CENTRE NATIONAL D'ÉTUDES SPATIALES

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

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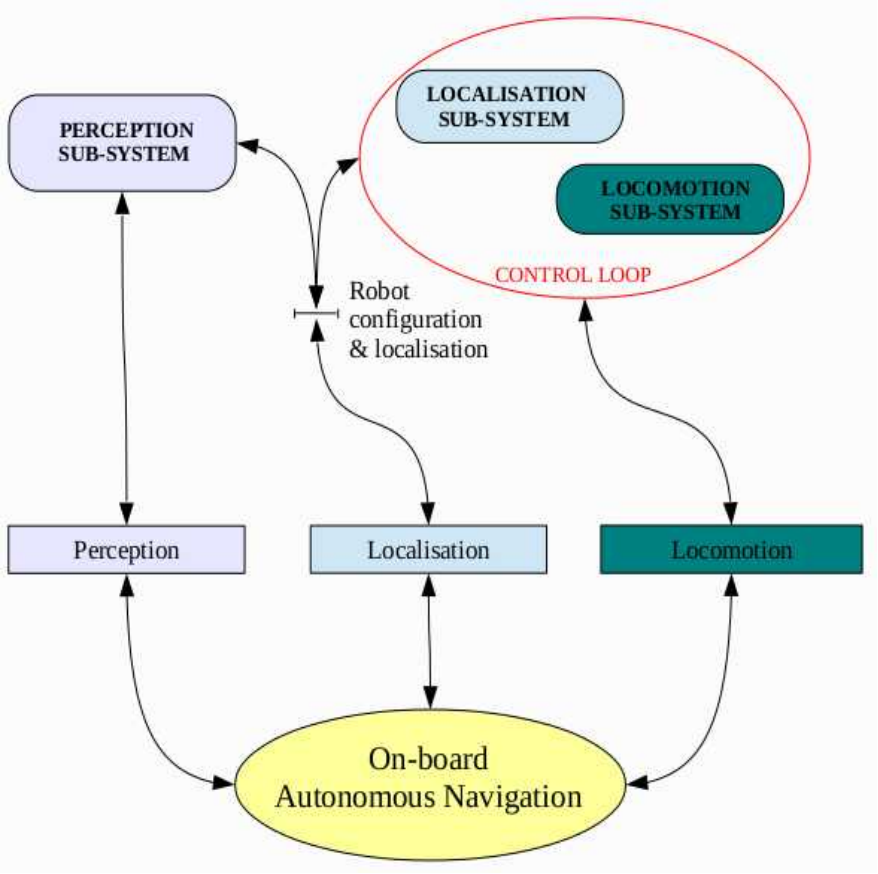
I.1. Context

- 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,
    - ...

Navigation modes	% total distance	Average speed
Direct driving	~25%	
Blind Goto Waypoint	~40%	133 m/h
Autonav	~25%	12-35 m/h
Visodom	~9%	12 m/h

I.2. CNES AN architecture

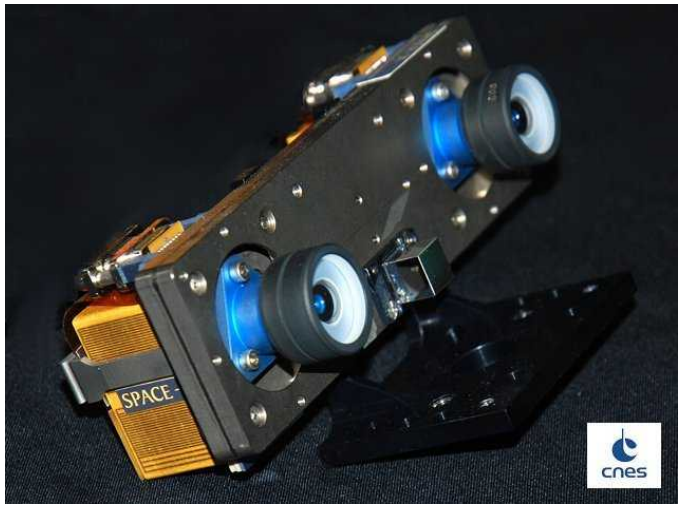
- AN architecture
  - Perception
    - Stereobenches, 3D modeling
  - Localisation
    - Wheel odometry + VME
  - Locomotion
  - Navigation
    - Kinematics maps building
    - Path & Perception planning



- On-board computation
  - Optimised algorithms (“ready to fly” at functional level)

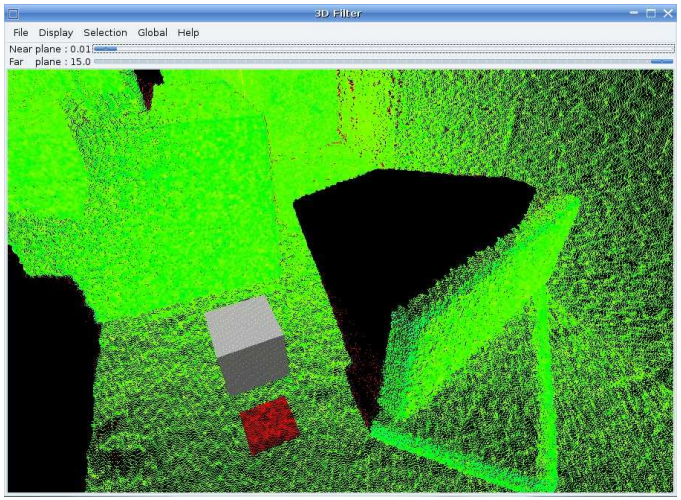
II.1.a. HW Perception Tools

- 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

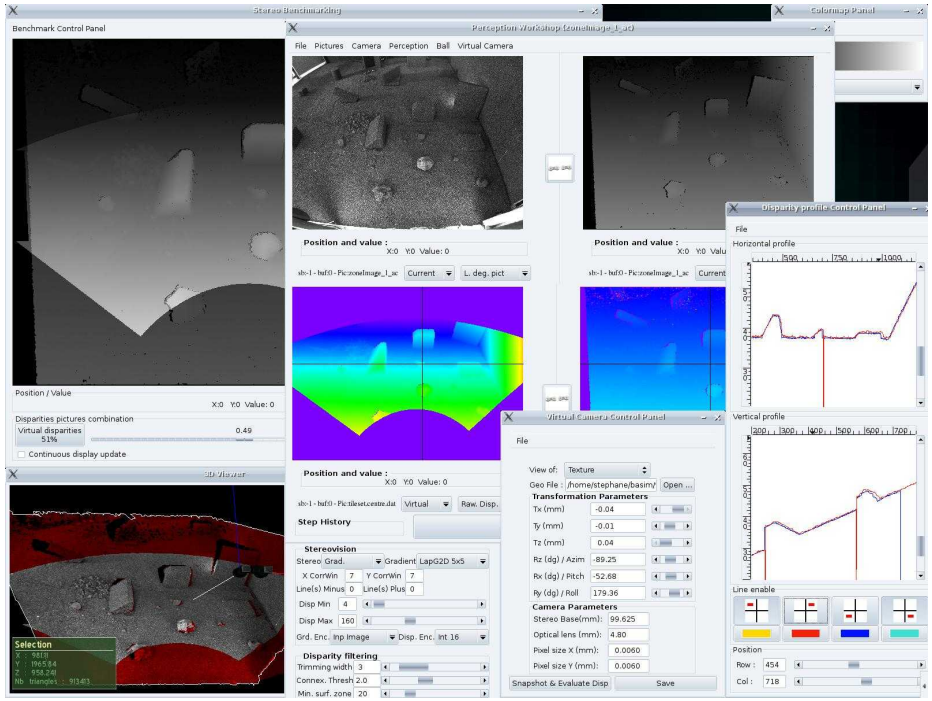
- Hi-dynamics cameras (>8bits)
  - Robustness
  - Radiometric correction
- Algorithms adaptation for an OBC configuration with more memory available
  - More accurate models of the environment
  - Spare computation time
    - ex : images rectification
  - Better precision for the 3D reconstruction
 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



Screenshot of the CNES 3D reconstruction tool

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



Snapshot of PW and Rec3D tools

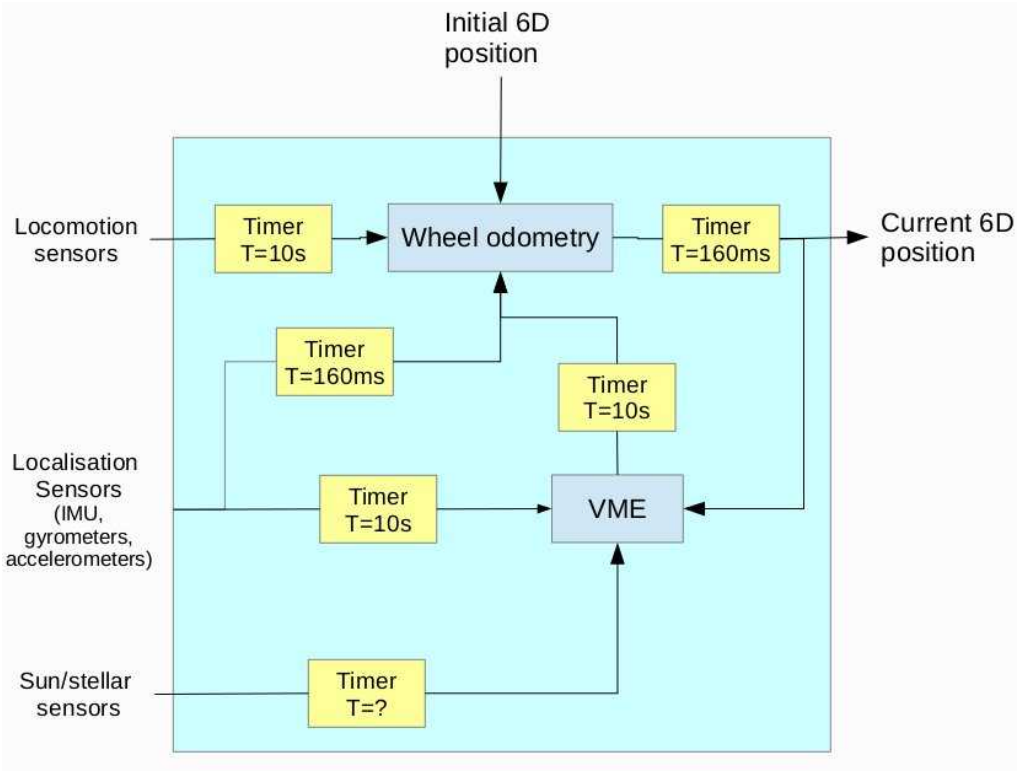
II.2.a. Recent Localisation activities

- 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

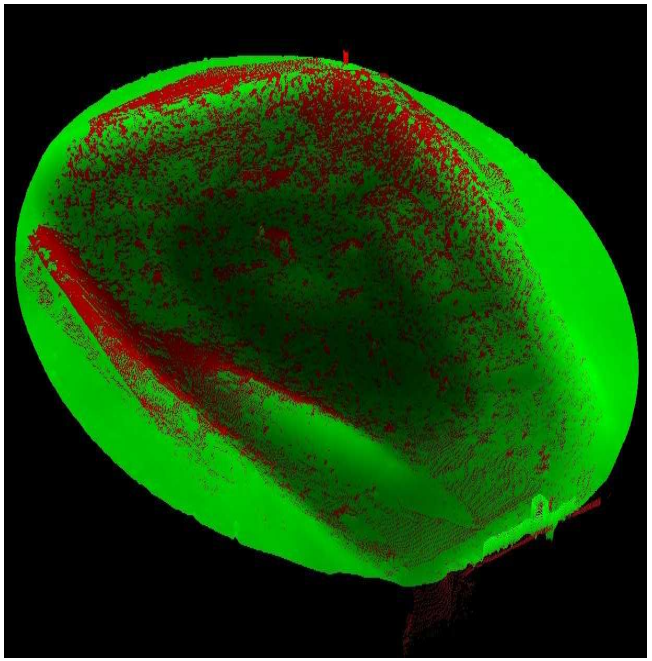
II.2.b. On-going & planned Localisation activities

- 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

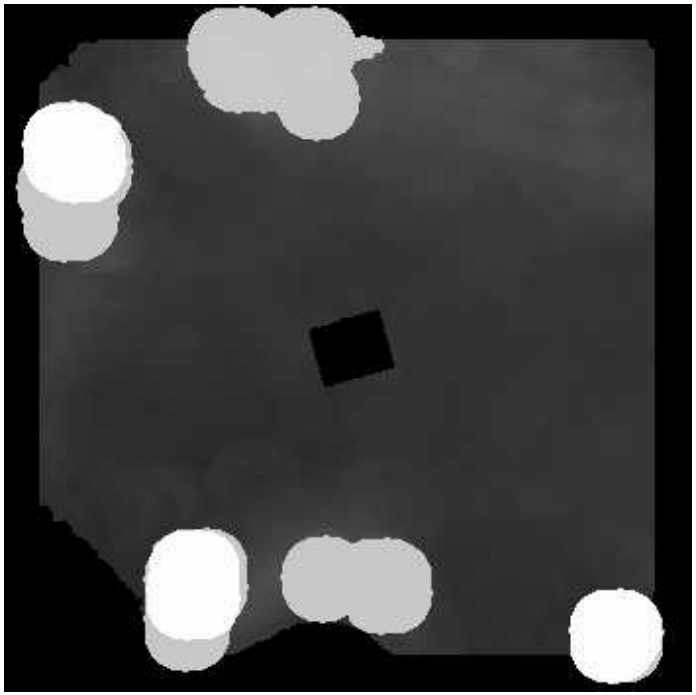
- Numerous improvements on AN SW
- Statistics tests on simulator
  - ~100km travelled
- Campaign for validation & robustness (autumn 2011)
  - Report delivered to ESA in early 2012
- ESTEC-CNES Remote Experiment #2
  - cf “ESTEC-CNES Remote Experiment”, ASTRA 2011
- CNES Mars yard DTM model
  - Cross-validation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



3D fitting on CNES Mars yard (2012) : CNES photogrammetry (green) / ESA laser scanner (red)

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

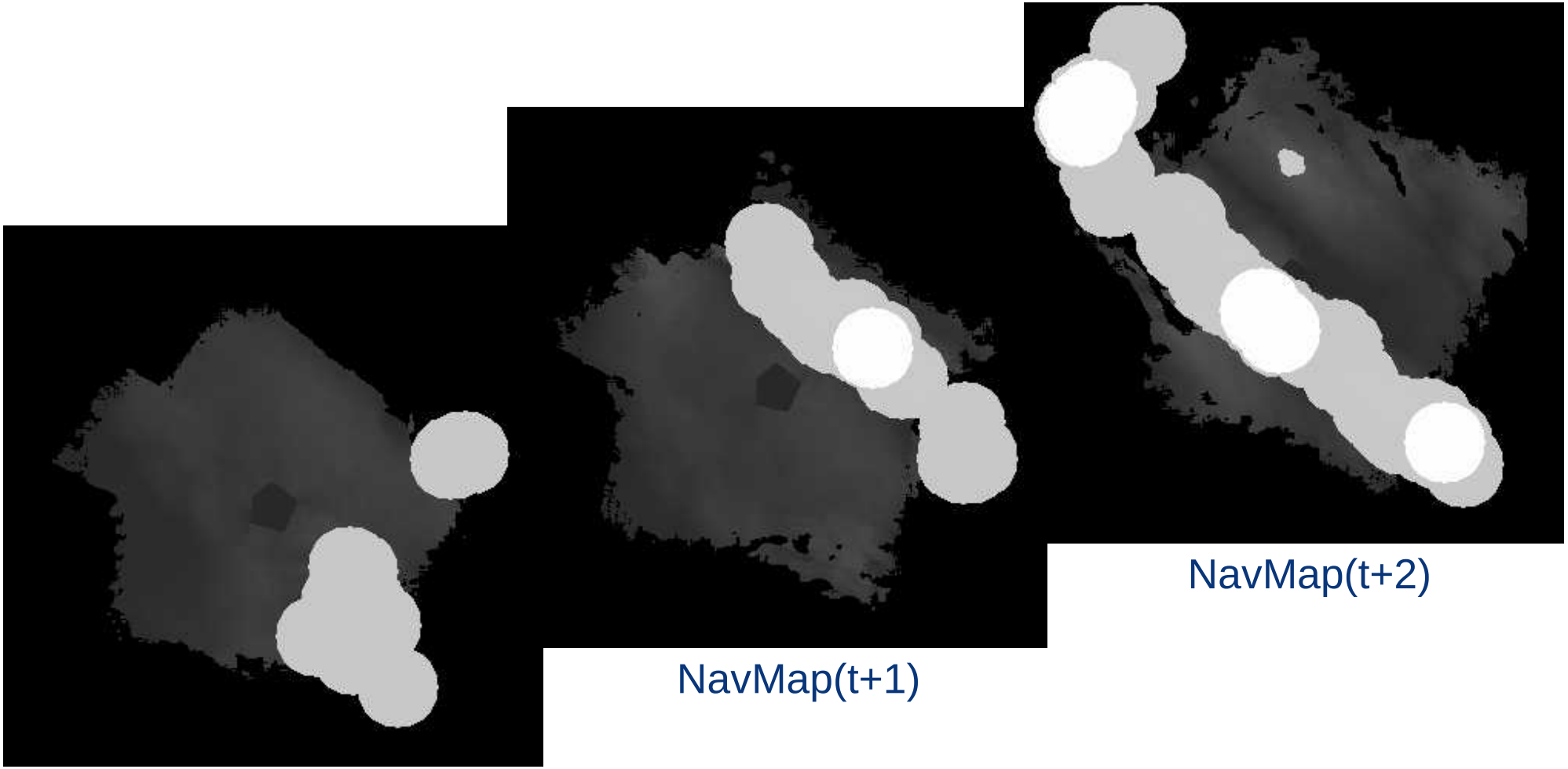


- Short term Path Planning
  - PP under kinematic constraints
    - Traj = curve instead of straight lines
  - FRA*, D*
  - DTM label : rover cross capabilities better taken into account
    - Kinematics + clearance

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

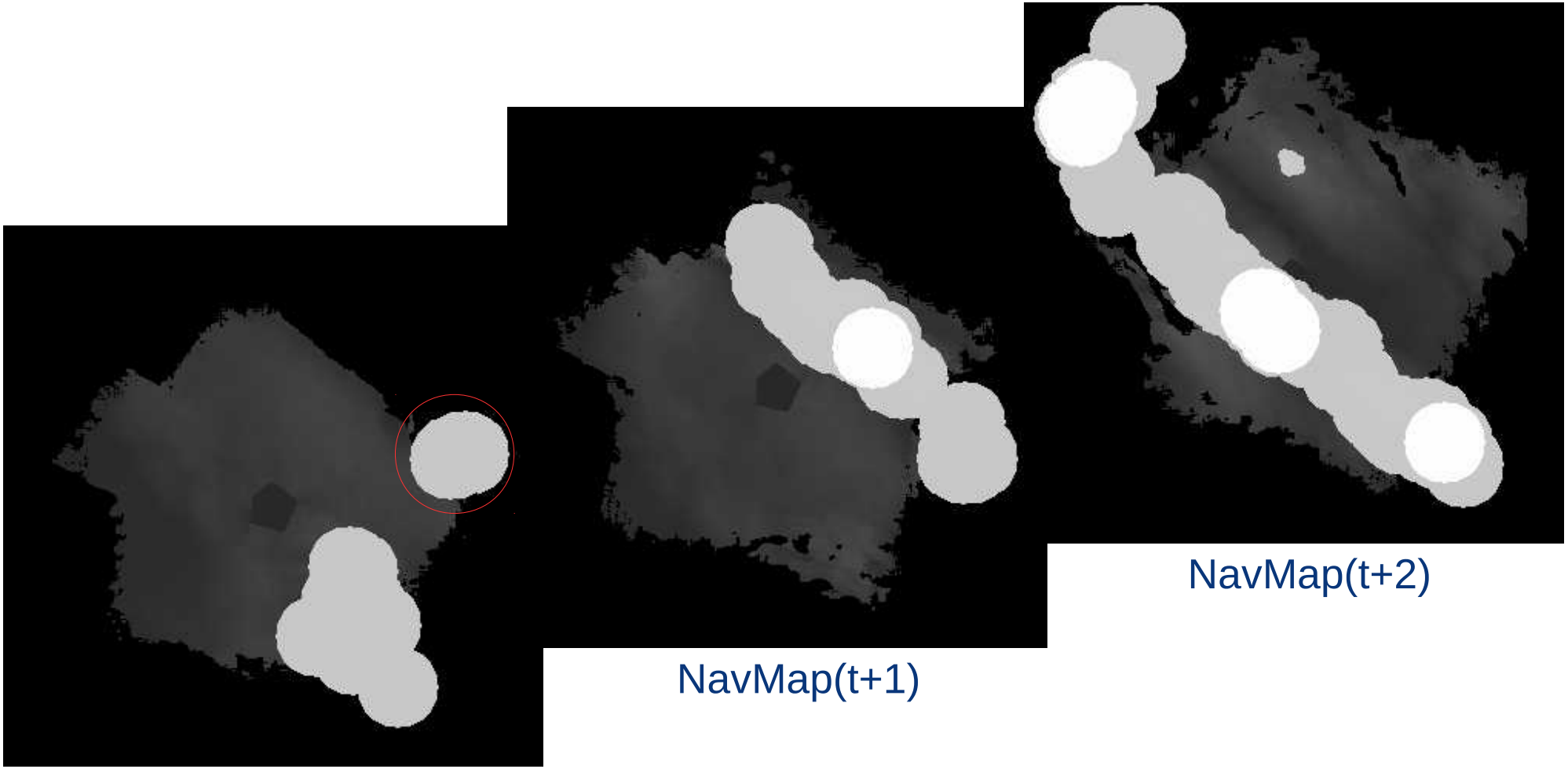


NavMap(t)

NavMap(t+1)

NavMap(t+2)

II.3.b On-going Navigation activities



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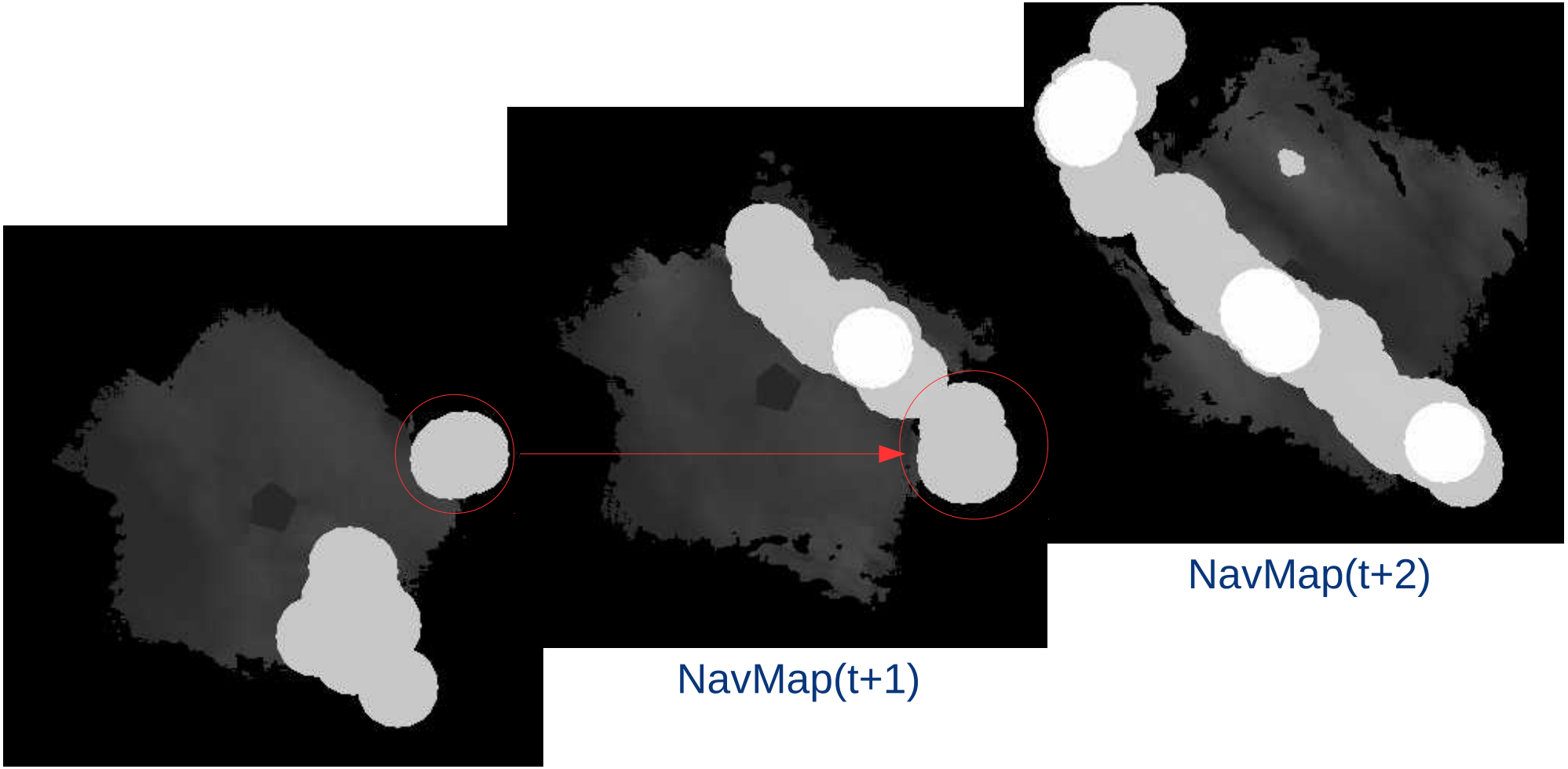

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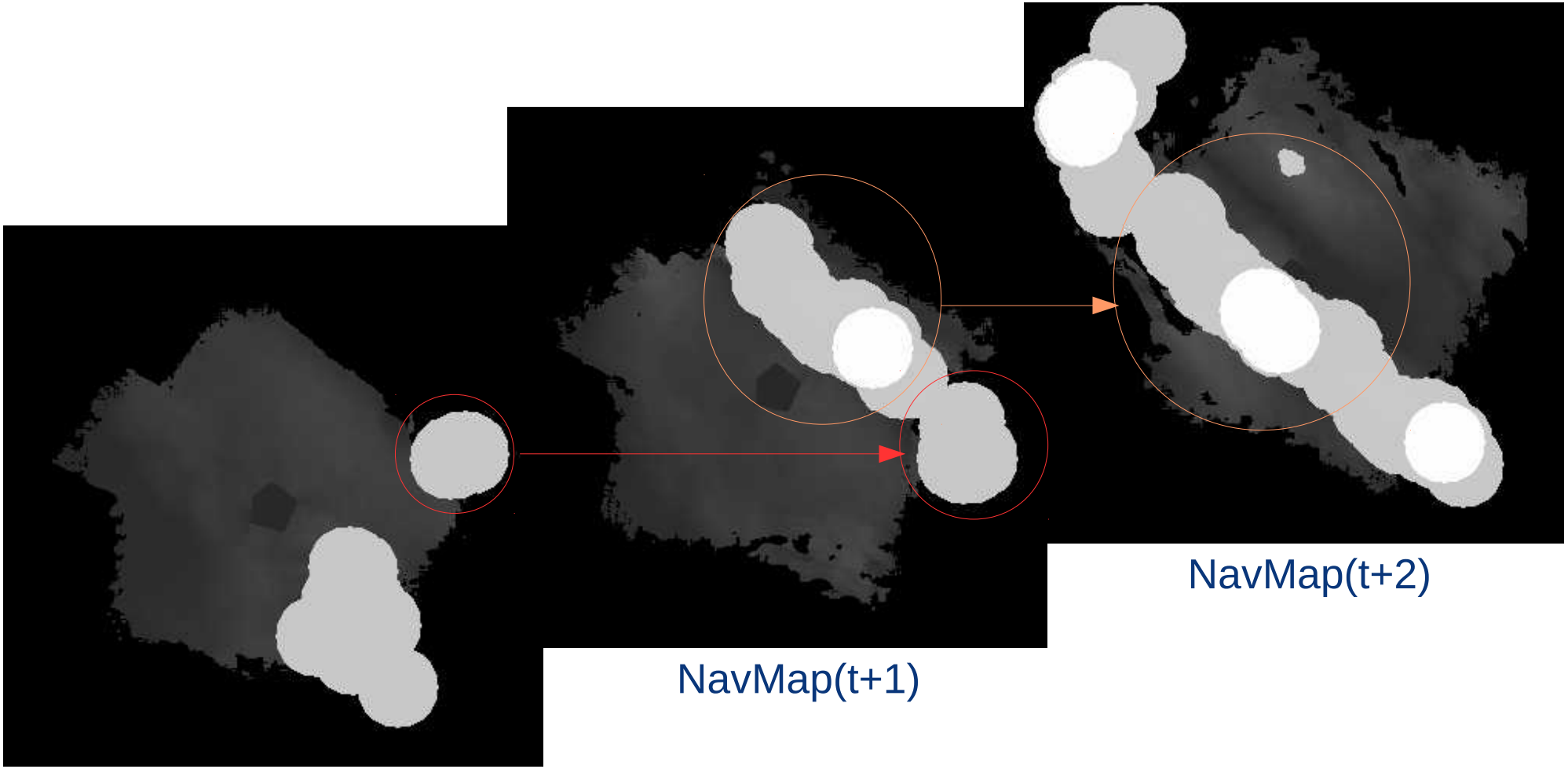

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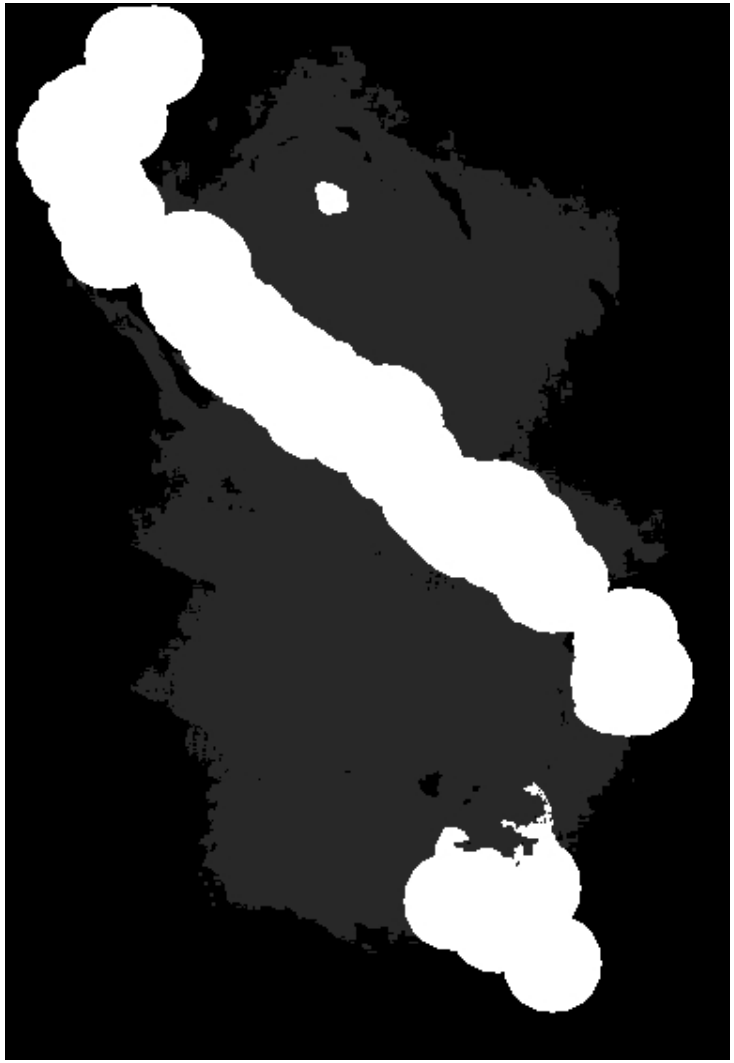

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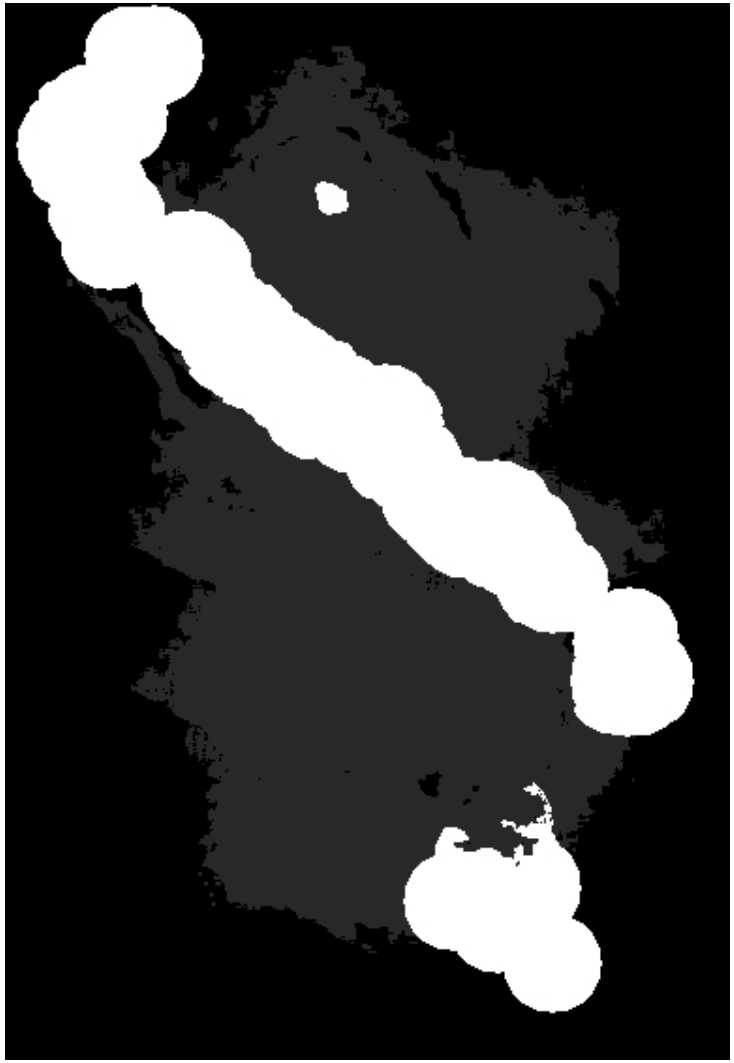
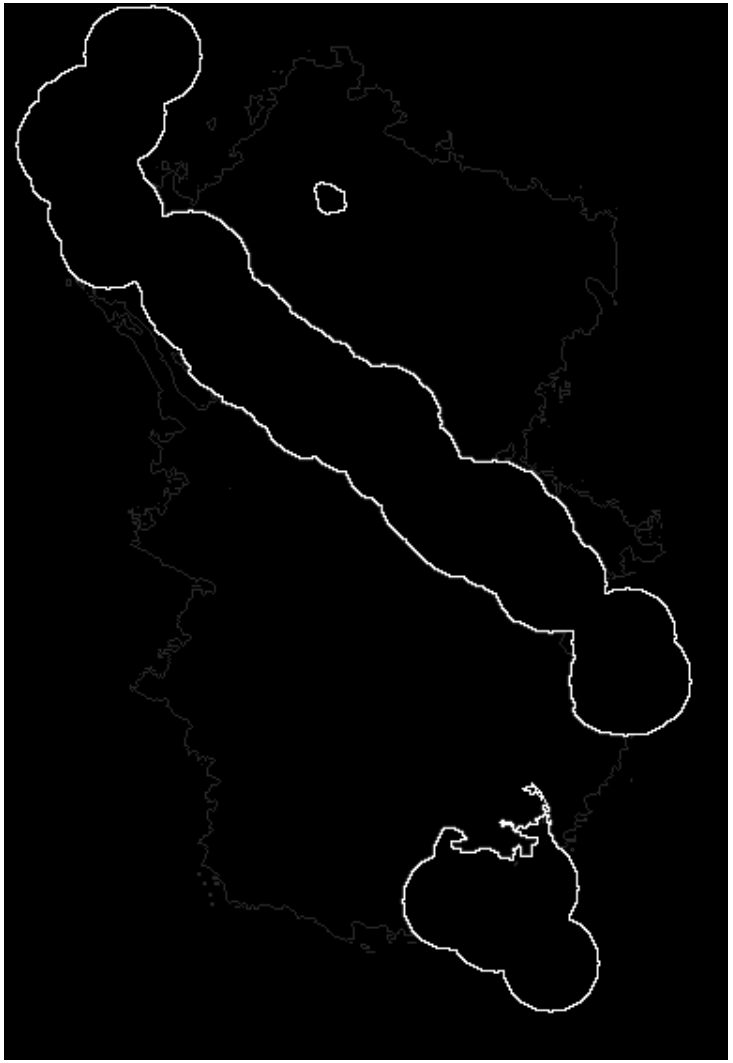
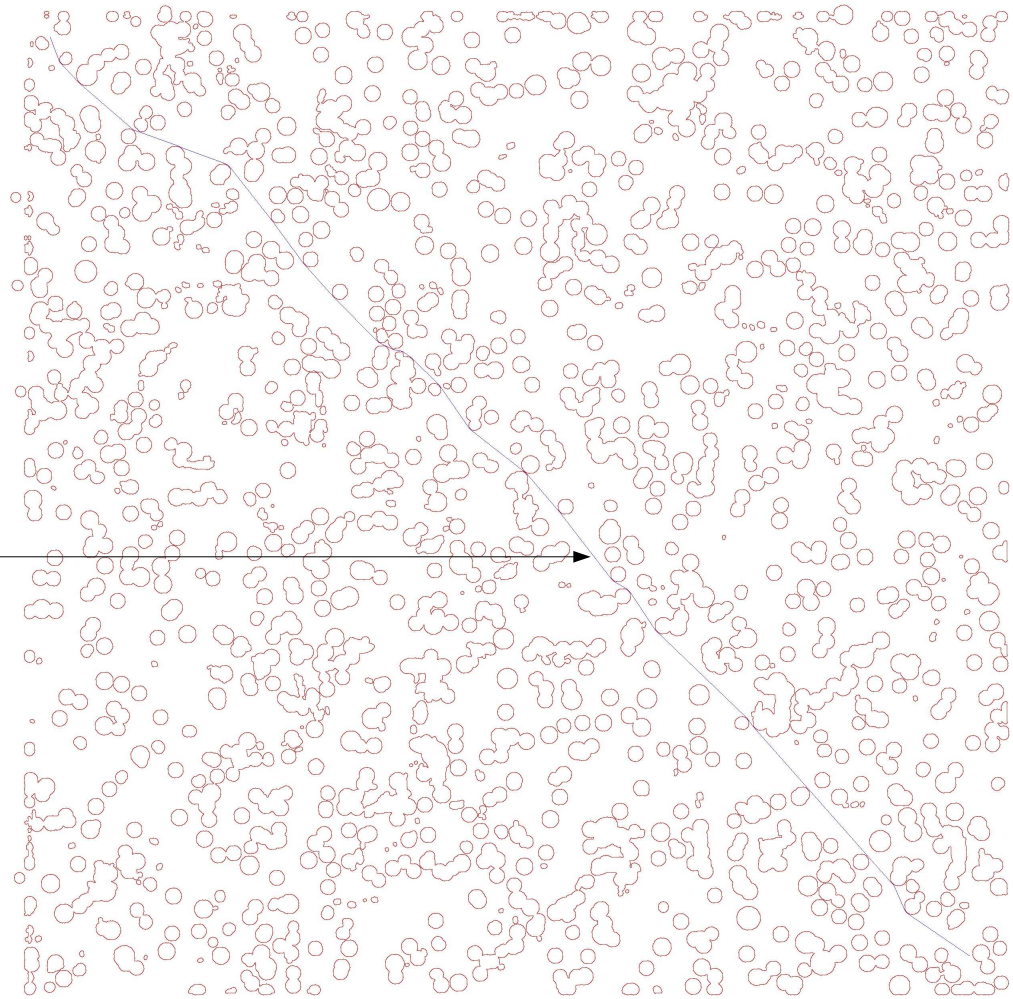


NavMap
to
TopoMap



II.3.b On-going Navigation activities

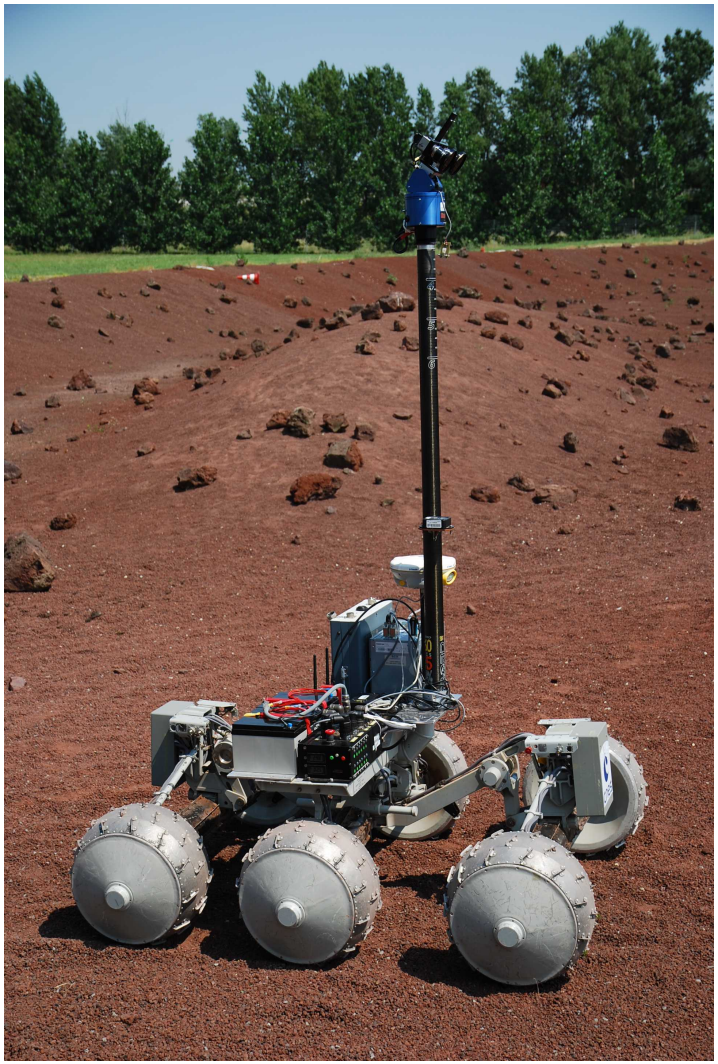
LDN
Computed Path



100m x 100m
Navigation Map

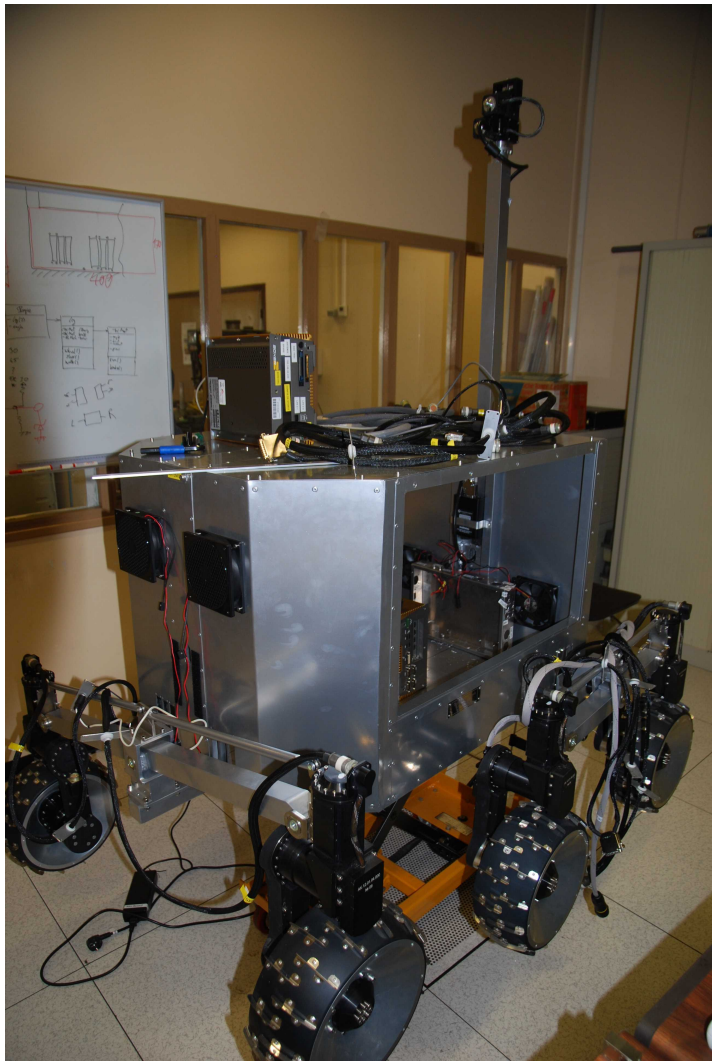
II.3.c Means for Navigation activities

- IARES
  - Rover delivered in 1997
  - 17 +2 dof
  - Still used for tests



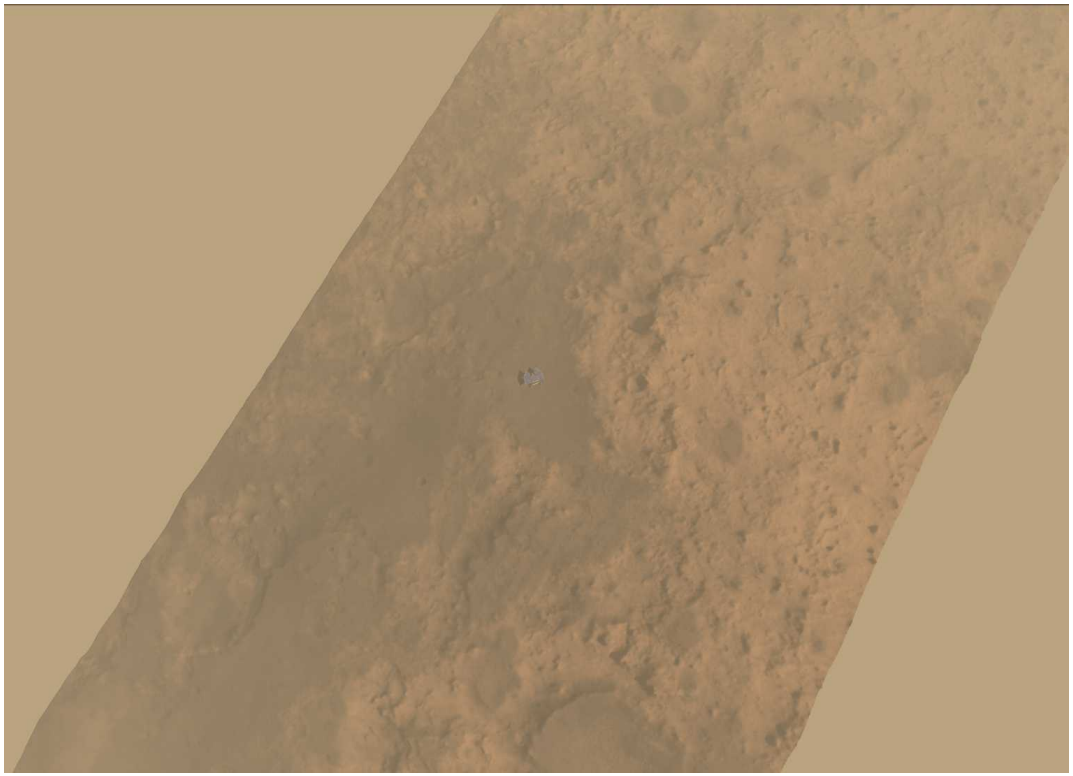
II.3.c Means for Navigation activities

- 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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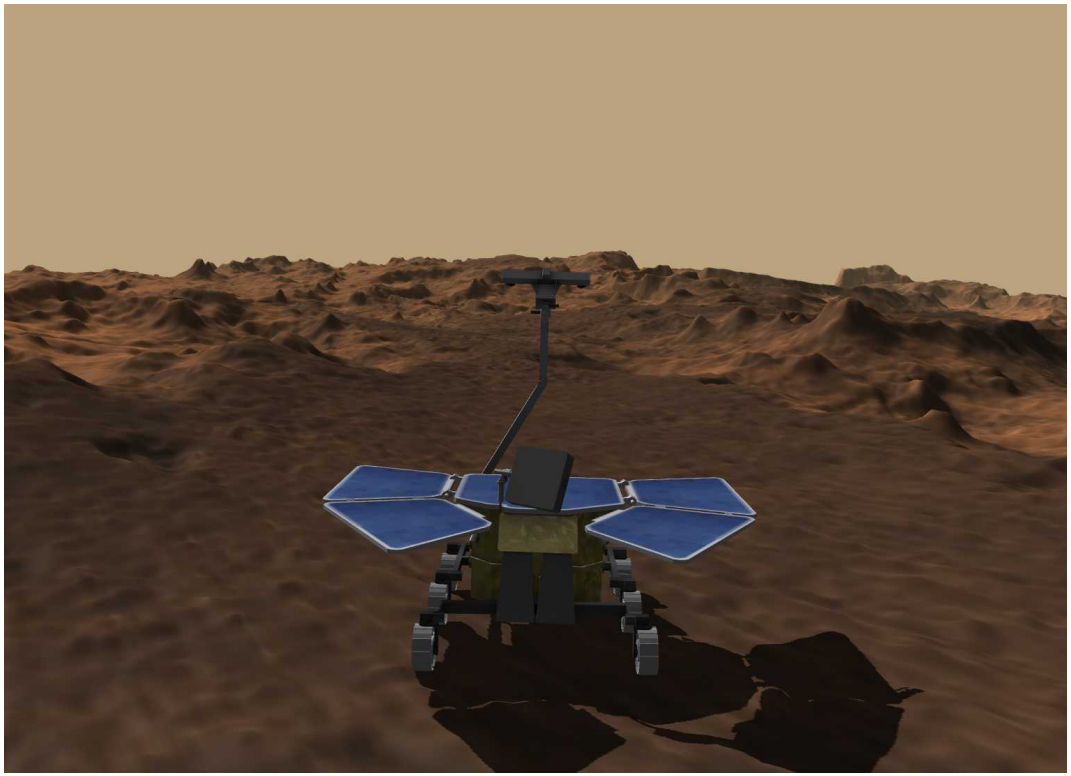

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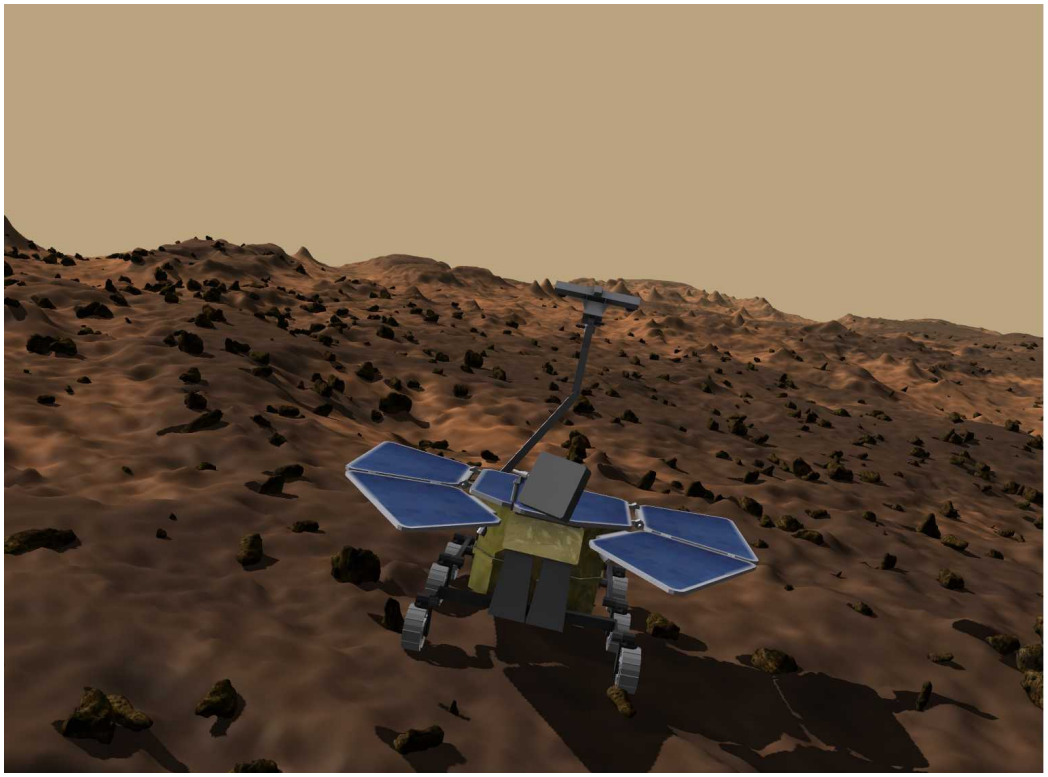

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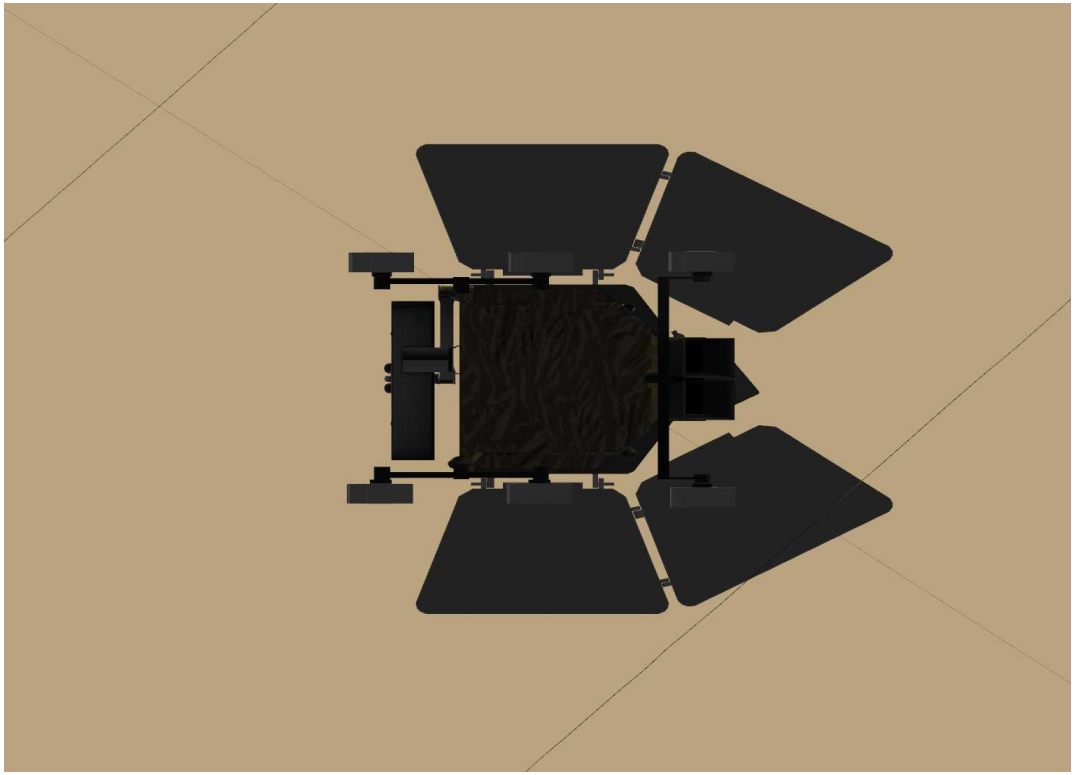

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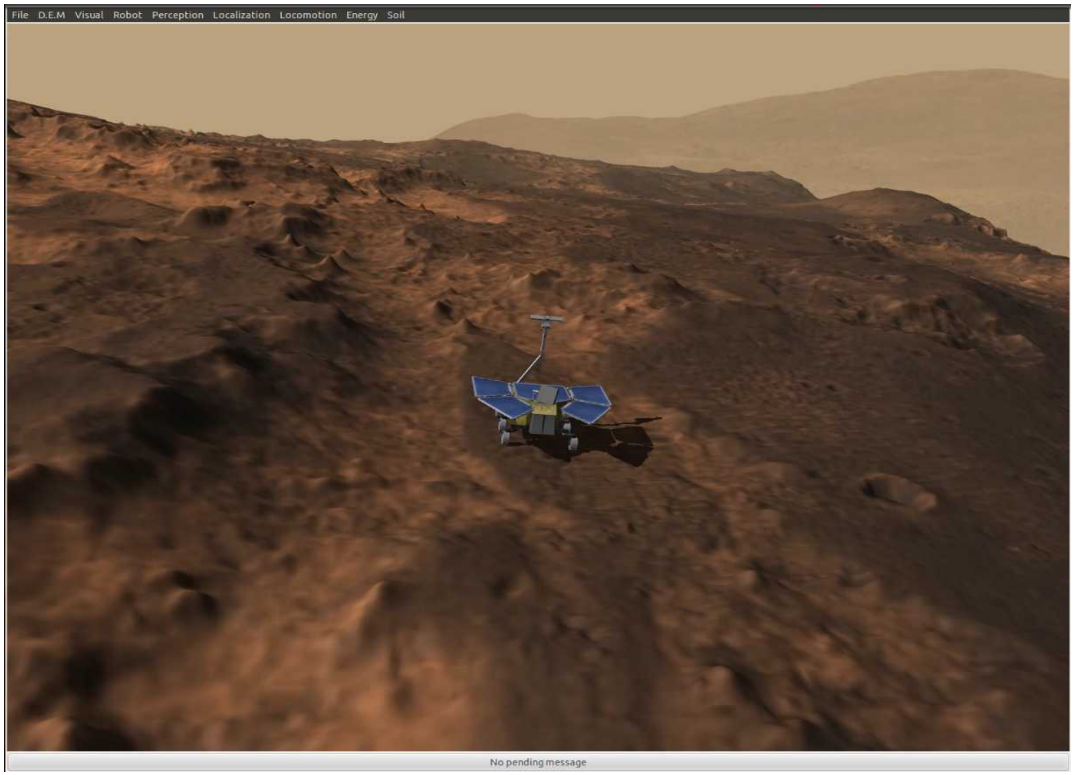

III. Conclusion

- 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 ?