Into the Unknown – Autonomous Navigation of the MMX Rover on the Unknown Surface of Mars' Moon Phobos

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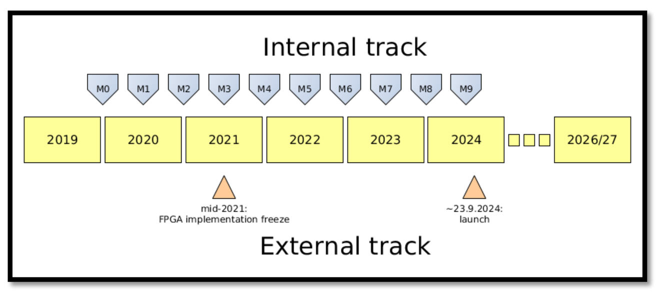
MMX Rover Navigation

The goal of our team is to develop an autonomous navigation solution for the MMX Rover. The rover, built jointly by CNES and DLR, is scheduled to launch onboard the MMX Spacecraft by JAXA, and is destined to operate on the surface of Phobos, the larger of Mars' two moons.

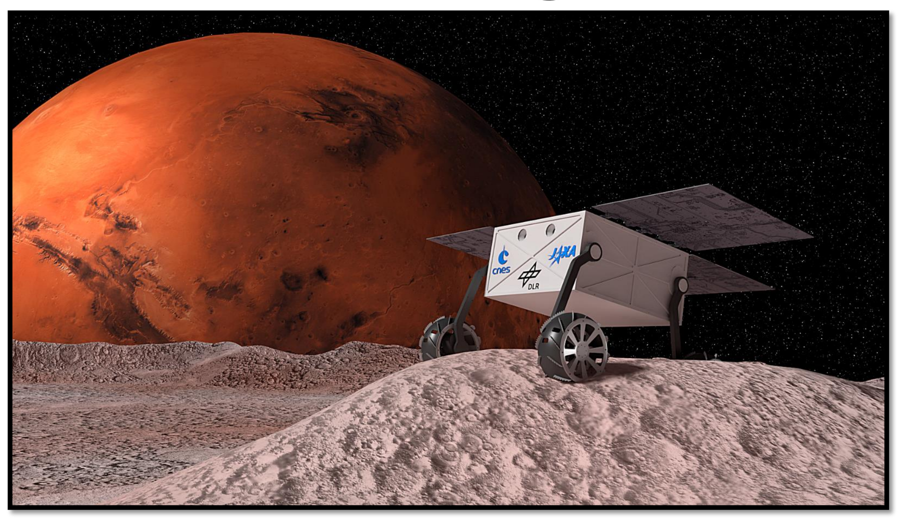
The MMX mission is unprecedented on many levels. In this poster we present a list of risks to be tackled as well as the approaches to be taken in the framework of developing an autonomous navigation software for MMX Rover.

Time Plan and Organization



We adopt an iterative software development model. Each iteration lasts 6 months. At its end, a new version of navigation solution exists. Each iteration begins and ends with an Internal Milestone Review Meeting. Current status is reviewed and next period is planned. FPGA implementation should be frozen by mid 2021, software implementation at the latest before the launch (September 2024).

Challenges and Planned Solutions

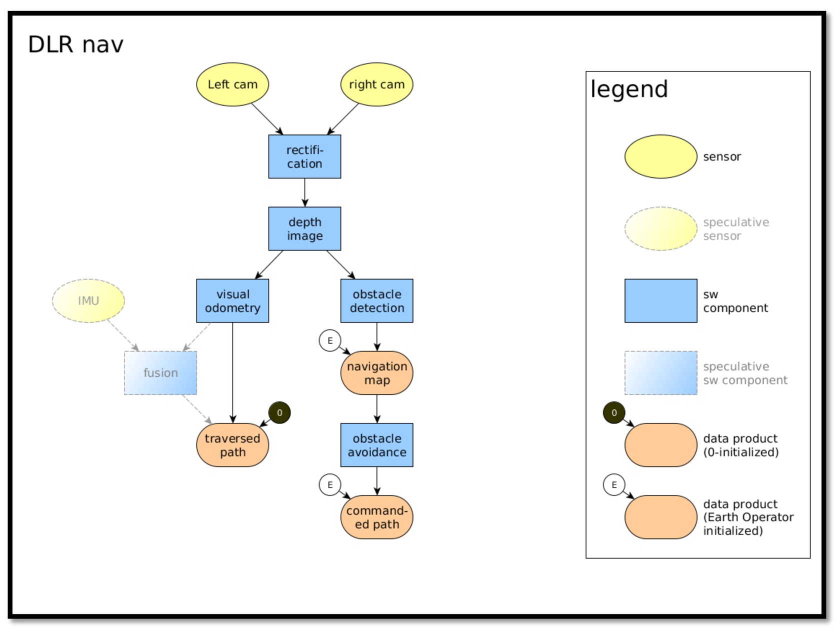


The artist's impression of the MMX rover mission. The main sources of challenges are Phobos, rover configuration, mission constraints and OBC resource limits.

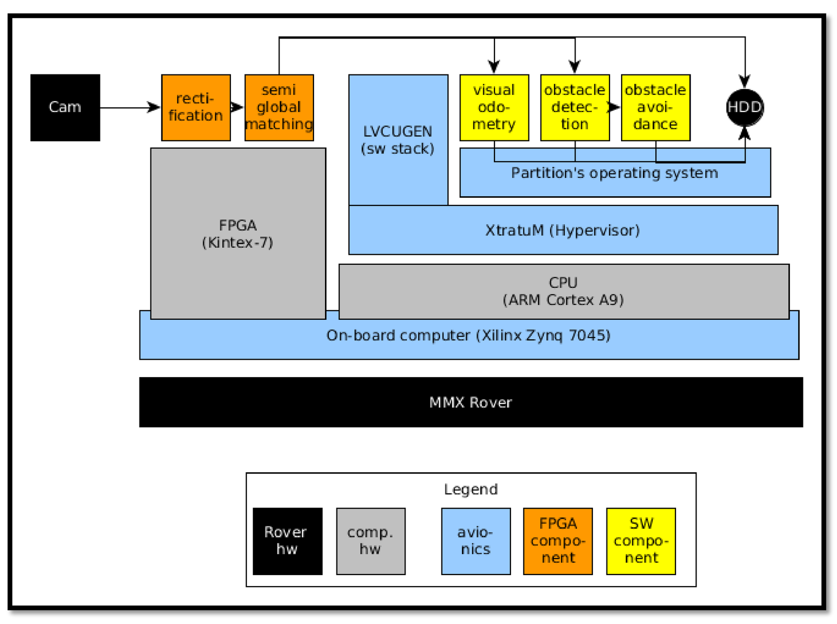
The table below is a categorized list of challenges and corresponding planned solutions.

Type	Challenge	(Planned) Solution
Phobos	• Unmapped terrain	• Use orbiter map + build own map
	• Obstacles endangering rover	• Obstacle detection (feature)
	• Possibly too many obstacles	• Navigation software shuts down
	• Possibly slippery terrain	• Visual odometry (feature)
	• Possibly featureless terrain	• Consider alternative detectors
	• Sharp shadows	• Consider shadow feature removal
	• Travelling shadows	• Consider compensation
	• Dust lifted by the rover	• Dust objects removal
Rover	• Skid-steered locomotion	• Visual odometry (feature)
	• Possible wheel slip	• Visual odometry as primary sensor
	• Body-inserted nav cameras	• Planning in current view
	• Possible camera failure	• Camera failure feedback
	• Possible over-/under-exposure	• Exposure feedback
	• Possible camera miscalibration	• Calibration feedback
	• High-noise IMU	• Don't rely on
	• High-slip wheel odometry	• Don't rely on
OBC	• Many simultaneous processes	• Use hypervisor to encapsulate
	• FPGA resources limited	• Allocate FPGA resources cautiously
	• Memory limited	• Take max 100 MB RAM
	• CPU limited	• Take max 10 s / stereo image pair
	• Persistent data storage limited	• Efficient data structures, compress
Ops	• Very tight energy budget	• One driving day every ~4th day
	• Infrequent comm windows	• Implement high(er)-level autonomy
	• Low data throughput	• Maximize onboard processing
	• Limited on-Earth testability	• Utilize commissioning phase
	• Limited confidence in higher modes of autonomy	• Utilize lower modes first, while commissioning higher ones slowly
MGMT	• Manage workforce fluctuation	• New-guy-friendly documentation
	• Many TBDs on higher level	• Stay agile (conflicts with ↓)
	• High sw quality demands	• Code rules, style, standards, ECSS, standardized build toolchain

Software Solution



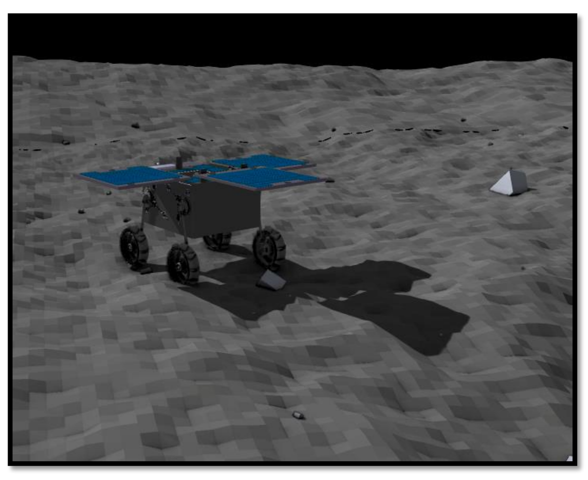
Navigation sw architecture



Software-to-hardware plan

From stereo image pairs, depth images are computed on an FPGA. This is the basis for a stereo visual odometry to estimate the robot's trajectory. Depth images and camera images will be used by obstacle classification and possibly further mapping modules to create maps. Such obstacle and map information can then be used to realize autonomous emergency stop behavior up to future reactive obstacle avoidance or path planning modules to support (semi-)autonomous operation.

Test Plan



Simulation (credit: DLR-SR)

Dataset acquisition (bg: DFKI SherpaTT)

Laboratory test

A resource-efficient test plan of consecutively increasing complexity to bootstrap the development is being formulated. We consider:

1. Tracks: Software, Agile model (COTS version), Flight model
2. Integration: Software-/Processor-/Hardware-/Rover-in-the-Loop
3. Test types: Simulation, Dataset-driven, Live experiment testing
4. Test levels: Unit test, component verification, ideal operation, Phobos nominal operation, extreme conditions

[1] Bertrand et al., "Roving on Phobos: Challenges of the MMX Rover for Space Robotics," *ASTRA 2019.*

[2] Ulamec et al., "A Rover for the JAXA MMX Mission to Phobos," *IAC* 2019.

[3] Schuster et al., "Towards Autonomous Planetary Exploration: The Lightweight Rover Unit (LRU), its Success in the SpaceBotCamp Challenge and Beyond," *JINT 2017.*

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