CNES robotics activities:
Towards long distance on-board decision-making navigation

S.MORENO

sabine.moreno@cnes.fr
Contents

I. Introduction
   1. Context
   2. Definition

II. CNES activities
   1. Perception
   2. Localisation
   3. Navigation

III. Conclusion
I. Context

Objective = full autonomous navigation on-board rovers

- close visible targets → ground in the loop
  - board systematic interventions in the decision protocol make steps slower
  - limited average speed
- distant targets → on-board decision-making required
  - Speed only limited by energy considerations

NASA rovers: MERs / MSL

- 8.7km / 120 sols
  → up to 40m/sol
- Different navigation modes
  - distance to the goal,
  - nature of the soil,
  - ...

<table>
<thead>
<tr>
<th>Navigation modes</th>
<th>% total distance</th>
<th>Average speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct driving</td>
<td>~25%</td>
<td></td>
</tr>
<tr>
<td>Blind Goto Waypoint</td>
<td>~40%</td>
<td>133 m/h</td>
</tr>
<tr>
<td>Autonav</td>
<td>~25%</td>
<td>12-35 m/h</td>
</tr>
<tr>
<td>Visodom</td>
<td>~9%</td>
<td>12 m/h</td>
</tr>
</tbody>
</table>
I.2. CNES AN architecture

AN architecture

- Perception
  - Stereobench, 3D modeling
- Localisation
  - Wheel odometry + VME
- Locomotion
- Navigation
  - Kinematics maps building
  - Path & Perception planning

On-board computation

- Optimised algorithms (“ready to fly” at functional level)
II.1.a. HW Perception Tools

- Stereo-benches for short term missions
  - Optimized characterisation process
  - Stereo base measurement methods
- Stereo-benches for future missions
  - Wider FOV
- Tools for tests & validation
  - MGSE = precise 3D measurement
    - cf “Dense stereo-vision algorithms validation and tuning using laser scanner hi-resolution reference models”, ASTRA2011
  - Light version under validation
    - Outdoor campaigns
II.1.b. SW Perception Tools

- **Hi-dynamics cameras (>8bits)**
  - Robustness
  - Radiometric correction
- **Algorithms adaptation for an OBC configuration with more memory available**
  - More accurate models of the environment
  - Spare computation time
    - ex: images rectification
  - Better precision for the 3D reconstruction
  - More accurate radiometric correction

![Screenshot of the CNES 3D reconstruction tool](image-url)
II.1.b. SW Perception Tools

- Accurate stereo-base measurement
  - Better knowledge of the scale factor
  - Better reliability of the navigation

- Multi-resolution stereo-vision
  - Faster
  - More robust in poor light conditions

- Exomars project requests
  - Algorithms validation
  - Rec3D tests
    - Campaign planned for summer 2013 to quantify the reconstruction performances
II.2.a. Recent Localisation activities

- **Wheel odometry**
  - Based on rovers kinematics
  - Used on-board for CNES campaigns
  - Increase of performances expected thanks to specific locomotion sensor (velocimeter)
    - R&D ongoing activity

- **VME**
  - cf “Vision-Based Motion Estimation for the ExoMars Rover”, ISAIRAS 2010
  - Campaigns for validation & robustness (autumn 2010)
    - Precision: relative localisation error <1% after 100m
    - Report delivered to ESA in early 2011
II.2.b. On-going & planned Localisation activities

- **VME**
  - Algorithms adaptation for increased OB memory
    - Increased precision
    - Reduced computation time
  - Test & validation with images taken on-board a moving rover
  - New localisation architecture evaluation
    - Cooperation between odometry/VME/sun sensor/data fusion
II.3.a Recent Navigation activities

- Numerous improvements on AN SW
- Statistics tests on simulator
  - ~100km travelled
- Campaign for validation & robustness (autumn 2011)
  - Report delivered to ESA in early 2012
- ESTEC-CNES Remote Experiment #2
  - cf “ESTEC-CNES Remote Experiment”, ASTRA 2011
- CNES Mars yard DTM model
  - Cross-validation ESA/CNES
II.3.b On-going Navigation activities

- Algorithms adaptation for increased OB memory
  - Increase of the NavMap size:
    - local knowledge (~14x14m)
    - → up to 1 sol traverse (~100x100m)
  - NavMaps = bitmaps directly issued from DTM

- Short term Path Planning
  - PP under kinematic constraints
    - Traj = curve instead of straight lines
  - FRA*, D*
  - DTM label: rover cross capabilities better taken into account
    - Kinematics + clearance
II.3.b On-going Navigation activities

- Long Distance Navigation
  - Maps updated at each Path&Perception Planning step (~4m)
  - Store NavMaps up to mission size
  - Vectorial representation of the NavMaps → TopoMaps
    - Save memory for storage
    - All previous knowledge available at each PP step
      - avoid dead-end loops,
      - enable (automated) secured return to landing site
  - Data fusion → multi-resolution :
    - Merge with precomputed maps
    - Merge with ground data (avoidance areas)
  - Algos compatible with currently available memory & CPU
II.3.b On-going Navigation activities

NavMap(t)

NavMap(t+1)

NavMap(t+2)
II.3.b On-going Navigation activities

NavMap(t)

NavMap(t+1)

NavMap(t+2)
II.3.b On-going Navigation activities

NavMap(t) → NavMap(t+1) → NavMap(t+2)
II.3.b On-going Navigation activities

NavMap(t) → NavMap(t+1) → NavMap(t+2)
II.3.b On-going Navigation activities
II.3.b On-going Navigation activities

NavMap to TopoMap
II.3.b On-going Navigation activities
II.3.c Means for Navigation activities

- IARES
  - Rover delivered in 1997
  - 17 +2 dof
  - Still used for tests
II.3.c Means for Navigation activities

- **ARTEMIS**
  - New rover, delivered in 2011, currently being assembled
  - Close to Exomars kinematics
  - Architecture mainly based on off-the-shelf components
    - Cheaper
    - Easier maintenance
II.3.c Means for Navigation activities

Simulator

- Improvements since last version provided to ESA:
  - Fog,
  - New vehicle,
  - Stones,
  - New perspectives,
  - Real time shadowing,
  - MNT refreshment,
  - ....
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III. Conclusion

- Numerous improvements of CNES technologies available for:
  - Exomars project,
  - R&D for future missions,
  - Some of the sample return requirements already met (Topo Maps),
  - ....

- Adaptation of these technologies/subsystems to other/various robotics applications/missions:
  - Ground modeling (landing, probe approaching phase, ...),
  - In orbit modeling (non cooperative objects, ...),
  - Short & long distance localisation (landing, robotics in orbit, ...),
Thank you for your attention.

Any questions?