OUTCOME STUDY

Summary of the FASTER project

FASTER
Forward Acquisition of Soil and Terrain data for Exploration Rover

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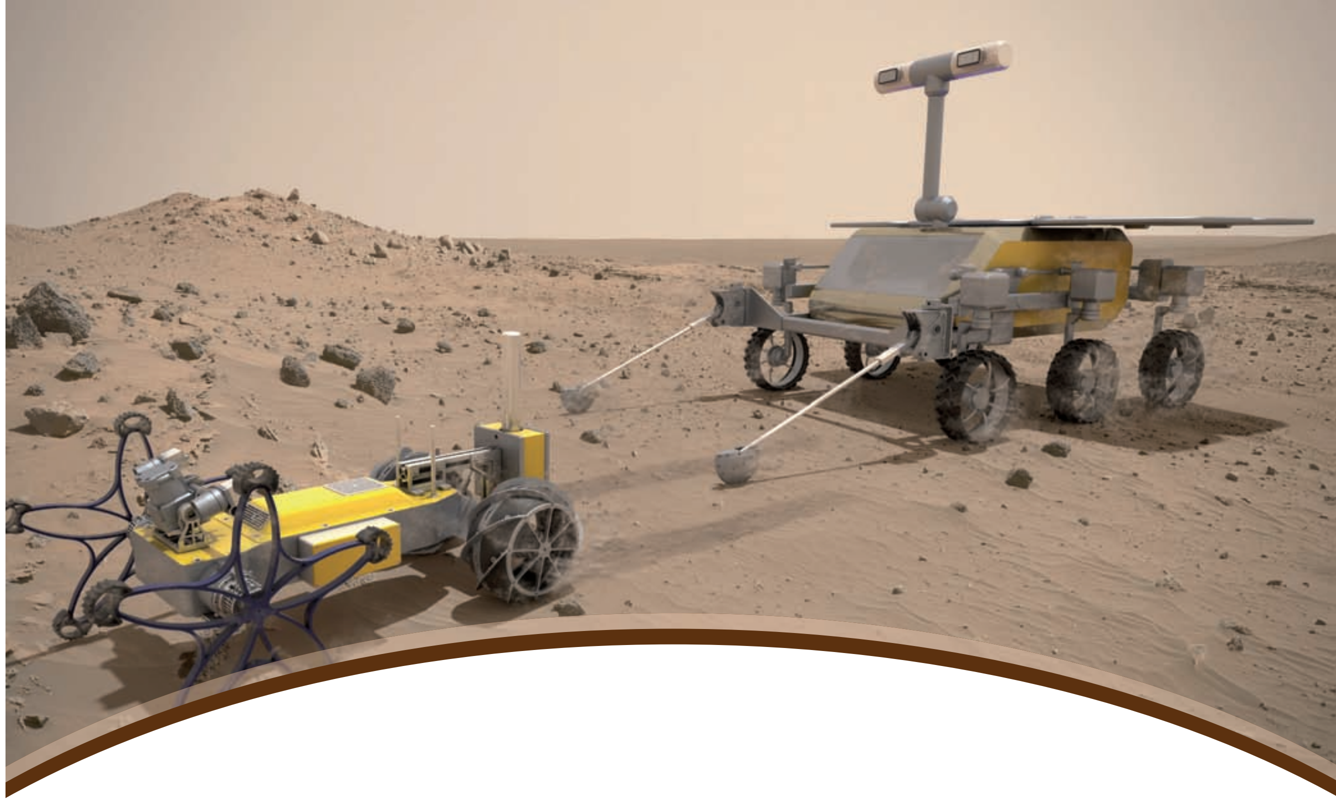
This booklet was prepared as a part of dissemination activities in FASTER project.

Pictures have been provided by Astri Polska (Wojciech Rosegnal, Krzysztof Skocki), LIQUIFER Systems Group and Airbus Defence and Space.

FASTER project was funded from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 284419, from November 1st, 2011 to November 30th, 2014.



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INTRODUCTION

Study Outcome document summarizes the achievements of the FASTER project. As an open public document, gives community the vision of the project flow, issues discussed, achievements and general problems found. The aim of the document is to serve as a basic knowledge source describing FASTER project activities and related issues discussed during the project. The document should present all aspects of the project, and underline the most important phases and moments influencing strongly the final results. FASTER Project Study Outcome structure supports the clear understanding of the key stages of the project and gives a potential feedback to the related project activities in the future.

The most important achievement of the FASTER project is the demonstration of the **co-operation of two planetary exploration rovers**, a main (Primary) rover and a supporting Scout rover. Equipped with a wide range of **soil sensors**, two robots are able to collect **in-situ measurement data** related to **soil trafficability**. Using data fusion and adaptive path planning algorithms, system can find the **safest and fastest path** to traverse an unknown planetary surface.

EXECUTIVE SUMMARY OF THE FASTER PROJECT

The FASTER project develops novel and innovative concepts to perform in situ forward evaluation of soil properties and terrain conditions in the planned path of a planetary exploration rover. Currently, the robotic exploration of planetary surfaces is seriously impeded by the lack of *a priori* detailed information about the soil and terrain conditions around the rover in question. In the best case, this lack of information leads to extremely slow and cautious exploration strategies (well below 5 cm/s). In the worst case, rovers may get stuck (temporarily or permanently) due to unforeseen terrain conditions. The recent immobilisation of the NASA MER *Spirit* rover, as it became trapped in hidden soft sand, dramatically illustrates this scenario.

Information about terrain conditions in the operation area of a planetary rover are currently gathered solely from remote sensing instruments. Several research projects (e.g. the FP7 project PRoVisG) are concerned with integration of the available remote sensing data. However, orbital remote sensing has inherent limitations. Currently, the surface conditions are primarily evaluated visually with a resolution in the order of the size of a rover and subsurface conditions have to be inferred from surface conditions and based on prior knowledge of the terrain. However, these data can be misleading due to their resolution and the lack of accurate information on the physical properties of the immediate subsurface layer. The knowledge of the latter is particularly crucial in determining the safe traverse of the rover.

FASTER started on November 1st, 2011 and ran for 37 months. The research has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 284419.

The consortium brings together European experts in the areas of planetary science, soil and terrain trafficability analysis, planetary exploration robotics, and robot autonomy and co-operation. All involved research centres, larger industrial companies, and SMEs do have competencies in aforementioned areas, which enabled a close cooperation within the individual tasks in the project.

FASTER project structure is typical for research and technology development projects and consists of nine main sections, called Work Packages (WP) covering various aspects of the project [description from Description of Work document (DoW)]:

WP1 Administrative Project Management

The objective of WP1 was to handle the overall coordination of the project, i.e. the administrative, legal, and financial management. This included reporting and coordinating of contacts with the EU, quality management and control of timeliness of delivery of project results, and the resolution of potential conflicts between the Consortium Partners.

WP2 Mission and System Requirements

The objectives of this Work Package were to:

- Derive and provide flight unit mission and system requirements applicable to the design and missions of rovers and scouts and their surface sensors operating on the Martian surface.
- Define unmanned mobile element hardware and software requirements for Martian surface missions.
- Define surface sensor (FASTER) requirements for unmanned mobile elements (Primary rover/Scout) conducting missions on the Martian surface.

WP3 Concept Identification and Selection

The objectives of this Work Package were to:

- Identify the logical architecture based on the outputs of WP2.
- Survey and assess the potential technological solutions/concepts.
- Perform trade-analyses for each of the potential technological solutions/concepts based on the logical architecture components.
- Select the various concepts to be integrated into the detailed architecture.
- Selection of the system concept for prototypes.
- Preparation of an outline prototype system test plan.

WP4 Development of Soil Sensing

The goal of this Work Package was to develop in-situ multimodal soil sensing capability (hardware and software) for the forward acquisition of soil and terrain data that would help to optimise the path for the main rover (sample fetch rover) and hence improve its speed. This would in turn result in maximum science return. WP4 investigated further the two top technologies for soil sensor probe and soil sensor coming out of the trade-off from WP3, such as a penetrometer and Bevameter. Preliminary testing conducted in last weeks of project duration suggests that a micro-penetrometer could be a suitable subsurface soil condition assessment device mounted on-board the Scout rover. Based on our understanding of the state-of-the-art, we propose to use a soil sensor on-board the main rover.

The objectives were to:

- Develop a light-weight in-situ soil test probe for the Scout rover to obtain parameters that characterize the mechanical properties and trafficability of Martian or Lunar soils.
- Develop a soil sensor for the main rover to further enhance the terrain characterization.
- Integrate remote sensing based terrain classification with data acquired using soil sensor probe and soil sensor.
- Propose scientific methods based on empirical experiments that are able to estimate soil properties and trafficability of terrain using the parameters gathered by the soil probe and sensor. This will result in optimum utilization of rover thrust and there by power consumption.
- Develop a methodology for in-situ soil trafficability assessment using soil sensors.

WP5 Concept Identification and Selection

The objective of this Work Package was to develop a terrestrial testbed for the co-operative mini Scout rover conceptualized in Work Package 3. Together with the BRIDGET ExoMars breadboard provided by Astrium (now Airbus Defence and Space) Partner of the project, this testbed was used to evaluate the following objectives:

- To evaluate the general operational concept of Rover-Scout interaction outlined in WP3.
- To evaluate an innovative locomotion / wheel design for the use in a small scout rover.
- To test the feasibility of the light-weight trafficability sensor developed in WP4.
- To evaluate and verify the software for co-operative mission planning and autonomy developed in WP6.

WP6 Mission Planning and Autonomy

Implementation of the mission planning and autonomy functions for the prototype system. This has been achieved through the development of the following items:

- Primary rover – Scout collaboration software.
- Primary rover – Scout communication software and hardware.
- System integration software.
- System test software.

WP7 Integration and Testing of Soil Sensors with Rover Platform

This Work Package was dedicated to prove a pivotal step towards bringing both hardware and software FASTER technologies seamlessly together to achieve overall technological operational state. The main goal of this Work Package was to integrate multimodal soil sensors, the Scout rover and the autonomous cooperative software architecture that have been developed under WP4, WP5 and WP6 respectively, with the Astrium's prototype ExoMars rover testbed. In WP7, main research and development efforts were guided towards achieving a modular plug and play type of hardware and software interfaces that conforms to popular planetary rover systems architecture practises across ESA as much as possible. This Work Package purpose was to ensure that the various software and hardware technologies that were under development in other Work Packages shared common interface architecture from conceptual stage to integration phase. The key objectives of this Work Package are highlighted below.

The objectives were to:

- Identify crucial interfaces between all the hardware and software.
- Develop and propose a common plug and play type of hardware and software interfaces.
- Conduct integration and testing of soil sensor hardware and software with ExoMars prototype rover Bridget.
- Integrate and test of soil sensor with Scout rover both hardware and software interfaces.
- Integrate and test for cooperative behaviour between Scout rover and mother rover.

WP8 Proof-of-Concept Field Trials

This WP aim was to provide a proof-of-concept of the rover and soil sensor technology developed in FASTER by testing and documenting the performance of the key methods and technologies of this project.

- To maximise the quality of the test and its return, a rigorous test plan was put in place to define the test procedure for each subsystem and for the operation of the rover pair.
- The field trials of the two rover system were conducted to evaluate the collection of soil data in the field by means of a number of new sensor designs as well as the updating of the trafficability map with acquired soil data, influencing the path planning behaviour of the main rover.
- Finally, the results were rigorously and accurately reported and discussed including the operation and performance of the various sensors, the operation and performance of the rover pair and of the selected control/autonomy/communication architectures and the discrepancies, if any, between the initial requirement and the field trial results.
- Based on the outcomes of testing in WP8, the system design (hardware and software) will be re-visited for further enhancement.

WP9 Dissemination and Outreach

The objective of this Work Package was to assure smooth and effective project-related dissemination, exchange and feedback of information to external interested parties including the EC bodies and among the Consortium Members.

All the Work Packages (WPs) presented above fully cover activities during the project flow. The next level of detail used typically in similar projects is task – every WP is divided into number of tasks.

The aim of the FASTER project is to present the common system acquiring and processing data from sensors, related to the physical properties of the traversed regolith. Such data will allow rovers to be safer, faster and more autonomous than it is possible today. It will thus greatly enhance the productivity of planetary exploration and of the scientific return of future missions such as the Mars Sample Return mission planned as a joint effort between NASA and ESA.

In the final solution soil sensors acquire the raw data related to the geotechnical properties of the sensed soil and uses a common, on board the sensor calculated, %Tr (% trafficability) value to be sent to the Data Fusion subsystem and later to the Path Planner (as a part of Navigation subsystem).

The FASTER project was realised by Consortium funded by six partners across the Europe: Deutches Forschungszentrum für Künstliche Intelligenz – DFKI (Germany), University of Surrey (UK), Airbus Defence and Space (UK), Space Applications Services (Belgium), LIQUIFER System Group (Austria) and Astri Polska (Poland). The overall management was done by German partner.

LIST OF RELATED INTERNAL DOCUMENTS

DoW	DFKI, et al, "FASTER Forward Acquisition of Soil and Terrain for Exploration Rover," EU FP7 Project No. 284419, Annex I, Description of Work, 5 July 2011.
Doc2.1	LSG, et al, "FASTER Mission and System Requirements," FASTER_LSG_D2.1 MSRD_V3.7 (Dated 13.06.2014).
Doc3.1	SAS, et al, "FASTER – System Concepts", FASTER_SAS_WP3_D3.1_V2.0 (Dated 06.11.2012).
Doc3.2	SAS, et al, "FASTER – Mission Scenario Prototype Specification", FASTER_SAS_WP3_D3.2_V2.0 (Dated 06.11.2012).
Doc3.3	ASP, et al, "FASTER – Prototype System Validation Test Plan", FASTER_ASP_WP3_D3.3_v2.0 (Dated 06.11.2012).
Doc4.1	UoS, et al, ""Validation of Soil Sensor Probe/Sensor Design and Operation Modes in Simulation", FASTER_UoS_WP4_D4.1_v1.0 (Dated 30.05.2013).
Doc4.2	UoS, et al, "Evaluation of Soil Sensor Probe and In-situ Soil Characterisation", FASTER_UoS_WP4_D4.2_v1.0 (Dated 10.10.2013).
Doc4.3	UoS, et al, "Development of control and automation software for the soil sensor probe and soil" sensor, FASTER_UoS_WP4_D4.3_v1.0 (Dated 30.10.2013).
Doc4.4	UoS, et al, "Surface hardness assessment using ground penetrating RADAR", FASTER_UoS_WP4_D4.4_v1.0 (Dated 30.10.2013).
Doc4.5	ASP, et al, "Integrated soil systems and technology for soil sensors probe & soil sensors", FASTER_ASP_WP4_D4.5_v1.0 (Dated 29.11.2013).
Doc5.1	SAS, et al, "Scout Rover Specification and Interface Specification", FASTER_SAS_WP5_D5.1_v1.4 (Draft dated 27.02.2013).
Doc6.1	SAS, et al, "Assessment of Co-operative Operation in Simulation", FASTER_SAS_WP6_D6.1_v0.6 (Draft dated 03.11.2013).
Doc6.2	SAS, et al, "Sensor Data Processing and Rover Interface", FASTER_SAS_WP6_D6.2_v1.0 (Draft dated 13.02.2014).
Doc7.1	UoS, et al, "System evaluation", FASTER_UoS_WP7_D7.1_v1.0 (Dated 8.10.2014).
Doc7.2	UoS, et al, "Toolbox on surface solidity testing for a range of terrains", FASTER_UoS_WP7_D7.2_v1.1 (Dated 8.10.2014).
Doc7.3	UoS, et al, "Sensor/Rover/Scout Interface Control Document", FASTER_UoS_WP7_D7.3_v1.0 (Dated 8.10.2014).
Doc8.1	ASU, et al, "Design, Development and Verification Plan", FASTER_ASU_WP8_D8.1_v1.0 (Dated 13.02.2014).
Doc8.2	ASU, et al, "WP8 Integrated Test Campaign Results", FASTER_ASU_WP8_D8.2_v1.0 (Dated 15.09.2014).
Doc8.3	ASU, et al, "Recommendations on the application of FASTER to MSR and future planetary rover applications", FASTER_ASU_WP8_D8.3_v1.0 (Dated 20.10.2014).
Doc8.4	ASU, et al, "Toolbox on surface solidity testing for a range of terrains", FASTER_ASU_WP8_D8.4_v0.2 (Dated 22.10.2014).
Doc9.1	ASP, et al, "Webpage including secured intranet site", FASTER_ASP_WP9_D9.1_v0.1 (Dated 18.06.2012).
Doc9.2	ASP, et al, "Newsletter 1 – First demonstration workshop announcement", FASTER_ASP_WP9_D9.2_v2.0 (Dated 05.04.2013).
Doc9.3	ASP, et al, "Newsletter 2 – Report on first demonstration workshop", FASTER_ASP_WP9_D9.3_v2.0 (Dated 13.01.2013).
Doc9.4	ASP, et al, "Newsletter 3 – Second demonstration workshop announcement", FASTER_ASP_WP9_D9.4_v2.0 (Dated 11.06.2014).
Doc9.5	ASP, et al, "Final dissemination report including results from second workshop", FASTER_ASP_WP9_D9.5_v1.0 (Dated 30.11.2014).
Doc9.6	ASP, et al, "Final Study Outcome publication", FASTER_ASP_WP9_D9.6_v1.0 (Dated 30.11.2014) [this document].
Doc9.7	ASP, et al, "Final images and animation", FASTER_ASP_WP9_D9.7_v1.0 (Dated 30.11.2014).
Doc9.8 +Doc9.9	SAS, et al, "Exploitation Plan", FASTER_SAS_WP9_9.8+D9.9_v3.0 (Dated 17.10.2014).

TOPIC 1 – TECHNOLOGY: REQUIREMENTS ANALYSIS

Summary

Doc 2.1 summarizes the requirements for the whole FASTER project. The requirements are defined on the basis of previously recognized main topics, part of them can be realized as the direct ones, and part as a supplementary requirements.

Requirements cover all aspects of the potential Martian mission, including solar radiation environment, Mars atmosphere conditions and surface regolith material, properties and features (eg. rocks, outcrops, dunes, etc.).

The mission requirements are divided into several logic parts, including the most general requirements, not directly applicable to the system design (in brackets abbreviations of the requirements groups):

- Overall Mission Requirements (MI)
- Mission Operational Requirements (OP)
- General Rover and Mission Requirements (GR)
- Operational Environment Requirements (EN)
- Communications Requirements (COM)

All these requirements are the highest level requirements, and due to relation to the final mission concept, finally not important for the FASTER system design. The definition of these high-level requirements can support any aim-focused check of the final system design.

The System Requirements for both FASTER rovers (Primary and Scout) were divided into several topics:

- Transport Requirements:
  - Launch and transit phase (LTP)
  - Descent and landing phase (EDL)
  - Hibernation phase (HP)
  - Deactivation phase (DP)
- Functional and Performance Requirements:
  - Rovers' mobility requirements (MOB)
  - Navigation localisation and autonomy requirements (GNC)
  - On board data handling requirements (DMS)
  - Telemetry and telecommand requirements (TTC)
  - Rower requirements (EPS)
  - Thermal protection requirements (TPS)
  - Mechanisms and robotics (MR)
- Primary Rover and Scout Rover Margins and Safety Requirements:
  - Design margins (DM)
  - Safety requirements (SR)
- Overall System Requirements – Software:
  - Task Planner (TP)
  - Data Management System (DSW)
  - Localization (LSW)
  - Navigation (NSW)
  - Telemetry and Telecommand (TSW)
  - Wheel Control (WSW)
  - Health Monitoring (HSW)
- Overall System Requirements – Soil Sensors
  - Soil Sensor Mission Requirements (SSM)
  - Soil Sensor System Operational Requirements (SSO)
  - Soil Sensor System Requirements (SSS)
  - Soil Sensor Data Analysis Requirements (SDA)
  - Soil Sensor Measurement Requirements (SME)
  - Soil Sensor/Rover Interface Requirements (SSI)

The full list of the requirements groups is presented to give a chance to understand the complexity of the analysed and managed aspects crucial for the planetary missions.

The most important requirements to be included into the actual system design and development, and influencing directly the development and design of the system, were defined mostly in MOB, GNC, MR, TP, DSW, NSW, SSM, SSO, SSS, SDA and SME.

All discussed requirements are referred to the phases of the mission, including full analysis of the whole MSR mission operational scenario that can influence the surface operations strategy important for FASTER scenarios.

Applicability of the requirements

Typically, requirements prepared for the engineering projects are focused directly on the final functionality and engineering constrains and technologies best fitted to the project needs. The wide analysis of the operation environment far behind the normal operational limits is not typically prepared for the project. In case of FASTER project, such wide analysis of the full mission, with all phases and possible external influences, as presented in Doc 2.1 was of the special interest because of the major changes of external conditions, defined in MSR or ExoMars mission concept. The extended requirements prepared in the first months of the project, enabled later the good understanding of possible influence of changing MSR concept on the final FASTER project concept.

Fixed or flexible requirements

Requirements are typically formulated once during the initial studies on the project, and checked through the project duration to identify the differences in initially proposed design. This well-working rule is a base for any further actions and cross-checks during the whole project.

In the case of the FASTER project, the concept of mission Mars Sample Return concept changed significantly, thus part of the strict requirements related to the preliminary mission concept were no longer valid. In such case, and in order to develop a final system applicable to various planetary missions, Project Partners decided to state the Doc 2.1 as a 'living document', and thus upgraded within the system development progress. It is worth to underline the important relations between the all Doc 2.1 versions with the actual state of the Mars Sample Return mission – FASTER project was proposed as a potential support for that mission. Therefore, the significant changes in MSR mission concept introduced during the project FASTER implementations, induced some major and minor issues to the final FASTER design. The statement of Doc 2.1 as the 'living document' enable to present a much wider, potential user/customer fitted design of the system, not fully prepared for the only one mission (ExoMars) and, therefore, is much more flexible. The modification needed to prepare and implement the final FASTER project system for various missions should not generate great problems, and should be only limited to the definition of the dynamic and static properties of the destination robotic platform.

The other situation is related to the Soil Sensing System (SSS), where the initial and mostly actual design is strictly related to the ExoMars mission requirements, eg. the strictly defined surface pressure, weight and dimensions of the rover chassis and wheels.

TOPIC 2 – TECHNOLOGY: SYSTEM CONCEPT AND INPUT FOR FUTURE MISSIONS

The system concept formulated during development phase of the project is based on the results of the analyses of requirements defined earlier in the preparatory phase of the project. The proposed system concept, both mechanical and software, meets all related requirements and is finally divided into two main parts: Primary rover mounted base On-Board Computer plus two (Wheeled Bevameter and Remote Sensing) sensors and Scout rover, and small reconnaissance rover, part of the FASTER system, equipped with two (two Wheel-Leg-Soil Interaction Observation Systems, Dynamic Cone Penetrometer, and possibly Ground Penetrating Radar) sensors. The Scout is the simple carrier of the most of the soil sensors, and the high terrain traversability rover capable to check nearly all kind of unknown terrain on the surface of the Mars.

It is worth emphasizing that the idea of using additional small, reconnaissance rover to collect data on terrain traversability in front of the main, or primary, mission rover is presented for the first time.

In the preliminary concept, presented in Doc 3.1 “System Concept”, as a variation of Remote Sensing (RS) technology to acquire the remote data on terrain trafficability, functionality of orbital RS data analysis was discussed and the extended version of base, surface, rover-mounted RS subsystem, with extended soil colour and texture analysis were discussed. Finally, simple on-board RS subsystem based on saliency was implemented and the only data available from RS subsystem is the position of the rocks in the field of view limited to 5 meters.

TOPIC 3 – TECHNOLOGY: SOIL SENSING TECHNIQUES AND PLATFORMS

The main components of the system are divided and located on both rovers (Primary – the supported main mission rover and Scout, specially developed small reconnaissance rover, used as a main platform for soil sensing sensor) and shortly described below:

Scout Rover:

Coyote II is a micro rover with high mobility performance in various terrains. Equipped with its own power source, on-board sensor suite and computer it is able to perform autonomous exploration tasks. The communication subsystem allows to cooperate with other systems and provides a link for remote control. Due to the robust structural design and powerful actuators, Coyote II is able to carry several kilograms (> 6 kg) of payload.

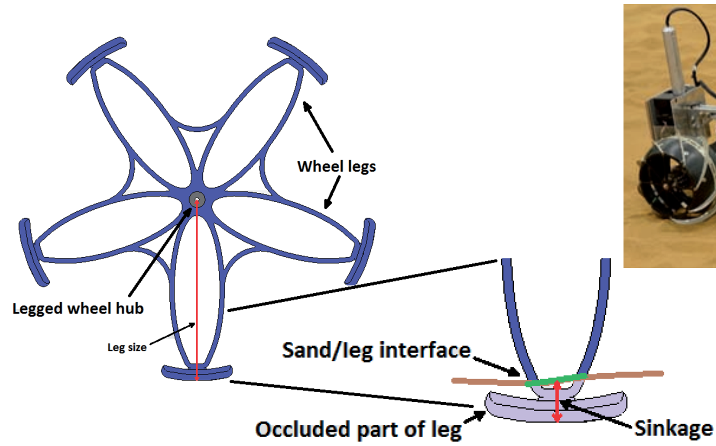
A special characteristic of Coyote II is its novel locomotion concept. It combines the high mobility performance of hybrid legged-wheels (in the front) with the smooth wheel movement of spherical helical wheels (in the rear). Therefore, the Scout rover is able to move on soft soil as well as on unstructured terrain and can perform side-to-side steering movements. It is however, possible to mechanically tilt the rear axis in a horizontal position allowing to operate Coyote II with four equally shaped wheels in the front and rear.

Within the FASTER project Coyote II acts as Scout rover with the aim to improve the mission safety and the effective traverse speed for planetary rover exploration. To avoid uncertain estimations concerning the trafficability of the areas to be explored, the Scout rover provides suitable information on the terrain ahead of a primary exploration rover. To handle this task Coyote II is equipped with an additional soil sensor payload. This contains first, a Wheel-Leg Soil Interaction Observation (WLSIO) system and second, a motorized Dynamic Cone Penetrometer (mDCP). Both sensor systems are developed by Surrey Space Center.

- **Wheel-Leg-Soil Interaction Observation (WLSIO) System**
  WLSIO System is based on the Scout’s front wheels, and utilize the visual data collected by two belly cameras, separately observing each wheel-soil interaction. From the collected images sinkage can be easily determined, and when combined with other wheel-leg operating parameters (e.g. motor current, IMU data) the %Tr is calculated. The most appealing characteristics of this soil sensing sub-system are the facts that it inherently runs while the Scout rover in motion and that it can operate continuously, making it ideal for producing a fast on-line trafficability diagnosis with minimum impact on the mission performance in terms of speed and power.

- **Motorised Dynamic Cone Penetrometer (mDCP)**
  Simple dynamic hammering device, designed to be self-hammered to measure the penetration depth per blow. Such data enable general discrimination of the soil type and give the overall characterization of the geotechnical parameters of the soils, based on experience with a similar and well-known terrestrial geotechnical tool.

  Based on the available penetrometer designs, only those modelled on the principles of the motorised Dynamic Cone Penetrometer (mDCP)



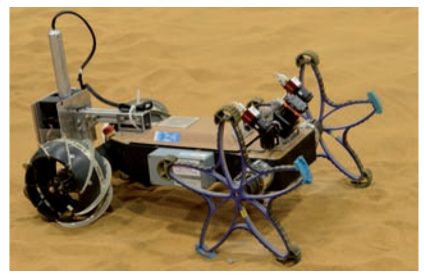


*Figure 1:
WLSIO system concept – wheel design [Doc4.1]*

for their mechanical operation appear feasible for the FASTER application. Other designs are either too massive to be carried by the Scout or require a significant reaction force to be applied during operation, which cannot be provided by a small vehicle operating in reduced gravity. The data generated by the mDCP is arguably somewhat crude – a simple index (DCPi) based on penetration/blow. Significant variability exists in the methods of determining DCPi. However, correlation between DCPi and useful soil parametric data is well established e.g. log-log correlation between DCPi and CBR (California Bearing Ratio), and should be sufficient to provide the baseline device and to enable Go/NoGo decisions to be made with sufficient accuracy.

The small, self-contained design of the mDCP makes it a good soil sensor for both space and terrestrial applications where terrain analysis of the upper soil layer is required. Its design can also be scaled up for deeper penetrations or for

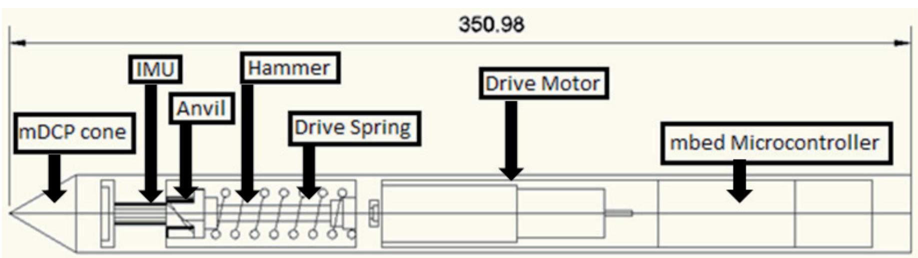


Figure 2: mDCP sensor design [Doc4.1]

- **Ground Penetrating Radar**

  Sensor operation is based on the reflections and attenuation of the beam of electromagnetic waves sent directly into the prospected soil and finally received by the device. Well-known terrestrial device, widely used by geologists, engineers and archaeologists can deliver valuable data of the subsurface soil properties. The principal objective of the soil sensors mounted on the Scout is to determine the suitability of the ground in terms of the mobility of the Primary rover without slowing the progress of this rover. The ideal scenario is that the Scout does not have to stop to deploy a soil sensor. A great deal can be determined about the suitability of the terrain from the behaviour (principally sinkage) of the Scout's legged wheels whilst moving. However, there are several hazards that may not be fully identified by this method. These are indurated crusts (duricrusts) overlying loose granular material and subsurface voids. In either case the ground may be strong enough to support the Scout but not the Primary rover. It would be very time consuming to deploy soil sensors such as a penetrometer at regular intervals to detect these hazards. Ground Penetrating Radar (GPR) has the potential to detect duricrusts and subsurface voids without having to stop the Scout, when special frequencies and signal processing methods are used. Once the hazard is detected by the GPR and the risk assessed in broad terms the Scout can be stopped and a suitable soil sensor deployed to determine the level of risk to Primary rover mobility.

Primary Rover:

Primary Rover is the main mission rover, the scientific and engineering platform supported by the FASTER system. Primarily, it was intended to prepare FASTER system as a direct support for ExoMars rover planned by ESA. However, after redefinition of the mission, FASTER system is now rather a technology demonstrator prepared with regards to ExoMars requirements (mass, volume, energy requirements, etc.) but in fact capable to be used as an universal safe terrain traversal supporting system for any planned rover of similar size. In the project, as the Primary Rover, existing ExoMars mockup Bridget, developed in Airbus DS, was practically used.

- **Wheeled Bevameter**

  Wheeled Bevameter (WB) is the device mounted directly on-board the Primary rover to obtain the 'last chance' data related to the geotechnical properties of the soil directly before the rover. The method of the measurements is simple: in its normal mode, the sinkage, motion resistance and rotation rate of the free rolling wheel are measured while the rover is driving. This enables to calculate %Tr of the soil using empirical equations and, using Bekker's equations, permits to solve for the soil geotechnical properties.

The WB as conceived by LSG uses a dedicated test wheel placed on the terrain as the loading device to enable both bearing strength and shear strength measurements while the host vehicle is driving. The method behind the WB is according to the terrain properties estimation method used on the NASA MER rovers with the primary difference being that for FASTER it would follow a real-time approach (and use a dedicated test wheel), rather than being an off-line method as done on MER. A measurement wheel ('test wheel') is used to load the terrain (from natural weight of the deployed test wheel assembly) for acquiring the needed terrain and vehicle-terrain interaction parameters. The test wheel is arranged such that it protrudes in the rover driving direction. It is not a driving wheel, i.e. it is not powered.

The WB includes a placement mechanism for the test wheel and would be stowed until after landing on Mars. It is expected that the test wheel would remain lowered onto the ground during nominal rover motion, including when climbing and descending slopes. During normal operations, the placement mechanism assumes the function of a passive suspension of the test wheel, allowing the wheel to follow the terrain contour (including rolling over rocks and climbing as well as descending slopes of up to 25° as per the FASTER Primary rover requirements). The system is capable of autonomously detecting test wheel 'stalls' against rocks exceeding the wheel obstacle climbing capability, permitting an autonomous raising of the test wheel off the surface, using the placement mechanism active joints, and its subsequent re-placement.

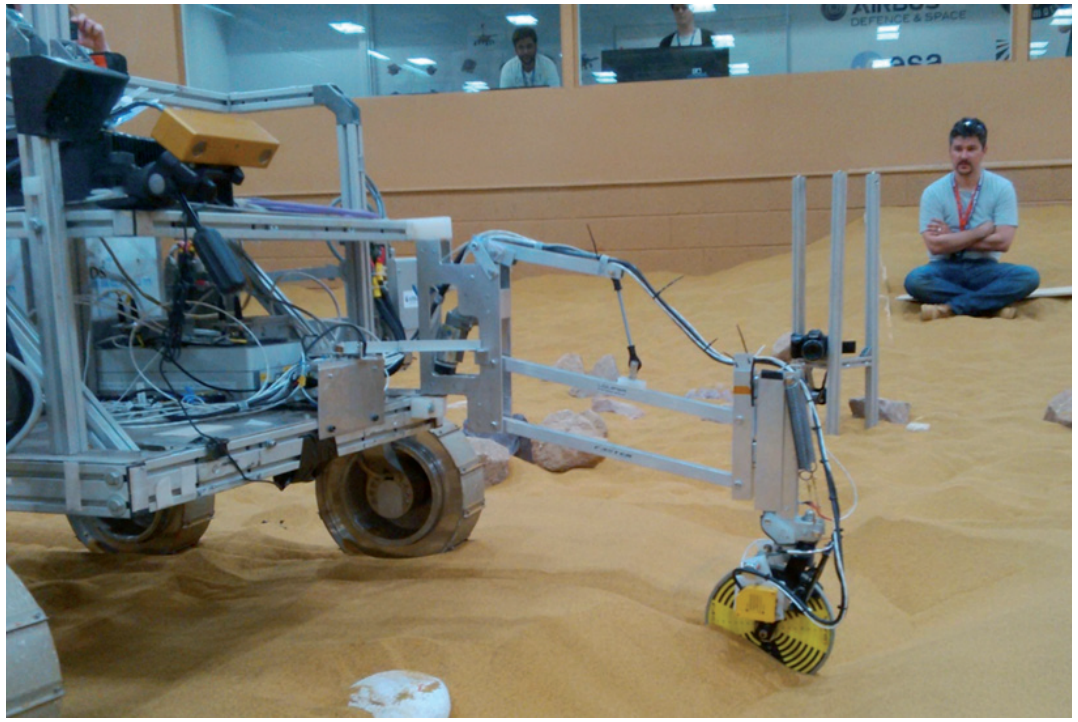


Figure 3: WB deployed from BRIDGET testbed rover

It is worth to note, the substitute device, called PathBeater, was analysed during the preliminary development phase of the project. After a trade-off, it was decided to do not develop this device as a final part of the soil sensing system for FASTER project.

Overall, the WB would also be suited as a soil physical properties scientific instrument on planetary rovers as key parameters of the soil along the vehicle traverse path are continually measured and thus documented.

- **Remote Sensing**

The Remote Sensing (RS) sensor enables the detection and localisation of rocks in the field of view of the camera mounted on the Primary rover.

Detection and tracking of rocks on the surface of planets can be achieved using unsupervised modelling techniques that can identify and describe 'regions of importance' (ROIs) in terms of quasi-thematic features, including colour, texture, intensity, shape and so on. In the context of this project, this involves detection and tracking based on visual saliency. Specific surface characteristics of objects on planetary surfaces provide sufficient information for them to be distinguished in the visual scene, and computer vision paradigms that use descriptions of objects in terms of their visual saliency to segregate them from their periphery are employed. Thus rock detection is performed via visual saliency based semantic description of objects using a modified saliency model based on the 'Rudinac' algorithm which incorporates colour information. This has the advantage over purely intensity based techniques of improving rejection

of false detections arising from textures in the sand, despite the relatively limited colourspace of planetary surfaces.

Once rocks have been identified using these saliency techniques, the actual dimensions and location of the rocks in 3D space is estimated using disparity information from the main rover stereo camera. The rock locations and dimensions identified are sent to the common Data Fusion subsystem in the same way as for the rest of the soil sensors.

TOPIC 4 – TECHNOLOGY: OPERATIONS OF PAIR OF ROVERS

Based on the project goal of improving average traversal speeds of planetary rovers through the forward acquisition of trafficability information by the use of a Scout rover the operational concept developed focusses on the 'traverse phase' of surface exploration missions, that is the segment of operations requiring the mission rover to traverse large distances with minimal or no science in that period.

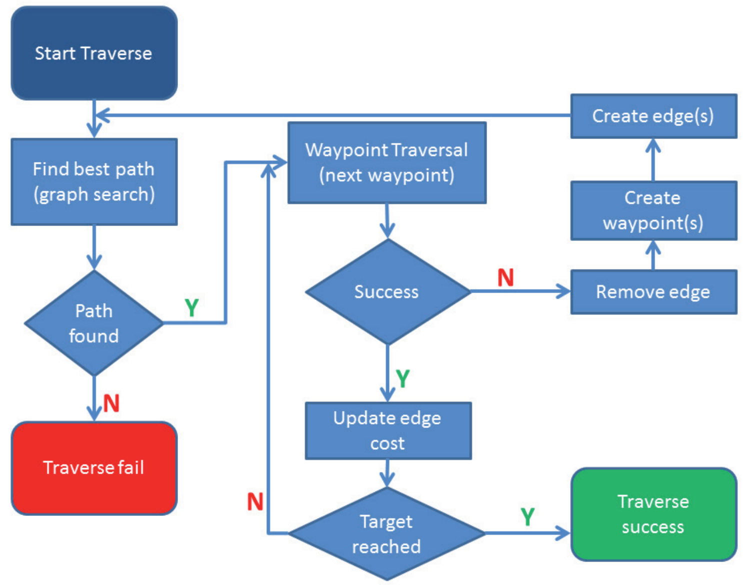


Figure 4: FASTER general operation scheme [Doc6.1]

The **key capabilities enabling primary rover autonomy** in the context of the FASTER operational scenario are:

- Traverse graph operations: Graph search and maintenance operations allowing the addition/deletion/modification of vertices and edges in the traverse graph.
- Mapping: Build Digital Elevation Maps (DEMs) based on stereo images. This should include the capability to merge data from multiple stereo image pairs, including those from the Scout rover. Additionally, images and/or data from the Primary rover should be filtered to ensure that the Scout rover is not included as part of the elevation map.
- Path planning: Planning a path to a local goal based on a DEM. Apart from geometric obstacles and rover capabilities, this should take into account the detected rocks (as reported by the visual soil sensing component of the FASTER Soil Sensing System (SSS)) and any known trafficability information.
- Path traversal (rover control): Following a planned path safely, while interacting with components of the FASTER SSS that have been deployed on the Primary rover. This should implicitly allow synchronization with the path traversal by the Scout rover, with the Scout rover acting as an artificial obstacle.
- Self-localization: Accurate self-localization is required for successful, long range traversal, both in the context of following a specific planned path that avoids nearby hazards, as well as being able to reach the target location specified by operators.
- Scout localization: Recognition and localization of the Scout rover using camera images from the Primary rover (potentially using the navigation stereo bench). This is to be used to support Scout rover traversal by providing bounds for the localization error.
- Communication with the Scout: Transmission of commands to the Scout rover, and reception of trafficability information and other data (such as stereo images and status).

Key Scout rover capabilities enabling the planned operation of the team are:

- Path traversal: Safely moving along a path planned by the Primary rover, provided to the Scout along with the local DEM, while conducting 'forward sensing' that is operating the components of the FASTER SSS that are part of the Scout rover.
- Self-localization: While it is expected that the Primary rover will provide periodic localization updates to the Scout, the Scout rover will be able to localize itself using the external localization updates from the Primary rover as a means of correction.
- Return to Primary rover: In certain cases of hazard detection during traversal, as well as some emergency scenarios (identified in D2.1), the Scout rover should be able to return to the Primary rover using the local DEM and the last path followed (or an updated path received from the Primary rover).
- Communication with Primary rover: Sending telemetry (especially trafficability) information to the Primary rover, and reception of tasks (primarily traversal commands).

FASTER project successfully discusses the specific requirements and operational schemes needed for two planetary rover common operations. The final functionality of the system can be found as a significant enhance of the mobility, which is the important goal for the planetary engineering. The planetary perspective and success metrics will be completely different from typical industrial standards presented by the terrestrial systems.

Effectiveness of the two rover common operations should be discussed separately. The additional planning of Scout rover path and Scout manoeuvres to reach the forward position to the Primary rover will spend a lot of computer time, so the overall effectiveness of pair of rovers will be typically lower than for one, separate rover. On the other hand, effectiveness of the arrival time and cost to the final point should be much higher than in typical straight movement through unknown terrain, especially when high variability and complexity of surface sediments (eg. dunes, ripples, windblown sand patches, etc.) are expected or present. Therefore, the level of safety should be significantly higher.

Additionally, all the Scout's manoeuvres can disturb the loose soil in front of the Primary rover, thus making it less traversable. Long discussion was made in the first phase of the project duration focused on the effective manoeuvring of the Scout to preserve the terrain unchanged. This request is important from the soil sensors point of view, especially RS and WB sensors – heavy disturbed soil can give additional shadows that can be resolved by RS subsystem like new boulders.

Final tests of the operational schemes show clearly, the system will rather not improve the speed of the terrain exploration then the overall safety of these operations. Due to calculation time for navigational data acquisition and path planning, the average traversal speed will be comparable with other planetary rover systems. Although, the main task for the FASTER system will be to enhance mission safety. The following Scout rover will check the terrain, and very high mobility of Scout preserves themselves from potential dangerous terrains. Thus, Primary rover will never reach the hard terrain and the overall safety of the mission will be significantly improved.

TOPIC 5 – TECHNOLOGY: DATA PROCESSING AND DATA FUSION

Data management and data processing for the FASTER system are realized by complex subsystem joining hardware and software components across the system. The data management for the FASTER can be simply divided into hardware component, including communication subsystem on both rovers and enabling the transmission of the data between them, on-board computer (OBC), enabling data processing and calculation and software of the FASTER system plus separated devices.

Data Fusion (DF) process in the systems integrating data from various sensors is crucial for overall system effectiveness and correct operations. Data Fusion subsystem is located in between the soil sensors interface nodes, additional data (e.g. time, position, rover attitude etc.) and, on the other side, the NAV MAP node (as a part of the Navigation Subsystem). This idea is presented on the graph below.

As presented on the diagram, all kind of data from sensors and additional data sources are used as input data on the same way. The specialized Data Fusion input interface simply read all data. The interface defined in this document is the base for all data incoming to DF module through input interface. Data Fusion is prepared as one ROS node, with additional possibility to prepare additional node before the DF module in case the need of further preprocessing data (e.g. problems with compatibility or timing of input data). The common definition of input interface makes the subsystem highly flexible.

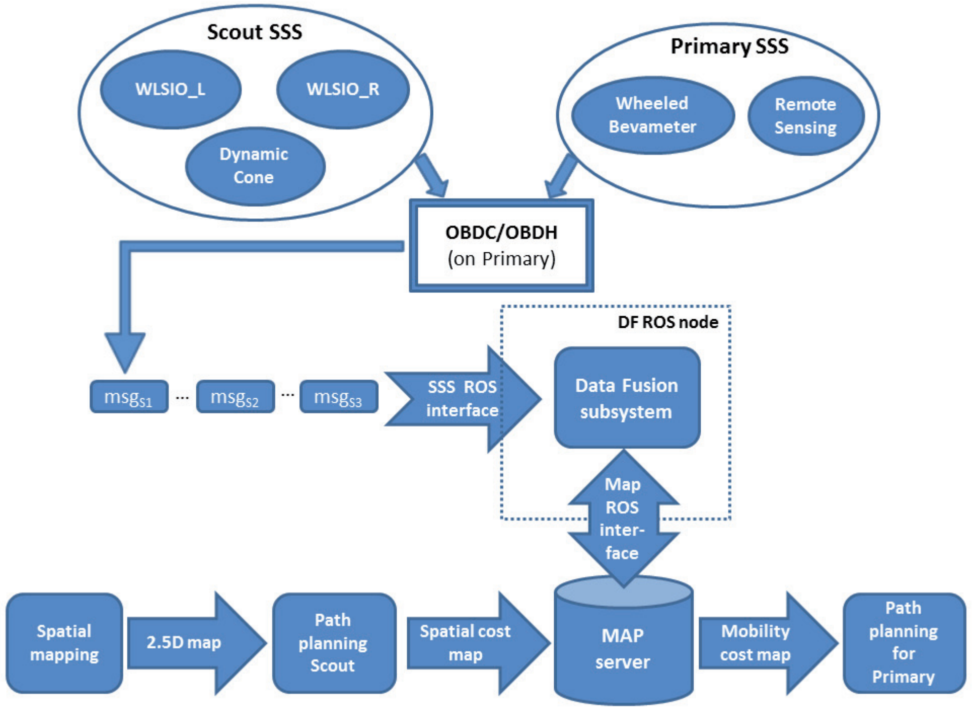


Figure 5: Data Fusion module operation scheme [Doc4.5]

The DF module is ready to acquire data from additional sources, like now discussed, possible simple addition of GPR sensor which can be a good example of the potential benefits of such DF module development strategy.

DF subsystem is capable to use both synchronous and asynchronous data as the input. Input interface diagram is presented in Figure 5. Asynchronous data are handled by publisher-subscriber architecture and each sensor publishes messages to common channel, which is subscribed by DF module. In case of synchronous data (client-server architecture) the prioritising can be used to processed time-restricted data sources e.g. sensors deployed on demand. Asynchronous interface is based on ROS messages. On this channel, input data are buffered, by internal ROS mechanism, and processed in continuous loop. Synchronous channel is implemented as a ROS service with request of the same type as asynchronous messages and empty response. Data passed by this interface are processed with highest priority and are not buffered.

Data exchanged by ROS are always packed in proper messages, and there is not necessary to check its consistency. However, part of fields has defined constraints and this formal correctness is checked on the interface level and rejected when any problem occurred. Mainly, the trafficability percentage (%Tr) value is finally in 0 to 100 range.

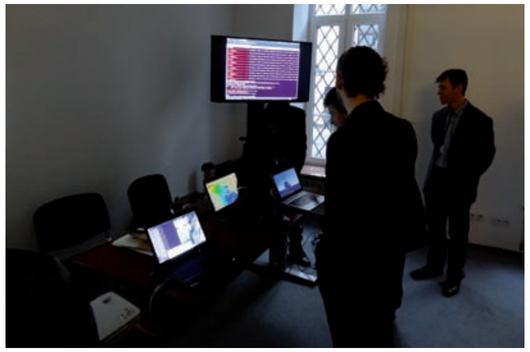
Pre-processing and analysis steps are provided for statistical algorithms and other methods, which produce sensor related model parameters for each data source and to generalise data and check it for inconsistency with developed core fusion method. While input interface make Data Fusion module independent on data format, this steps provides versatility on measurement source values parameters, both over time and over value level.

Because of that fact, fusion of the measurements should be done in two step algorithm.

First step is called **Recursive Update**, in which current measurement is fused with estimation computed from previous readings from the same sensor, in current map cell. In this step algorithm fuses measurements of the same sensor over time and **Bayes Filter** is a standard algorithm to compute that estimation.

In second step, algorithm merges information from each sensor estimation over current cell. Because of different sensors measurement methods, which could cause different properties/obstacles detection over data from different sensors, it is not appropriate to use Bayes Filtering during this step. In this case, a simple solution called **Worst Case Scenario** Merging is implemented.

Main task for Data Fusion is to update the trafficability layer of the global map. This information and the terrain cost map on a second layer are used as a base for path planning process. Because whole control system is managed by scheduler, DF module should update global map on demand sent from it. For that interface the ROS service (or ROS action) will be used. General idea is to exchange local part of map. The map for update will be as large as range of robots system perception and distance to the next planned waypoint. We should take into account an additional buffer, which will be needed because of Primary rover traverse.
The work on Data Fusion algorithm was focused not only on the direct management and processing of the incoming data, but also on the wide discussion on the uncertainty of the acquired data. Although the simple algorithm was finally chosen by the partners, the other possible algorithms and ideas on data comparison and validation were also discussed. Additionally, the further activities in the topic of fusion of soil were recognized and discussed.



TOPIC 6 – PROJECT MANAGEMENT

Management of large and long-term technology projects, like FASTER, is a challenging task. In order to address a continuous care of such project the involvement and responsibility of all level employees is required.

During the FASTER project, high level project managers – the Project Coordinator and the Project Technical Manager, focused on the project management basics, which are cost, time, scope and quality. The Project Managers were paying attention to achieve WP-level goals, prepare the deliverables (documents) and report to the Project Officer.

The technical work was effectively coordinated by the Technical Manager with support from the Project Coordinator and partners. The Project Managers were the bridging gap between the EC and the technical team, whose work was actively and successfully managed by the leaders of various project tasks. Therefore, a lot of the technical issues were solved on the level of technical staff directly engaged in the work.

Effective communication via emails, teleconferences, site visits for integration work and project meetings enabled collaborative work and exchange of know-how between partners. The project was running to schedule and there are no major coordination issues to report.

The idea of management was based on four basic rules:

- Enabling the common communication channel by organizing frequent teleconferences and a series of technical meetings for staff engaged in the project.
- Management of documents and deliverables in close co-operation with the Project Officer.
- Dynamic management of previously prepared requirements and flexibility of development paths.
- Agile project development scheme.

It is worth to underline that the FASTER Consortium engaged very well with the ExoMars Team at Airbus Defence and Space at Stevenage, UK. The access to the Airbus Mars yard enabled to undertake extensive testing of the FASTER integrated rover-sensor platforms under a realistic indoor test environment. The project was able to acquire more insight into the operation of the primary rover testbed from Airbus DS.

The details of presented workflow is fully discussed in the preface of this document.

FASTER
Forward Acquisition of Soil and Terrain data for Exploration Rover

The general structure of the project is presented below.

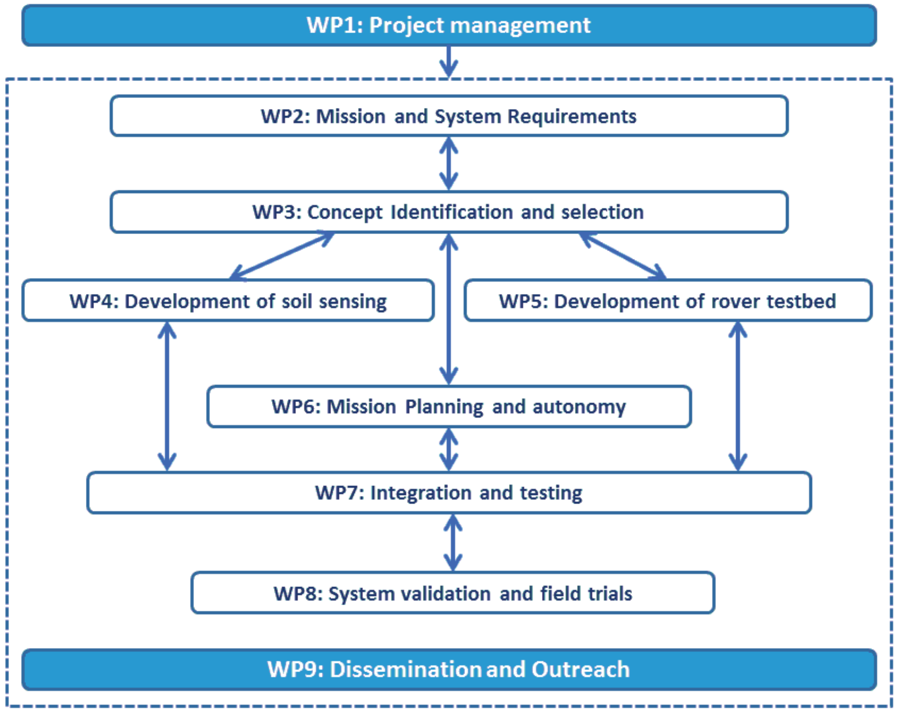


Figure 6: FASTER project organisation scheme

TOPIC 7 – DISSEMINATION: ACTIVATION OF PLANETARY COMMUNITY

The major objective of the **WP9 Dissemination and Outreach** was to effectively and efficiently raise awareness and understanding of the project FASTER, from the concept to the final results, to maximize the influence of the project and to promote adoption/exploitation of the project results. It is also an opportunity to gain publicity to the 7th Framework Programme. Further, the objectives includes the production of outreach material which can be published in various media and is especially created for the general public to make the project and is framework publicly visible.

The FASTER dissemination process itself was split into the following subsequent phases: first the activity targeted mostly the R&D community, that are open to a still unfolding, yet promising European initiative; the next step was to extend the project FASTER audience, building on available project results; finally we went on to exploitability of FASTER results to the widest audiences and pave the way for a fruitful project afterlife.

To enhance the process and achieve above mentioned goals the following tools were used: releases, newsletters, technical papers & conference presentations, internal company presentations, external presentations to experts, public web site with associated mailing list, an intranet page (set up as a central information hub for all the consortium members and the EC relevant services, providing actual project documentation, an archive and a contact platform for the internal users) and many more. The activity was also supported by the use of several images, showing the system at different levels, which were used in many of the dissemination materials.

Within the three years of the project FASTER the focus was to target the scientific community, industrial stakeholders, the public sector, and other groups who might be interested in its achievements. The main goal of first year was to spread the word about FASTER as an R&D initiative and its preliminary findings, which was mainly achieved by certain offline activities (presenting the project and its results on conferences, workshops, exhibitions and other events, using an dissemination materials and scientific papers & presentations) along with means gaining online visibility (e.g. updates of the official FASTER website etc.). During the second and third years of FASTER project the Consortium continued the dissemination activities reaching major stakeholders by making a number of presentations on many events and publishing several peer-reviewed papers in the research related magazines.

One of the major activities within the Dissemination and Outreach work in FASTER project was to organize two demonstration workshops:

- 'FIRST DEMONSTRATIOM WORKSHOP' in Warsaw, Poland at the end of year 2 of the project.
- 'FINAL DEMONSTRATION WORKSHOP' in Stevenage, United Kingdom at the end of the project, as the final meeting, summarizing the whole project.

The goal of the workshops was to present the achievements of the FASTER Project after two years of project duration and at the end of the project and also to give the participants the possibility to discuss topics related to planetary rover technology and soil sensing techniques. The workshops were open for external guests, grouping the FASTER consortium partners with key robotics and geology experts. Furthermore, information about the workshops was sent to academic groups and students, so major actors working in the space exploration domain were present at the events. This enabled the FASTER team to discuss concepts and achievements of the project with attendees from European institutes & industry and invited ESA and EU representatives.

The workshops were divided into sessions focused on the main topics defined during the conception phase of the project. In addition to presentations and discussions, hands-on demonstrations were organized to show the intermediate and final results. Different levels of the working mechanisms, devices and algorithms developed in the FASTER project were presented to the interested audiences.

The first interactive demonstration was a good starting point for an effective and, intensive discussion among attendees. The hardware demo took place in two sandboxes specially built for the event. One box was filled with quartz sand the second was filled with basaltic sand and silt.

The second FASTER demonstration workshop, held at Airbus Defence and Space in UK, was intended to be the final summary of the FASTER project achievements. Gathered together about 40 people representing big, medium and small industry, universities and European Space Agency (ESA) to recognize the main results of the project presented at the five sessions related to the project activities. One of the most interesting part of the workshop was a practical demonstration. The full system, Bridged mockup of ExoMars rover and FASTER's Scout rover, operating on a common strategy on New Mars Yard in Airbus DS

was prepared for the attendees. Demonstration, gave the observers an opportunity to realise the complicity of the issues covered in the FASTER project. The workshop finished with a discussion about the issues of autonomic (or semi-autonomic) planetary operations, recognition of terrain trafficability and problems with definition of base parameters for the system software to secure correct system decision making process. The final conclusion was positive, the system presented the functionality needed and can serve as a basis for further activities related to planetary surface operations.

As the part of the Dissemination and Outreach tasks the overall exploitation strategy for the FASTER results and IPR related activities in relation to the consortium partners were developed and executed.

It is important to underline the high interest of the Students Teams (eg. planetary robotic student teams, as presented during Warsaw Workshop) or students alone in the FASTER achievements. Furthermore, significant interest in the project findings have been shown by the terrestrial scientists, like geologist, who are the end users of such a projects as FASTER. Although the interest of the mentioned groups of stakeholders is high and promising for further researches, the involvement of the engineering and scientific community in the project was limited. This is, however, the general approach observed in such technology demonstration projects, which is FASTER.

Nonetheless, the overall dissemination output of the FASTER is an indication of the global excellence and recognition of the project partners.

During the FASTER project, set of papers or presentations was prepared to discuss the project goals and development status. List of papers is presented below:

- Shaukat, A., Spiteri, C., Gao, Y., Al-Milli, S., & Bajpai, A. (2013). **Quasi-thematic feature detection and tracking for future rover long-distance autonomous navigation**. *12th Symposium on Advanced Space Technologies in Robotics and Automation*, ESA/ESTEC, Noordwijk, the Netherlands, 15–17 May 2013.
- Y. Nevatia, F. Bulens, J. Gancet, Y. Gao, S. Al-Mili, R. U. Sonsalla, T. P. Kaupisch, M. Fritsche, T. Vögele, E. Allouis, K. Skocki, S. Ransom, C. Saaj, M. Matthews, B. Yeomans, L. Richter, **"Safe Long-Range Travel for Planetary Rovers through Forward Sensing"**, accepted for the *12th Symposium on Advanced Space Technologies in Robotics and Automation*, ESA/ESTEC, Noordwijk, the Netherlands, 15–17 May 2013.
- W. A. Lewinger, F. Comin, S. Ransom, L. Richter, S. Al-Milli, C. Spiteri, Y. Gao, M. Matthews, C. Saaj, **"Multi-Level Soil Sensing Systems to Identify Safe Trafficability Areas for Extra-Planetary Rovers"**, accepted for the *12th Symposium on Advanced Space Technologies in Robotics and Automation*, ESA/ESTEC, Noordwijk, the Netherlands, 15–17 May 2013.

- Y. H. Nevatia, J. Gancet, F. Bulens, T. Voegele, R. U. Sonsalla, C. M. Saaj, W. A. Lewinger, M. Mat-thews, F. J. C. Cabrera, Y. Gao, E. Allouis, B. Imhof, S. Ransom, L. Richter and K. Skocki, **"Improved Traversal for Planetary Rovers through Forward Acquisition of Terrain Trafficability"**, accepted for the 2013 IEEE International Conference on Robotics and Automation Planetary Rovers Workshop, Karlsruhe, 6–10 May, 2013.
- Al-Milli, S., Spiteri, C., Comin, F., & Gao, Y., **"Real-time Vision Based Dynamic Sinkage Detection for Exploration Rovers"**, In *International Conference on Intelligent Robots and Systems*. Tokyo Big Sight, Japan, 3 November, 2013.
- R. U. Sonsalla, M. Fritsche, T. Voegele, F. Kirchner **"Concept Study for the FASTER Micro Scout Rover"**, accepted for the *12th Symposium on Advanced Space Technologies in Robotics and Automation*, ESA/ESTEC, Noordwijk, the Netherlands, 15–17 May 2013.
- **"Design of a High Mobile Micro Rover within a Dual Rover Configuration for Autonomous Operations"**. R. Sonsalla, Y. Nevatia, M. Fritsche, J. Bessekon Akpo, J. Gancet, F. Kirchner. In Proceedings of the *International Symposium on Artificial Intelligence, Robotics and Automation in Space (i-SAIRAS 2014), (iSAIRAS-2014)*, 17.6.––19.6.2014, Montreal, o.A., Jun/2014.
- **"Remote Sensing of Martian Terrain Hazards via Visually Salient Feature Detection"** S. Al-Milli, A. Shaukat, C. Spiteri, and Y. Gao, *European Planetary Science Congress EPSC2014-801*.
- **"Examination of recent Martian rovers data for supporting the planetary terrain trafficability assessment techniques and algorithms development"** K. Skocki and P. Węclewski. *European Planetary Science Congress EPSC2014-805.*
- **Autonomous Path Tracking Steering Controller for Extraterrestrial Terrain Exploration Rover** M. Ahmed, R. Sonsalla, F. Kirchner, In *40th COSPAR Scientific Assembly 2014, (COSPAR-2014)*, 02.8.–10.8.2014, Moscow, Elsevier, Aug/2014.
- **"Development of the FASTER Wheeled Bevameter"**, L. Richter, V. Eder, W. Hoheneder, B. Imhof, W. Lewinger, S. Ransom, C. Saaj, P. Weclewski, and R, Waclavicek. *European Planetary Science Congress EPSC2014-818.*
- **"Scout Rover Applications for Forward Acquisition of Soil and Terrain Data"**, R. Sonsalla, M. Ahmed, M. Fritsche, J. Akpo, and T. Voegele. *European Planetary Science Congress EPSC2014-819.*
- **„FASTER – trafficability data fusion subsystem"**, P. Węclewski, K. Skocki, *European Rover Challenge 2014.*
- **„Wybrane wyniki georadarowych badań analogów regolitu marsjańskiego"**, Proceedings : M. Pasternak, K. Skocki, P. Kaczmarek, W. Czarnecki, 2014

LESSONS LEARNED

This paragraph shortly summarizes lessons learned during the realization of the project.

A detailed requirements analysis, prepared as Doc2.1, was the starting point of the whole development activity at the beginning of the FASTER project. Some aspects analysed during preparation of D2.1 proved to be too detailed and too far away from the point of view of final development and design phase. The lesson learned in this case is to make a requirement preparation in two separate phases, when in the first phase all aspects should be roughly analysed, but in the second phase only direct requirements related to the technology and direct engineering purposes should be expanded into full requirement discussion. The second phase should be placed later during the development process, enabling parallel discussion of final system concept and requirements needed to be analysed. Thus, requirement definition period should be significantly extended in time and two deliverables should be prepared: preliminary one discussing all related requirements and giving the wide view on the overall system environment, and the final one, discussing much deeper selected and directly related to the final (or semi-final) system concept.

'living document' and fixed requirements
The 'living document' concept presented in the FASTER project was a good solution when the project-related mission concept of Mars Sample Return changed significantly. Fixed D2.1 deliverable deadline, when managed typically, could finally highly limits the development phase. Such limitation could highly affect the final engineering flexibility of design, making the final effect not optimal.

Wide discussion and brain storms during development phase
Technology projects like FASTER require a long and effective development phase to reach the project goals and to correctly define the final technology to be used in the project. Thus, many project meetings should be organized in the first phase of development. One of the most effective ways to discuss complicated engineering solutions is a brain-storming among designers and other project members, who can state not expected questions and find important issues.

Timing of development phase
Based on the project FASTER experience it can be stated that the early development phases should not be too long and the design, prototyping and testing period should be extended. The significant pressure should be put by the project partners to make an early development phase effective and time limited, with many brain storming sessions(as discussed above), and to start the actual design phase as early as possible.

Early definition of overall project concept needed
The most important milestone in each common project is to define the overall concept. Although the end of the WP3 was specified as a concept definition deadline, the final concept was later discussed and was completed not until the end of 2013. It was definitely too late to make a following design and testing actions effective and not disrupted.
Additionally, apart from separate concepts for hardware and software there should be and additional document (formal deliverable or informal document) clearly describing the full system concept, both hardware and software, outlining one common vision of the system.

Early definition of general communication structure, data formats and interfaces
The definition of the type and version of the software, core formats, common code repositories, interfaces and software structures should be defined before the final system concept description. The delay due to late definition of these elements can severely influence further software and hardware design activity. Structures, data formats, interfaces and even versions of the software used should be widely discussed among project partners during the brain storming sessions , and the final conclusions should be available as an important internal document – the basis for any further works.

Relations with external projects (ExoMars) – current analysis
In case where the realised project is based on requirements or definitionsfrom external projects, there should be permanent analysis of potential changes in the external project(s). The response to such changes should be fast and, if there are no restrictions, the external project team(s) should be informed on any critical issues related to such changes.

Preparation of the test range
All aspects of required preparation of the test range for project purposes should be early recognized and discussed among the project partners and with the owner of the test range. This is needed to avoid problems with final preparation of the required conditions related to the tested properties of the system on the test range.

Using a terrestrial planetary analogues terrain as a test range
During the middle phase of the project, the potential terrestrial trial areas should be deeply analysed and described. The economical, logistics and operational analysis should be prepared and the comparison table of pros and cons should be prepared to show the value of the potential outdoor tests vs. laboratory tests.

Definition of optimal common soil samples for tests needed
Sufficient analyses on the common and variable suite of the soil samples have to be made to avoid misunderstanding of real or potential problems related to the system answer on the soils. Soil samples should be carefully chosen, discussed and prepared in terms of tested system properties. The samples should be well suited as a planetary analogues for the project.

Management of the integration phase and tests, timing
The achievements of preliminary analyses regarding the tests scheme and timing should be taken into account during the preparations to the final tests at the end of the project. Timing should include the risk of delays related to the development phase, design phase, risks calculated separately for devices, teams and environmental conditions, as well as unexpected delays external from the project.

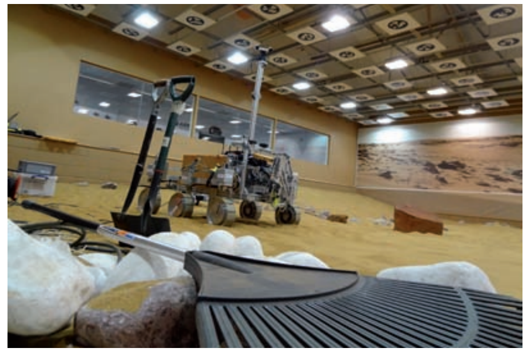
Trial tests vs integration phase delays
Trial tests or integration tests should be prepared in such way that the eventual delays coming from late integration of the system will not significantly influence the successful performance of the trials. The additional 'contingency' time should be planned in the tests structure.

- **Dissemination of pure technological project among scientists, only young are interested**
  With many parallel events competing for the attention of the scientific and engineering community, the external interest of the technological demonstration project like FASTER is not on the high level among the scientists and engineers. R&D projects that do not have in-orbit demonstration component are generally not of high interest for the scientific and engineering communities, so the dissemination activities should be focused on the underlining the potential wide perspectives of the technology tested and presented. This approach could in the future projects results in the successful technological project dissemination.

- **Dissemination: trainings not possible**
  Projects, where the final technology demonstrator will be in fact ready in the last phase of the project realisation period, will only be able to offer limited training possibilities .

- **Teleconferences discussions and statements**
  All the teleconferences, meetings and any bilateral or multilateral talks strictly related to the project have to be summarized by short note, where the most important elements will be noted: topics, opinions, final findings, decisions, deadlines or agreed timeline and eventual separate votes. Such documentation can be analysed later by project management staff to find any important and not finished issues, and to permanently manage the opinion/decision flow in the project.

- **Project meetings: topics, decision process**
  Regarding to project meetings, full documentation of the discussion in form of the extended MoMs has to be saved and distributed among partners. Additionally, there should be a kind of MoMs execution matrix prepared and managed by project management to permanently check the execution of the decisions and to find which alternate opinions should be taken into account at the later stages of the projects.



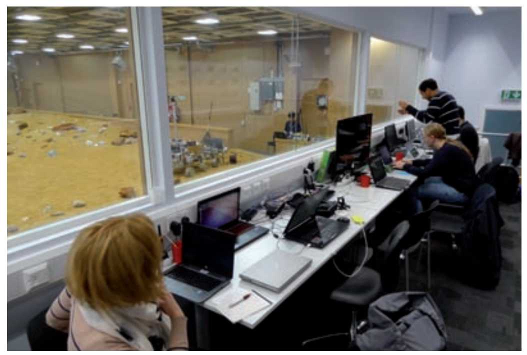
- **Integration campaigns planning**
  Integration campaigns should be planned, if possible, on a regular basis to enable early planning of activities and best management of the achieved results. Generally, tests related to components and interfaces should be scheduled as soon as possible, and should be planned for as long time as possible. Additionally, works should be planned also in advance, to enable the development of the modules (mostly: software) in between the integration sessions planned.

- **Controlled testing environment needed**
  As realised during the integration phase of the FASTER project, access to a at least partly environmentally controlled test area is crucial for the success of integration and testing . The possibility of using the New Mars Yard at Airbus DS, well equipped with the Bridget mock-up, was the very important point in successful accomplishing the project. The full access (round the clock) to testing infrastructure can be considered as an additional point.

- **Final system tests preparation and goals**
  As very typical for similar projects, the planned final testing phase was too short to fully cover all possible tests. In general words, all required tests were performed, although to obtain better final results, a much longer period of tests is needed (the limitation here is the time frame for the whole project).
  Recognition of possible testing/demonstration/trial place limitations should be made as early as possible – such limitations (due to conditions, variability or formal requirements) can highly affect effectiveness of further testing phase.

- **Final workshop – discussion of topics**
  The mostly standardized agenda of both workshops meet the expectations of the guests on well-structured discussion scheme. It was an effective way to present and discuss all the main key topics of the FASTER project.

- **Final demonstration organisation**
  Final demonstration of simulated planetary operations performed by pair of rovers demands well-chosen place (real, open terrain or lab conditions) and time to reach all required goals. The choice of New Mars Yard as a place of Final Demonstration was a good decision, regarding to season, complicity of system, and infrastructure requirements. The existing limitations is preparing terrain for the demo (sand traps preparation etc.) and availability of presentation tools should be recognized earlier.

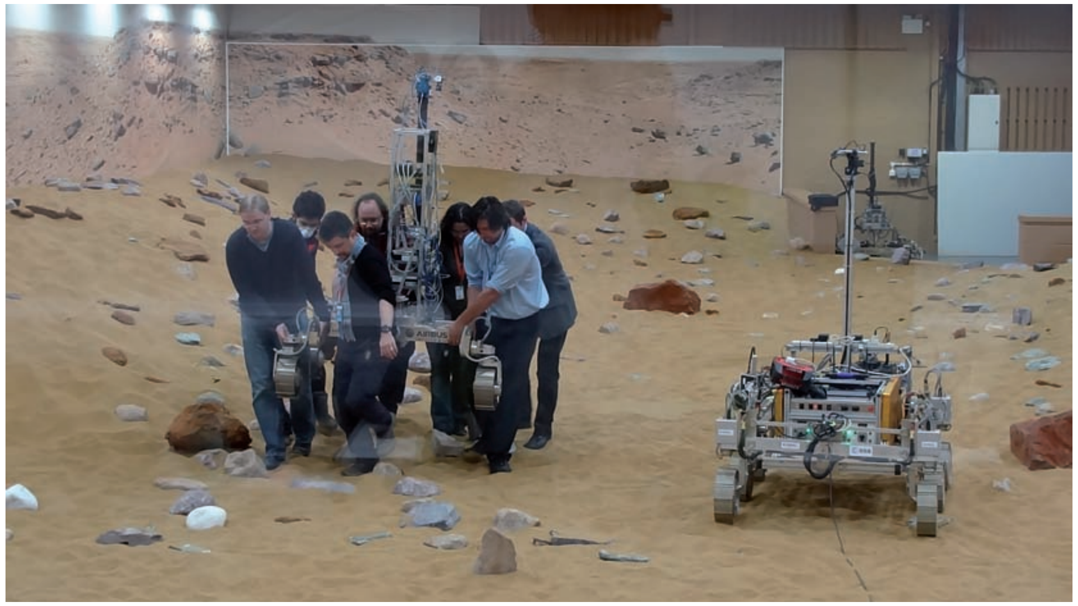


FINAL FINDINGS AND CONCLUSIONS

- Trafficability assessment of planetary rovers is not trivial issue, and practical realisation is limited by our basic knowledge on the conditions and properties of the planetary surfaces.
- Until a large amount of measurements data is collected (on real planetary surfaces and on terrestrial analogue materials) the uncertainty of software and data fusion parameters can highly influence the correct operations of the system.
- Common documents (regularly upgraded) describing the idea of the full system as well as common interfaces document should be prepared as early as possible in the development phase of the project.
- Definition of software and hardware interfaces should be made as early as possible.
- Tests will need much more time than you ever planned.
- The preparations for the demonstration of the autonomous co-operation of planetary rovers take a lot of time.

FINAL RECOMMENDATIONS

- Check at least twice the Description of Work document logics and consistency to avoid any interpretation issues during the work.
- Be open minded and discuss basic and alternative solutions during the project realisation. Do not fix fully on one idea at the start of the project.
- Organize brain-storming sessions rather than static informative meetings.
- Discuss project (regularly) with potential end users and scientists (e.g. the Scientific Advisory Board).
- Take into account the comments of your reviewers – they often simply present you a good idea or solution.
- Plan your integration and testing phase for a longer period than you previously expected to do.
- Find potential workshop/conference/demonstration guests and other interested audience well in time before these events.
- Permanently monitor the project flow and discuss any issues with technical staff.



- Discuss your concept with potential end users.

… and finally – discuss ideas, there can be just another way to do it **FASTER**…

LIST OF ABBREVIATIONS

ASP	Astri Polska
ASU	Astrium UK (now Airbus Defence and Space)
DCPi	Dynamic Cone Penetration index
DEM	Digital Elevation Model
DF	Data Fusion
DFKI	Deutsches Forschungszentrum für Künstliche Intelligenz GmBH
Dx.x	Internal document numbering
DoW	Description of Work
EC	European Commision
IMU	Inertial Measurement Unit
LSG	Liquifer Space Group
mDCP	motorised Dynamic Cone Penetrometer
MER	Mars Exploration Rovers
MoM	Minutes of Meeting
MSR	Mars Sample Return
OBC	On-Board Computer
ROS	Robot Operating System
SSS	Soil Sensing System
TRL	Technology Readiness Level
UoS	University of Surrey
WB	Wheeled Bevameter
WLSIO	Wheel-Leg Soil Interaction and Observation
WP	Work Package
%Tr	percent of trafficability

FASTER CONSORTIUM

FASTER project was realised by European Consortium of six partners:

- **Deutsches Forschungszentrum für Künstliche Intelligenz GmbH (DFKI)**
  PROJECT FASTER COORDINATOR

  The Robotics Innovation Center (RIC) belongs to the Bremen location of the German Research Center for Artificial Intelligence (DFKI GmbH). Here and in the RIC branch office at the University of Osnabrück, under the direction of Prof. Dr. Frank Kirchner, scientists develop mobile robot systems which are able to solve complex tasks on land, under water, in the air, or in space. These design concepts benefit from the variety of nature: climbing/walking four-, six-, or eight-legged robots, snake-like underwater vehicles, and two-armed transport robots resemble patterns from a natural environment, combining advantages of new materials with successfully evolved locomotion patterns and forms.

  The German Research Center for Artificial Intelligence (DFKI) GmbH, based in Kaiserslautern, Saarbrücken, and Bremen, and with a project office in Berlin, is the largest research centre worldwide in the field of artificial intelligence.

- **University of Surrey (UoS)**
  PROJECT FASTER TECHNICAL MANAGER

  The Surrey Space Centre (SSC) is a world leading research centre in space systems and small satellite engineering at the University of Surrey (UoS). The University of Surrey is one of the few universities, which has an end-to-end space design capability to conceive, design, implement and operate space concepts. SSC has close collaboration with the Surrey Satellite Technology Ltd and EADS Astrium. SSC is actively involved in the development of many robot system technologies such as: micro-rovers, robot manipulators, pin-point planetary landers, lunar orbiters and penetrators and aerobots. Surrey is participating in a few studies related to the ExoMars mission and is actively involved in developing wheeled, legged and tracked micro-rover technology. The Geotechnics Research Group is based in the Division of Civil, Chemical and Environmental Engineering (CCE) at the University of Surrey. Current research interests of the geotechnical research group include numerical soil mechanics, soil remediation and environmental soil mechanics, and extra-terrestrial geomechanics. The group has significant experience in field and experimental studies and has over the years undertaken projects in surface wave geophysics, very small and small strain stiffness behaviour of soils and weak rocks, ground energy systems and the characterization of soils for use as Martian simulants.

- **Airbus Defence and Space (former Astrium Limited) (ASU)**

  Since 1st January 2014 the former Astrium, Cassidian and Airbus Military divisions have been collectively known as Airbus Defence and Space (Airbus DS). Airbus DS is the second largest space company in the world and the largest company in European satellites. With c.40,000 employees and annual revenues of c. €14bn, it has expertise in launchers, satellites and human space flight.

  As an established prime Airbus DS has extensive knowledge and experience in the field of planetary rovers, sample handling and manipulation solutions, along with extensive implementation of planetary protection requirements and knowledge of the Martian environment. This unique experience has been gained from major roles on projects and studies such as the Mars Sample Return (MSR) Phase A studies, Sample Fetching Rover, and as prime contractor for the Beagle 2 mission. Airbus DS is responsible for the ExoMars rover vehicle design, currently at phase A/B1, giving an in-depth understanding of the flight-level requirements for design, manufacture and testing of a robotic exploration vehicle. Concurrently, Airbus DS also has demonstrated expertise conducting test campaigns involving planetary rovers in the UK and abroad such as for the ProVisG, SAFER and FASTER projects.

- **Space Applications Services NV (SAS)**

  Space Applications Services NV (aka SpaceApps) is an independent company founded in 1987. The company aim is to research and develop innovative systems, solutions and products for the aerospace markets and related industries. The company headquarters are located in Zaventem. Since 2004, the company has a subsidiary named Aerospace Applications North America Incorporated established in Houston in the United States of America. The company's main business covers manned and unmanned spacecraft and launch/re-entry vehicle programmes, air traffic management, design of HMI, Virtual Reality applications and robotics.

- **LIQUIFER Systems Group Hoheneder und Imhof GnbR (LSG)**

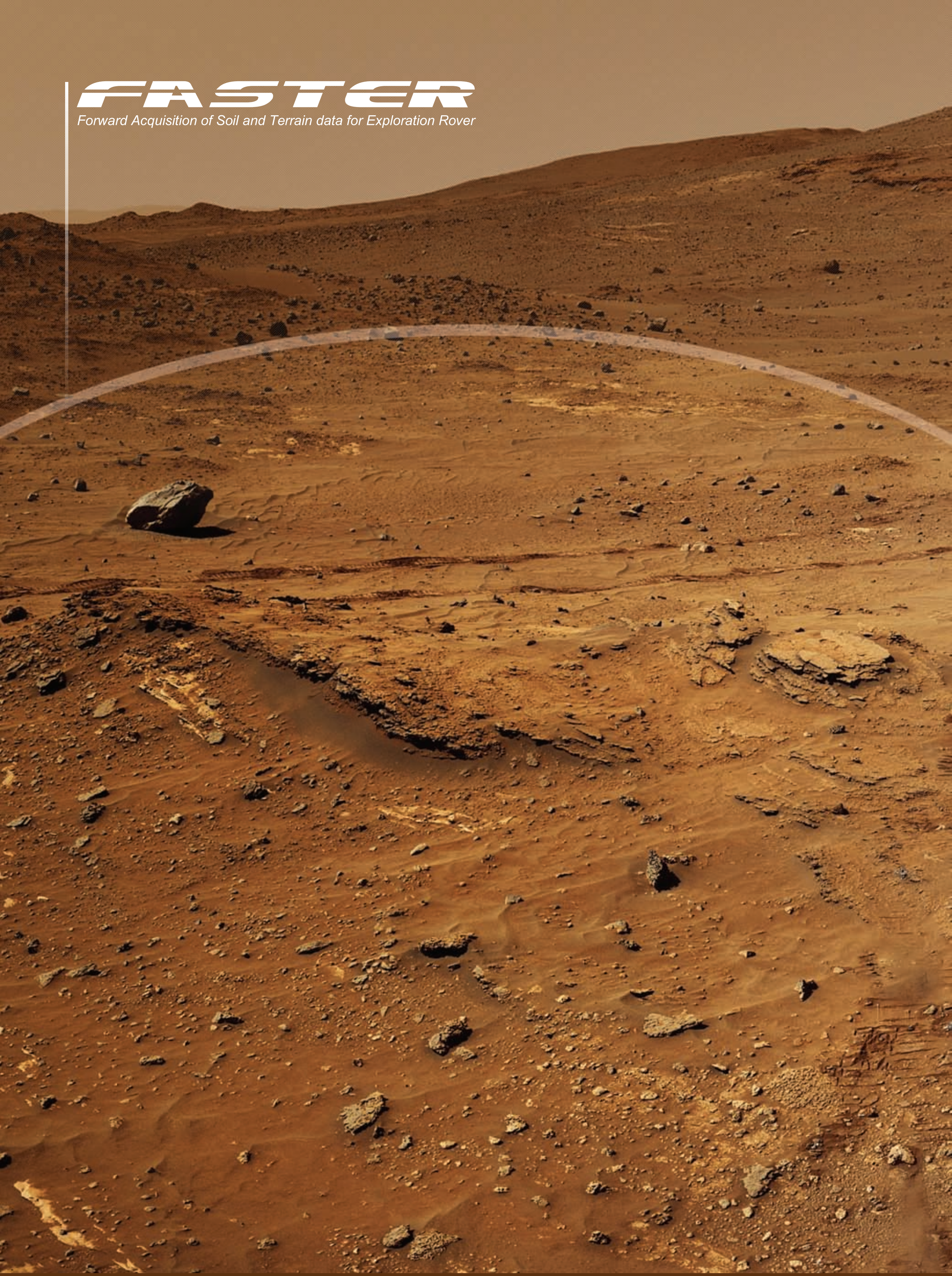
  LIQUIFER Systems Group (LSG) was established in 2004 with the object of creating a multidisciplinary task force that can design and develop space systems and engineering projects for the European Space Agency (ESA) and the European Industry as a whole. LSG combines a wide range of expertise within one team and covers fields from Satellite communications, Science, Systems Architecture and Engineering, Robotics through to Human Factors. The composition of the company provides a unique environment for innovative research and product development.

FASTER
Forward Acquisition of Soil and Terrain data for Exploration Rover

- **Astri Polska sp. z o.o. (ASP)**

Astri Polska sp. z o.o. is a research and development company working in satellite and space technology branch. Our mission is to support space industry development in Poland in cooperation with institutes and companies both from public and private sector. Branches in which Astri specializes include electronics, optoelectronics, GNSS (Global Navigation Satellite System), satellite observation, robotics and materials science. Astri Polska closely co-operates with ESA (European Space Agency) by realisation of Technology Transfer Programme within European representatives network.

Thanks to close co-operation with our shareholders, the company as a first in Poland offers integrated satellite applications that join localisation and three-dimensional technologies, environmental protection, precision agriculture, modern forest management and others. Astri Polska is a private-public partnership brought into life by European aeronautic and spatial concern Airbus Defence and Space and Space Research Centre of the Polish Academy of Sciences in September 2010.



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