Visual Odometry
For Autonomous Navigation On Mars

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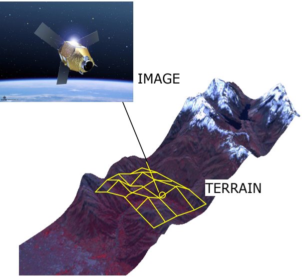
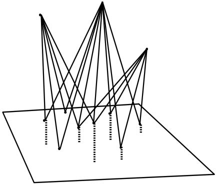
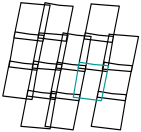
EUCLIDIUM : Spatiotriangulation multicapteurs



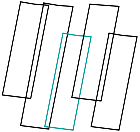
Exemple de localisation Image/Terrain avec MNT



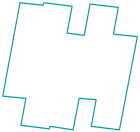
Triangulation 3D



Images



Vues



Bloc de prises de vues

- **Outil logiciel standard, intégrable et opérationnel (origine IGN + CNES)**

- Orbitographie + Modélisation du capteur

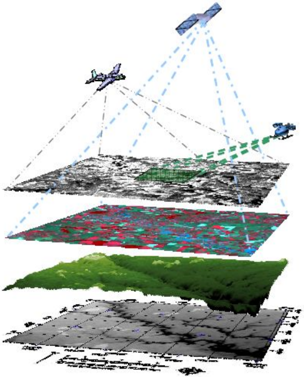
- Localisation Sol -> Image
- Localisation Image -> Sol

- Modélisation image, segment, bloc d'images
- Modélisation de capteurs optiques barrettes, matrices, et capteurs actifs (SAR)
- Cohérence interne et qualité de localisation
- Optimisation du processus de modélisation
- Modules SPOT, H, ERS, Landsat, Radarsat, ASTER, Quickbird, IRS, Aérien, pseudo-physique,…
- Et Pléiades, Parasol, Meris, …
- Applications : localisation de cibles, géoréférencement, rééchantillonnage, orthorectification....
- GEOVIEW, IPU, GEQI, APM3Di, …

Euclidium : coeur de la chaîne de traitement géométrique Pléiades

Exemple : géolocalisation automatique d'images

- PEA DGA : 2007 – 2009, R&D interne
- Objectif :
  - améliorer la localisation des images en cherchant à se recaler sur une base de référence d'images (GéoBase Défense)
- Technologies :
  - recalage d'une large variété de modalités de capteurs (du spatial aux drones) et de type d'imagerie (optique, infra-rouge thermique, radar)



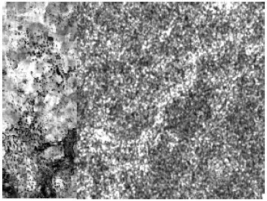
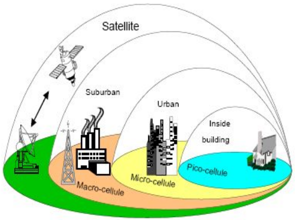
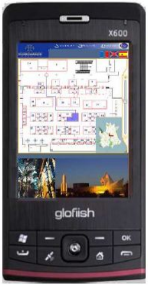


Image radar

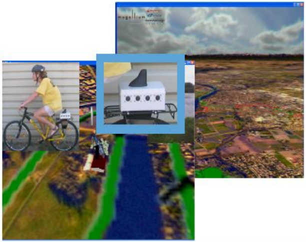
Exemples d'Applications : Navigation - Positionnement

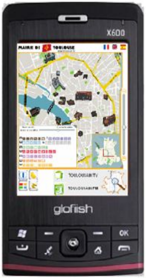


Filonas – Sécurité Civile



Fil Vert- Géovélo localisation de vélos





GEOEXPO

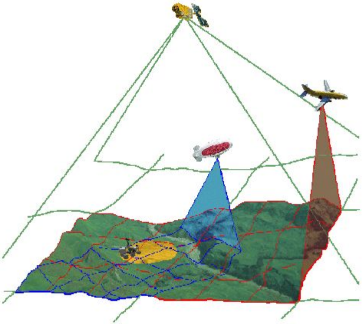
URBAN NAVIGATOR

MYT13

SITEEG

Bd Urbaines et Environnementales

Exemples d'Applications : Robotique



Coopération Robots terrestres et aériens et données satellites

Robotique Martienne - Exomars

Thèse LAAS-MAGELLIUM

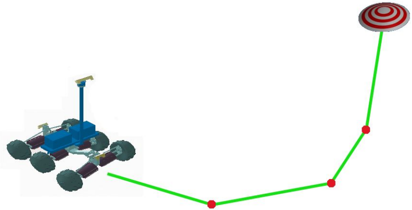
ExoMars Context

Daily objectives :

- Reach a given distant goal,
- Respect optional way points,

Environment :

- Natural, weakly known,
- Absolute localization limited : twice a day at maximum,



Visual Odometry

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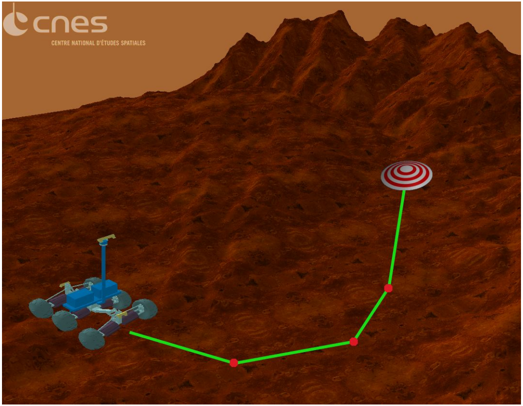


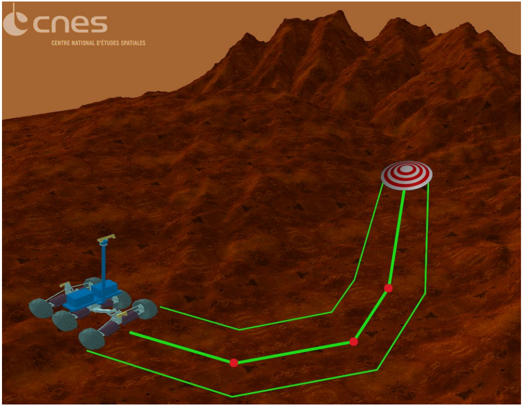
ExoMars Context

Constraints on localization :

- Long term accuracy : objective hitting,
- Short term accuracy : obstacle avoidance, safety margins,

Embedded solutions :

- Inertial Measurement Unit : not for chaotic and low motions,
- Wheel odometry : it suffers from wheel slippage,



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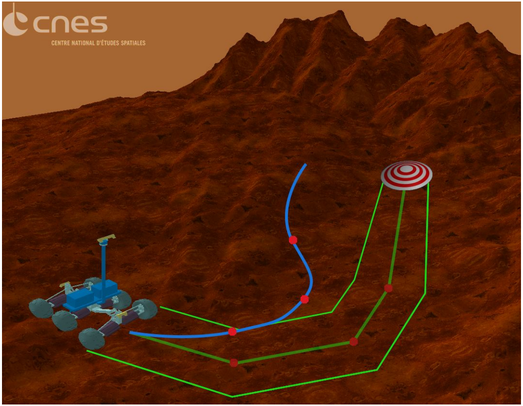
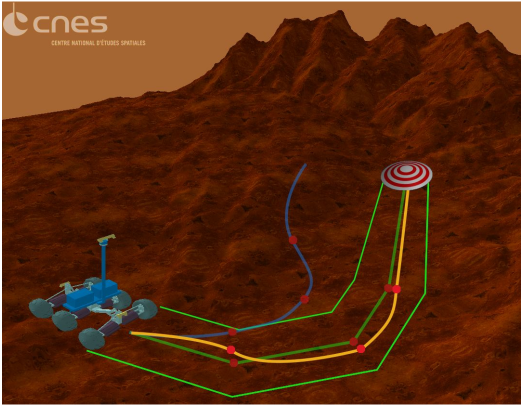


ExoMars Context

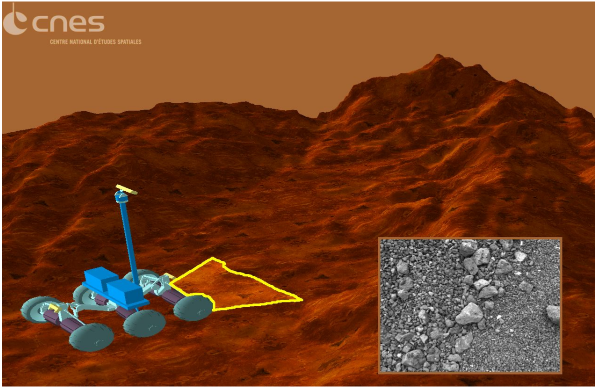
An alternative : Visual Motion Estimation ...

[Se et al., 2005, YANG et al., 2006]



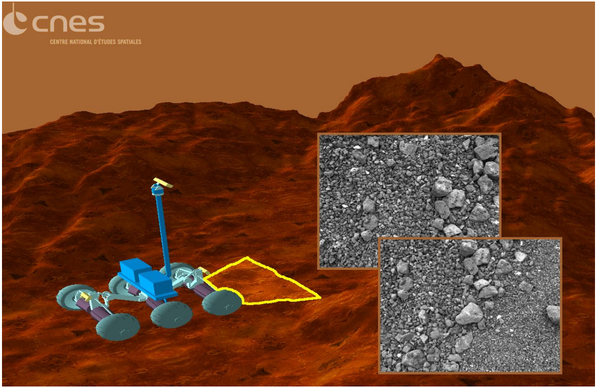
Outline

Visual Motion Estimation Principle



- Get a sequence of images
- Detect landmarks
- Match landmarks across images
- Estimate and integrate motion

Visual Motion Estimation Principle



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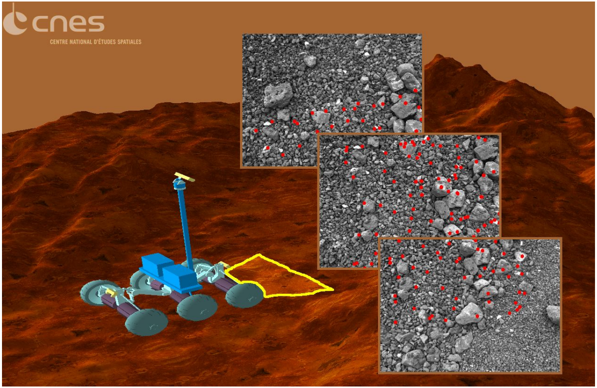

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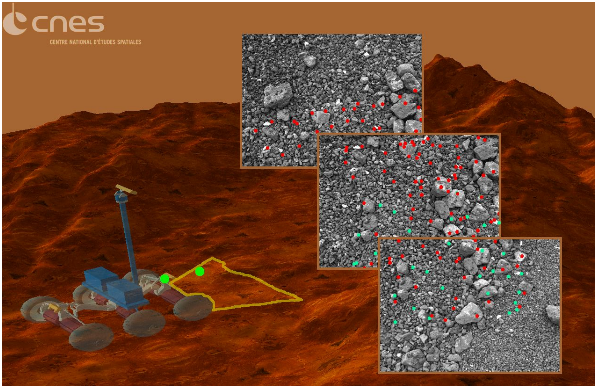

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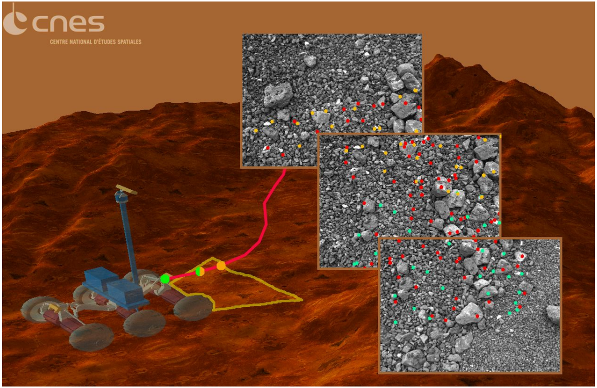

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- Detect landmarks
- Match landmarks across images
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Retained Architecture

- Stereoscopy :
  - Accurate depth measurement and telemetry,
  - Monocular vision works up to a scale factor,
- Matching of landmarks :
  - Tracking [Mallet et al., 2000] :
    - close images,
    - aiding sensors to bound searching areas,
    - few constraints on the landmark selection strategy,
  - Matching [Hirschmuller et al., 2002] :
    - complex,
    - requires a good landmark selection strategy,
    - robust wrt. initial motion estimate,
  - Matching by geometric constraint conservation :
    - Norm conservation,
    - Orientation conservation : requires attitude registration,

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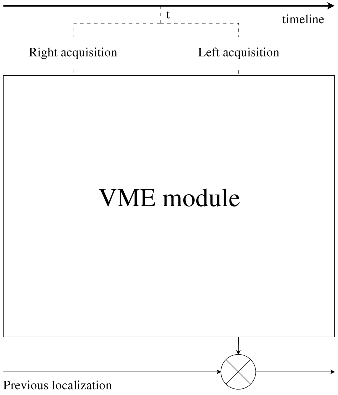
Visual Odometry Algorithm

Input

- Two stereoscopic acquisitions at $(t-1)$ and (t),
- Initial estimate of the motion between $(t-1)$ and (t).

Output

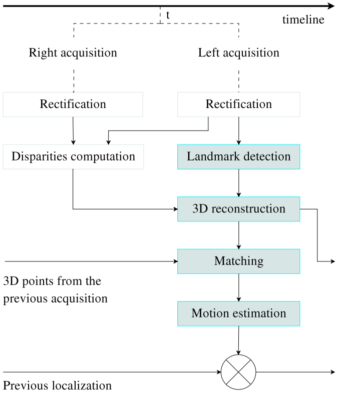
- Visual estimate of the ego-motion, 6-DOF or 3-DOF,
- New rover localization by integration.



Visual Odometry Algorithm

Algorithm

- Image rectification,
- Dense 3D reconstruction from stereoscopic views,
- Harris corner detector [Harris and Stephens, 1988] ,
- 3D matching based on geometrical constraints,
- 3-DOF or 6-DOF motion estimation.



Matching Principle - 1

- Segment length conservation of matching points between images :

$$||S_{M_p,M'_p}|| = ||S_{M_c,M'_c}||$$

- Segment orientation conservation of matching points between images :

$$\sin(S_{M_p,M'_p}, R.S_{M_c,M'_c}) = 0$$

- We deduce the matching score as :

$$S_M(M_p, M_c) = \sum_{M'_p,M'_c} f_b(\overrightarrow{M_pM'_p}, \overrightarrow{M_cM'_c})$$

$$f_b(\overrightarrow{M_pM'_p}, \overrightarrow{M_cM'_c}) = \begin{cases} 1 & \text{if } \left| ||\overrightarrow{M_pM'_p}|| - ||\overrightarrow{M_cM'_c}|| \right| < \epsilon_n \text{ and} \\ & \text{if } \left| \sin(\overrightarrow{M_pM'_p}, (R.\overrightarrow{M_cM'_c})) \right| < \epsilon_p \\ 0 & \textit{otherwise} \end{cases}$$

Matching Principle - 2

- Select best potential matches wrt. $S_M(M_p, M_c)$
- Select biggest subset of consistent matches :
  - Iteratively remove worst matches until all matches are compatible,
  - Consistency matrix :

$$\mathbf{C} = \left(\begin{array}{c|cccc} & M_p^1 & M_p^2 & \dots & M_p^P \\ \hline M_c^1 & 1 & 0 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ M_c^C & 0 & 1 & \dots & 0 \end{array} \right)$$

Matching Principle - 2

Visual Odometry

VME Overview

Towards More Efficiency

Test Campaign

Conclusion

- Select best potential matches wrt. $S_M(M_p, M_c)$
- Select biggest subset of consistent matches :
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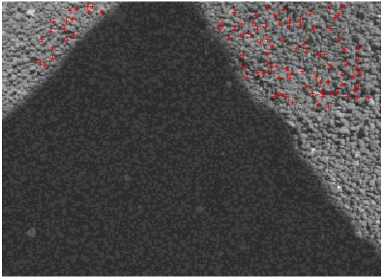
  - Consistency matrix :

$$\mathbf{C} = \left(\begin{array}{c|cccc} & M_p^4 & M_p^{10} & \dots & M_p^{P'} \\ \hline M_c^2 & 1 & 1 & \dots & 1 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ M_c^{C'} & 1 & 1 & \dots & 1 \end{array}\right)$$

Feature Detection

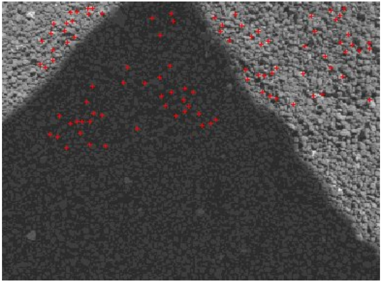
Observation

- Features strongly gathered in highly contrasted areas.



Solution

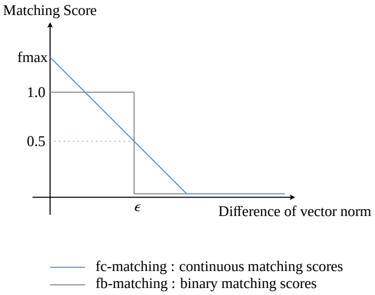
- Local normalization of Harris' scores.



Optimizations

Matching

- Continuous matching for better discrimination,



Computation time reduction

- Matching complexity in $O(n^4)$,
- Best landmarks often sufficient,
- *Solution : Iterative matching,*

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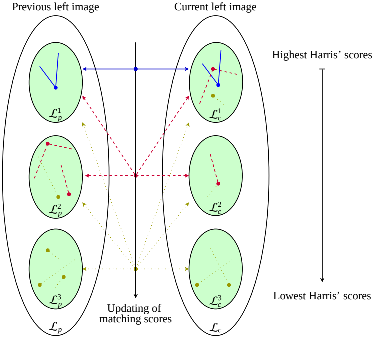


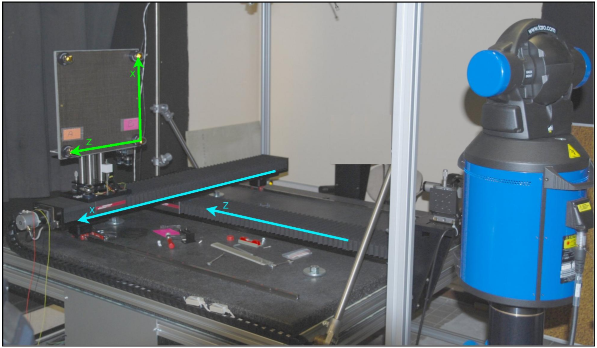
Fast matching

Acquisition System

- Precisely mounted and calibrated stereobench,
- A validation procedure of 3D reconstruction performances is actually studied.

Accurate Reference Localization

- Fine localization : Faro laser tracker and four targets,
- Extra noise is added to simulated the error from embedded localization systems.

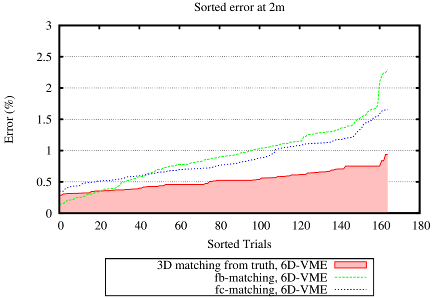


Campaign

- Acquisitions were done on the place of Serom at CNES,
- 122 stereoscopic views or a trajectory of 27m,
- Image resolution degraded by 4 $\Rightarrow$ 320 $\times$ 256 pixels.

Localization Accuracy : Short Term

Short term (2m) : distance between path planning tasks.



Comparison between the two matching methods : from binary or continuous scores.

- Fc-matching is more robust and achieves better matching,
- Fast matching provides same performances,
- Requirements on short term localization for ExoMars are compatible,

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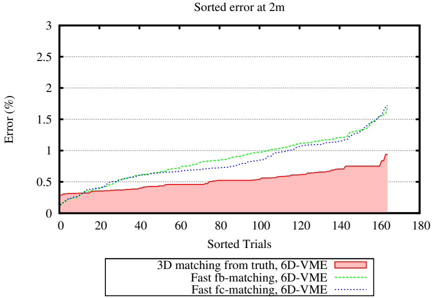

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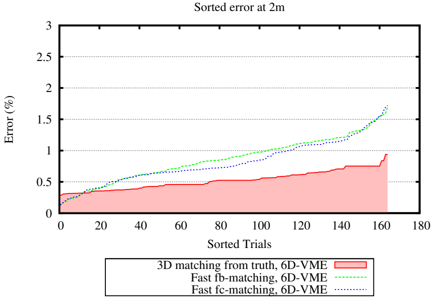

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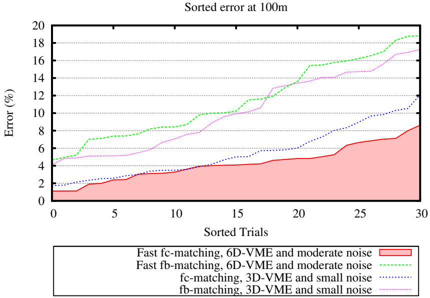
Localization Accuracy : Long Term

Long term (100m) : daily objective.



6D-VME integration in presence of moderate noise. No calibration of the attitude.

- It confirms the robustness of fc-matching and the efficiency of fast matching,
- 3D-VME performs very well in presence of small noise,
- Requirements on long term localization for ExoMars are just fulfilled. A regular calibration of the attitude is recommended.

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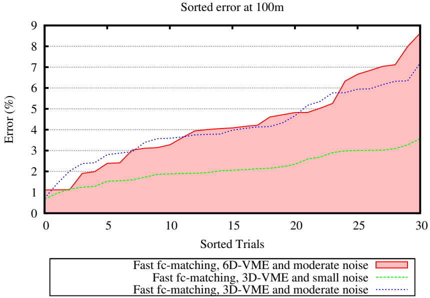

3D-VME integration in presence of small and moderate noise. No calibration of the attitude.

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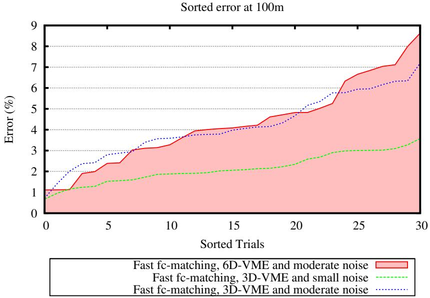

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Time and Memory Consumption

Table: Memory usage of VME components on Linux. See **??**

System	Virtual Memory Peak
Perception	9.68 (MB)
VME	6.24 (MB)

Table: Execution time of VME components. Gray values are used for extrapolation. They do not take into account memory access latencies on Leon between algorithms. See **??**

System	Time on Linux	Time on Leon
Nav	403 (ms)	9340 (ms)
VME	554 or 454 (ms)	12841 or 10524 (ms)

Conclusion

Summary

- Weak accuracy of the orientation estimate, yet sufficient at short term,
- Good localization as far as regular calibration is achieved,

Work Plan

- Validate algorithm robustness to translation errors,
- Validate localization accuracy on a large data set,
- Better characterize VME performances on configurations compatible with ExoMars,
- Optimize the matching algorithm to reduce its computation time.

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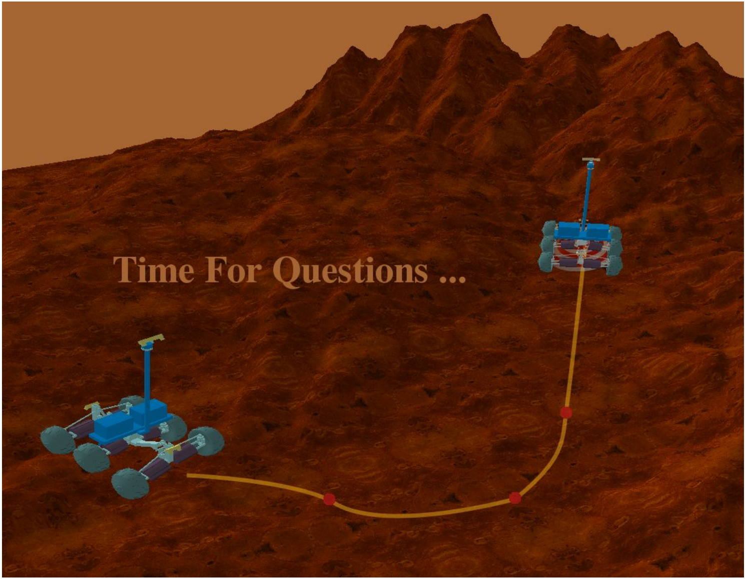
Time For Questions ...

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