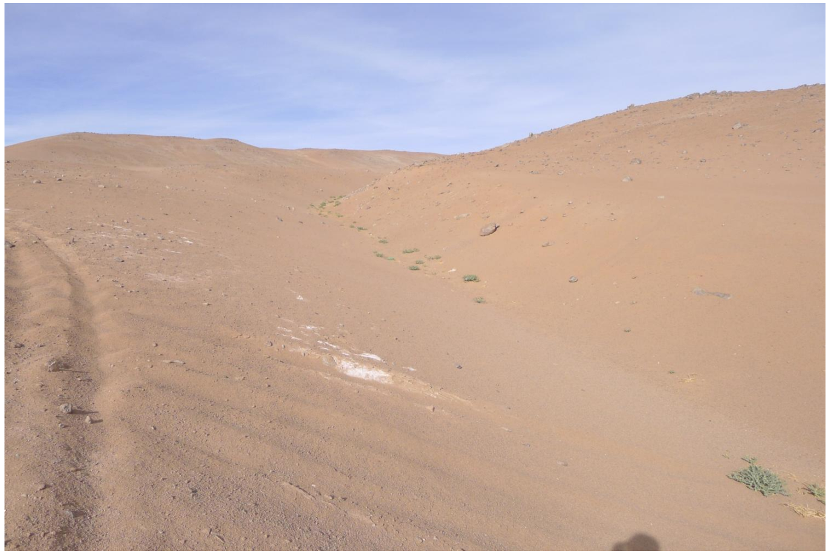
Summary and outlook (1/2)

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



No terrain relief: no absolute localization possible



Sufficient terrain relief: possible absolute localization

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)

Outlook (2/2)

- More generally on localization:
  - A variety of needs
  - A variety of solutions

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

SLAM processes are at the heart of such a framework