AMADEE-20 Exploration Cascade using Robotic Vehicles

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I. INTRODUCTION

In this extended abstract we present a team of robotic systems that is involved in the exploration cascade of the Mars Analog Simulation AMADEE-20 to be conducted in the Ramon Crator, Negev Desert, Israel.

II. MARS ANALOG RESEARCH

The first human-robotic Mars missions are envisioned to take place in the late 2030ies, aiming for surface exploration and sojourns lasting at least one month [1]. Starting in the Apollo era, where the National Aeronautics and Space Administration (NASA) used analog planetary research to train astronauts, analog research represents an effective tool to prepare and train for such surface missions. Mars analog regions on Earth in particular facilitate the field testing of equipment, scientific strategies and robotic operations in a representative environment.

In the past, analog missions such as the NASA D-RATS campaigns between 1997 and 2010, the NASA HI-SEAS missions, or the European MOONWALK project have supported the preparations for future Mars exploration missions. Since 2006, the Austrian Space Forum (OeWF) has conducted 12 multi-disciplinary Mars analog missions [2], [3]. These field campaigns focus on high fidelity surface operations by using space suit simulators and conducting experiments in the domains of geoscience, human factors and astrobiology. The analog missions further enable the validation of advanced human-robotic interactions. All OeWF analog missions are embedded in the AMADEE research program: Building upon 20+ years of experience, the AMADEE program of the OeWF develops strategies to enable the detection of life on extraterrestrial planetary bodies and ensures a high fidelity for all OeWF analog missions[1]. This endeavour also encompasses the establishment of the Exploration Cascade (see Sect. III)

III. AMADEE-20 EXPLORATION CASCADE

In order to maximize the efficiency and scientific output of Mars exploration missions, they need to be properly planned both from a scientific as well as from an operational perspective. Only then, key performance aspects of planetary surface exploration and the search for life can be optimized: i) the establishment of a geological context, ii) the prevention of contaminated sample sites of astrobiological interest and iii) the efficient deployment of instruments in the proper sequence and the right location to enable operational decision-taking with sufficient information.

The AMADEE Exploration Cascade (EC) was developed to facilitate the inclusion of those key aspects into planetary surface operations [4]. The EC defines a procedure for an efficient asset deployment sequence, providing the framework for the following question: *"which instrument needs to be active where and when, yielding what kind of data sets, leading to what kind of knowledge and resulting in what type of input for tactical flight planning"*. From a scientific point of view, the EC with the experiments therein, aims to study the geology of the analog site by investigating geological samples and their composition (organic/inorganic/mineralogical). Those results shall provide insights into geomorphic processes, whether aqueous formations have been present and what forms of life could have dominated throughout different periods of time, exploring the test sites' habitability potential.

Incorporating those aspects, the EC represents the framework for the robotic experiments outlined in the following sections. The order represents the deployment sequence to first obtain high altitude areal imaging and leading to in-situ investigations by rovers in the end.

The daily operations then consist of the deployment of the experiments in this sequence on pre-defined regions of interest. The deployment, preparatory activities and additional experiments (e.g. geological sampling) performed by human analog astronauts are all scheduled in the Daily Activity Plan by the Flight Plan Team of the OeWF, which is situated in the Mission Support Center (MSC). The MSC is also the focal point of all scientific data, mission planning and mission support activities. The generated scientific data will be stored online on the Science Data Archive of the OeWF and is available upon request for the scientific community.

A. Higher Altitude - AEROSCAN

X5, the AEROSCAN Drone (see Figure 1a), is a convertible Vertical Take Off and Landing (VTOL) UAV, designed for high autonomy flights (down-sunset flight time) that carries cameras and a range of atmospheric sensors. Its main purpose is to autonomously survey areas of interests selected

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[1]https://oewf.org/en/amadee-program/

from available satellite data in order to obtain detailed maps. This results are useful to plan site-specific operations like Extra-Vehicular Activities (EVAs) and robotic surveys. The X5 Drone is a 3 kg aircraft with a 2 meters wingspan. It is a highly versatile VTOL vehicle, as it is capable to quickly transition between vertical and horizontal flight. This allows the drone to take-off and land from confined spaces, without the need for wide areas to be used as a runway, like conventional aircraft. The payload of the X5 consist of a Red+Green+NIR (RGN) camera and a set of sensors for flight control. The vehicle is completely autonomous, as the flight paths, divided in way-points, are written in the drone's flight controller before the mission.

In the frame of the AMADEE-20 exploration cascade, the AEROSCAN X5 drone is transported by astronauts in EVAs. The two side wings, originally separated for an easier transfer, are attached to the drone's body and some checks are performed before take-off, which is commanded by the crew in the habitat. From this moment, until after landing, the drone performs its tasks autonomously, following a pre-loaded mission. In the meantime, the habitat crew monitors the drone's telemetry to ensure that the path is followed, and takes necessary action in case of a non-nominal event.

Three different potential scenarios have been planned: mapping, search&rescue and rover co-op. For mapping missions, several areas of interest around the AMADEE-20 station will be photographed with the drone's RGN camera. The images will be later assembled to obtain a geo-referenced map, with an expected ground resolution of 13 cm/pixel. The second scenario will test a Search&Rescue mission as part of a LoC (Loss of Communication) simulation with an EVA crew. After the crew is assessed as missing by the habitat crew, the drone will be dispatched on the last known crew location, where it will fly along a search grid in order to identify the missing crew on the ground. An object-tracking algorithm, trained on the EVA suit appearance, will be used to automate the crew identification process. The last scenario will be performed in collaboration with the EXOSCOT rover: the drone will fly along the specific path of the rover, in order to provide detailed terrain data that will be used to plan the rover's path to its final destination.

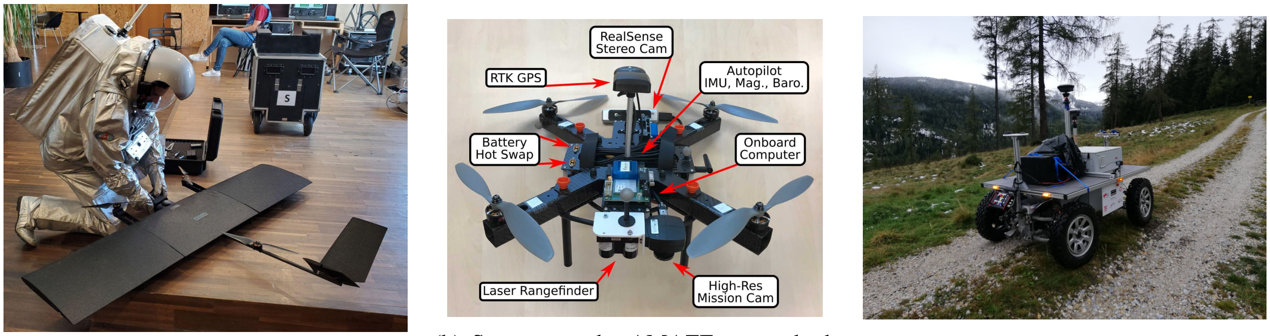
B. Lower Altitude - AMAZE

In order to obtain higher details of different zones in the area to be explored, autonomous vehicles flying at lower altitude are deployed. While higher altitude missions yield an overview of the entire area at a medium resolution, very high-resolution is sought with the low-altitude flights. In addition, specific zones deemed to be of special interest (be it for geological, biological, or other foci) require ego-motion free images and close up views. Thus the low-altitude vehicle should be able to perform hovering on specific spots at very low altitude without disturbing the environment. For the exploration cascade in AMADEE-20, a multi-rotorcraft was chosen (see Figure 1b). The platform features a high-resolution camera in the visual spectrum, a Laser Range Finder (LRF), and an Inertial Measurement Unit (IMU). While the camera also serves as science sensor, these sensors present the navigation-sensor suite to guide the vehicle autonomously from A to B including take-off and safe landing following the manually provided exploration path. We use a version of [5] extended for multiple sensors for the sensor fusion and navigation task.

A typical mission for the Autonomous Mars-Analog Zone Exploration (AMAZE) aerial vehicle is to take off from a spot defined by the analog astronauts and autonomously follow a defined route to explore in detail a previously defined zone in the area of interest. The vehicle will autonomously navigate to all waypoints only based on its on-board sensors (camera, LRF, and IMU) leveraging a feature based visual-inertial odometry framework supported by the LRF for better metric scaling. We showed the long-term autonomy of such a system in [6] as a proof of concept with GNSS signals. The minimal flight height not impacting the environment due to turbulences of the rotors is about 3m. Depending on the desired visual resolution (pixels per meter) the analog astronauts define the flight path height and special points of interest. All data is stored on the vehicle and will be retrieved by the analog astronauts after landing. The image data can be directly inspected manually and can be used for automated anomaly detection, 3D reconstruction, and other analysis. This data will support the next step in the exploration cascade to send in-situ rovers or analog astronauts to the identified spots in the explored zones.

C. In Situ - EXOSCOT

In order to provide detailed maps of an interesting area or close up inspection (e.g. visual or spectroscopy) of an interesting spot the EXOSCOT experiment adds an autonomous rover to the exploration cascade. The rover is depicted in Figure 1c and is a further development of the rover used in the privious AMADEE18 mission [7]. While in this mission the exploration and mapping relied strongly on Lidar the actual rover's main sensors are stereo cameras and IMU. The developments for the actual mission focus on three major aspects. First exploration, mapping and navigation will be transferred to a vision-based approach which is based on work presented in [8]. Here the challenge is that such approaches are well tested with data sets like KITTI but often fail in Mars-like environments. The second aspect is the rover platform itself which has been developed from scratch for this mission to provide high payload ($> 300\ kg$) to carry a wide range of instruments of other experiments, to allow long traverses (several km) to reach remote locations and to provide precise low-speed navigation (4-wheel steering with a few cm/s) to high-speed transfer (up to 60 km/h due to concepts from automotive engineering). Third on-board planning of exploration activities and a decent activity and data interface to the remote sciences support team (RSS) are of particular interest. In order to achieve these goals we developed a robust planning (based on the temporal planner OPTIC) and plan execution (based on OpenPRS) approach for the rover that is able to plan and execute advanced in situ exploration activities like performing a particular



(a) AEROSCAN during a test with an AMADEE-20 suited analog astronaut.

(b) Sensors on the AMAZE copter both for navigation and ground truthing.

(c) EXOSCOT rover with AMADEE-20 payload.

Fig. 1: The different platforms used in the AMADEE-20 exploration cascade.

measurement at a particular place and time. Data products provided by the other platform can be either utilized directly as maps for navigation purposes or are used by the analog astronauts to specify exploration activities.

IV. Discussion

The ADAMEE-20 Analog Mars Mission provides a detailed and sophisticated framework for research groups focused on planetary robots to test their systems in Mars-like realistic environments. With the natural limitations of reproducing gravity and atmospheric conditions, the topology, visual scenes, and ground material properties allow test and validation of a multitude of components on the robotic platforms and the overall robotic system itself to a great extent. More importantly, the strict operational setup given by the mission layout allows realistic tests and verification of the exploration cascade processes. This includes not only the cascade of data streams and re-usage towards finer grained resolutions and details but also the involvement of human factors during the operation of the systems and finally in-person involvement in the exploration.

Due to the pandemic, the planned efforts will be executed in 2021.

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