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DLR SpaceBot Cup 2013

A Space Robotics Competition

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Abstract In November 2013, the German Aerospace Center (DLR) in Bonn hosted the SpaceBot Cup, Germany's first of its kind space robotics competition. The scenario is set in a planetary exploration environment with some manipulation tasks. Ten entrants had eight month to define, develop, and build robotic systems and the according ground station setup to conduct a remote testbed mission. Then, the robotic element(s) were deployed onto a sparsely known planetary surface and had to conduct exploration of the environment, find and collect two artificial objects, and mount them to a third object. Communication between ground control station and planetary surface was limited and impaired by delay, making autonomous functionality crucial for the success of the mission. In this report, the motivation, scenario, tasks, and final competition event of the DLR SpaceBot Cup 2013 are presented.

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1 Introduction

In the past decades, the main focus of space robotics in Germany lay on orbital systems e.g. with the experiments ROTEX [1] and ROKVISS [2]. By 2010 though, robotics was identified as one of the key technologies to further space activities with a strong transfer potential towards terrestrial applications. Thereby it became a major objective in Germany's space strategy [3]. Based on this, a multitude of research projects and one major mission (DEOS) [4] were triggered, funded under the National Space Program. In this scope, planetary operation played and plays a vital role, resulting in a considerable built up of capability and expertise. Among others, planetary missions with a German mobility element were conceived [5], though not yet conducted.
As means of taking humans out of hazardous environments and fulfilling tasks in places, not yet reachable by manned missions, robotics increased its contribution to space research, exploration, and operations from its first steps in the 1970s to the various robotic manipulators on orbital systems and several more or less successful lander missions within our solar system. This period was also dominated by manned missions, orbiters, and deep space probes that were all closely ground controlled. The first robotic planetary missions with surface mobility, like Lunokhod [6], were bound to pure teleoperation. Since then, especially on mission level,

autonomy in perceiving, evaluating, and acting in and on the environment a robotic system is deployed into, has been experimental and not part of regular operations. In order to advance space robotics as means to support human spaceflight and to increase the scientific return of unmanned missions, it is necessary to push the envelope of hardware, software, and especially elements of artificial intelligence in this field.

The DLR SpaceBot Cup contributes to the efforts of enabling Germany in the field of semi-autonomous extraterrestrial surface mobility and manipulation by uncovering untapped potential in German industry and academia and showcasing the state-of-the-art in space oriented ground robotics. To accomplish this, typical planetary exploration and infrastructure tasks were set in a demanding mobility and communications environment. The main goals were to identify capabilities, potential, and shortcomings of the presented solutions regarding mobility, manipulation, and autonomy of the systems in order to direct future efforts. Besides the direct technical aspects, the SpaceBot Cup is also a vehicle to promote scientific, technological, engineering, and mathematical (STEM) fields and robotics in particular to a young audience and to bring industry and research from space robotics and non space related fields into contact.

2 The SpaceBot Cup

The original concept of the SpaceBot Cup was conceived subsequently to the National Conferences on Space Robotics in 2009 and 2012. The central results of these conferences are the recognition of the need to expand German expertise in space robotics to play a major role in international collaboration, focus on on-orbit servicing and exploration robotics, sustainability of research and funding effort in this area, and transfer potential between space and terrestrial applications. The competition was designed to encourage robotics related research institutes, university groups, and small and medium enterprises (SME) from the space sector to give their current work a competitive boost towards autonomous operations. At the same time, it was intended to be an outreach to robotics groups, which had no prior involvement in space technology. The initial announcement was then made prominently at the ILA Berlin Air Show 2012.

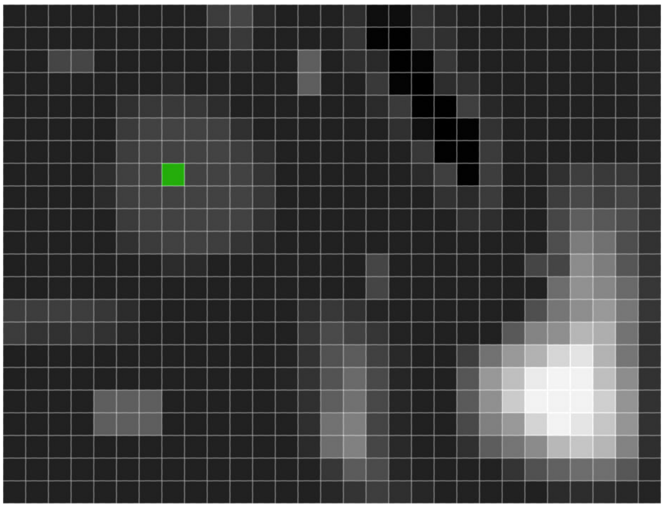

Fig. 1 The grey coded height map provided to the teams. Black is 0 m, white is 2 m. Resolution is 1 m per grid cell. Start position is marked green. Source: DLR (CC-BY 3.0)

2.1 Mission

The SpaceBot Cup mission inherits parts of planetary exploration missions, like MER [7] and MSL [8], and adds parts of possible future missions like the upcoming Exomars [9] and the Mars Sample Return concept [10]. It is designed to demand capabilities expected to be necessary or highly beneficial for such missions like mobility, manipulation, mapping, localization, navigation, and autonomous mission execution. Since these features can be generalized to some extent regarding the target surface, the SpaceBot Cup 2013 planetary environment combines demanding aspects of Earth, Mars, and Moon. The mission steps are as follows:

1. A reconnaissance mission inserts a satellite into an orbit around our model planet. Sparse a priori height maps are generated and are the basis for landing site selection. During the surface mission it serves as a data relay link to earth with periodic black outs given by orbit properties.
2. The rover(s) are then transferred through a lander mission consisting of the rovers itself and a descent platform, which provides power and a communications link between the orbiter and the surface elements.
3. The competition run starts at the end of the deployment, commissioning, and check-out phase.

The challenge of the competition was, to build an entire robotic system end to end including ground segment, surface communication infrastructure (the lander), and mobile agents between March 2013 and the competition event in November 2013. The limiting factors and their rationale for the teams were:

– The rough height map is given (see Fig. 1). [Typical orbiter / pre-landing mapping.]
– The mass limit for the surface element is 100 kg. [This resembles a reasonable mass budget for an interplanetary rover mission.]
– GPS is not available.[The target planet has an insufficient satellite infrastructure.]
– There is no direct access by the ground station crew to the surface element. [No manned mission present.]
– Communication is impaired by 2 seconds of delay in both directions and two 4 minute black outs. A detailed network description was provided. [There is a latency induced by the time a radio signal travels from Earth to the planet's surface. The value is kept low (roughly Earth-Moon scenario) to make it compatible with the 60 minute time limit. Black outs occur due to the relay satellite being below the horizon every 20 minutes.]
– Commands are only allowed within discrete 5 minute windows of which three can be used freely without penalty. [This rule limits time of direct access to the system, increasing the demand for autonomous operation.]

During their 60 minute competition runs, the teams had to execute navigation and mapping, show mobility on rough terrain, find and collect two artificial objects (a battery pack and a cup of water), transport and mount the objects to a measuring station (base station) and return to the landing site. This finding, transporting, and manipulating of purposefully designed objects is similar to what a Sample Fetching Rover would do in a two-stage Sample Return scenario, however it can also be adapted to building an outpost, operating large scientific experiments, or accomplishing tasks in disaster response back on earth.

2.2 Scoring and Evaluating

To evaluate the performance of the teams, a scoring system was devised. The basic rule is that the time needed for the run, penalties for left out tasks or irregular behaviour, and bonuses are summed up to get

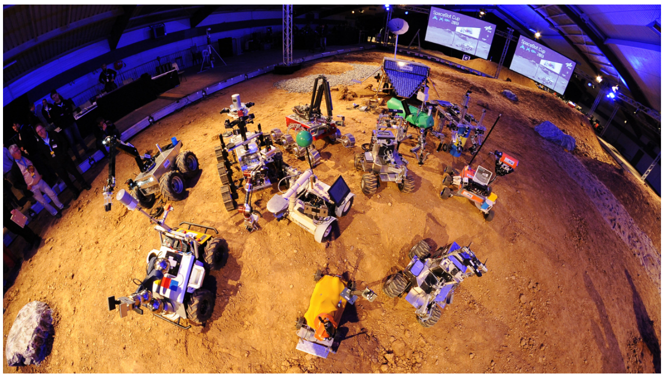

Fig. 2 Participating systems of the SpaceBot Cup 2013 Source: DLR (CC-BY 3.0)

the resulting score time (see Equation 1). The balancing of penalties and bonuses showed to be crucial to the approach the teams would choose and ran through several iterations before the final version was released to the teams. This proved to be relevant in the actual event, where decisions of some teams appeared to be score driven rather than performance oriented. Examples are not claiming a command "check point" or "human intervention" that would very likely have gained a better task completion for the cost of some penalty. This shows that further balancing is needed to support mission oriented behaviour. The scoring itself was conducted by an independent jury of five that inspected field performance as well as ground station crew behaviour (to estimate the degree of autonomy) and returned digital material from the robotic systems. The jury also had the liberty to alter the applicability of rules and penalty values to tackle unforeseen rule exploitation and loop holes, though this showed to be not necessary in the actual runs since most teams behaved rather cautious regarding rule interpretation.

$$t_{total} = t_{runtime} + t_{penalty} - t_{bonus} \tag{1}$$

2.3 Participants

Figure 2 shows all systems participating in the DLR SpaceBot Cup 2013. The teams in alphabetic order are listed in Table 1. Preceding the acceptance to the competition, the prospective participants had to turn in a four page application, describing their approach and presenting their capabilities. The applications were assessed by an internal group regarding approach, design, likelihood of success, ingenuity, and others factors. This

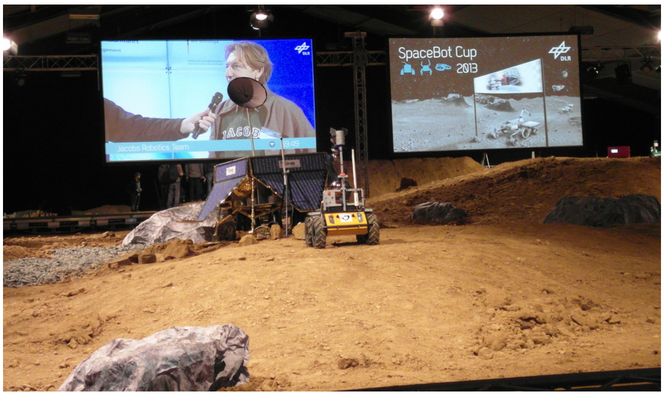

Fig. 3 The planetary surface of the SpaceBot Cup 2013. View from start to goal. Source: DLR (CC-BY 3.0)

Table 1 The ten selected teams of DLR SpaceBot Cup 2013

Team	Organisation
ARTEMIS	DFKI Bremen
Berlin Rockets	FU Berlin
Chemnitz University Robotics Team	TU Chemnitz
Jacobs Robotics Team	Jacobs University Bremen
LAUROPE	FZI Karlsruhe
Locomotec Research Team	Locomotec Augsburg
NimbRo Centauro	Uni Bonn
SEAR	TU Berlin
space-bot 21	hochschule 21 Buxtehude
SpaceLions	TU Braunschweig

process showed an overall high quality of the entries which resulted in acceptance of all ten applicants.

3 Competition Event

On November 11th and 12th 2013 all participating teams of the DLR SpaceBot Cup had the chance to test their robotic systems in the described tasks on a simulated planetary surface, set up inside a supercross hall near Bonn. Figure 3 shows the view on the field, as it was presented at the event. The teams had one and a half days to prepare and adapt their systems to the actual properties of the environment. In addition to the competition aspect of the event, a space robotics expo and a rich educational program through the DLR_School_Labs with hands-on sessions with the subjects autonomous flying systems, bipedal systems, and service robotics were established. There were in total seven groups of 121 high school students involved in these educational sessions and several more as visitors on site. This re-

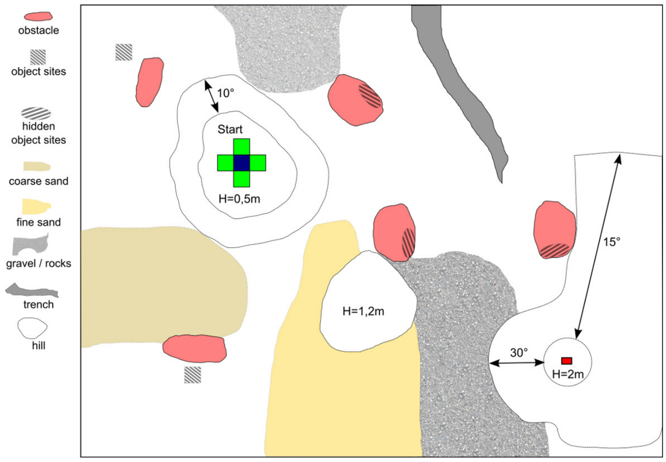

Fig. 4 Layout for the planetary surface of the SpaceBot Cup 2013. Source: DLR (CC-BY 3.0)

flects the success of the public outreach effort as well as the interest of the general public in robotics and space related subjects.

3.1 Setup

The simulated planetary surface (21 m by 21.5 m) was built like a supercross track with the given layout (see Fig. 4). Features like soft sand, gravel (several cm), rocks (several tens of cm), and artificial boulders (around 2 m) were added subsequently. Two ground control stations were set up in parallel in office containers outside the building. The LAN connection between ground station and the landing site was routed through a separate computer, called Network Emulator and set inside the ground station, where the delay and other network restrictions were managed (e.g. 2 s delay per direction, 100 MBit data rate, one port each for telemetry / telecommand). On the field, the teams connected their communications equipment to the network emulator through a switch, positioned at the landing site. Power for the on-site equipment was provided at the lander mock up with a rule limit for current of 3 A throughout the run. This was intended to simulate the limited ability of a landing vehicle to provide power for surface operations, though it was never exceeded during the competition. The robotic systems started at the landing site with one of the collectable items and the base station in unobstructed line of sight. The second collectable item was hidden from direct view, ground or air, but accessible. The hidden object was placed

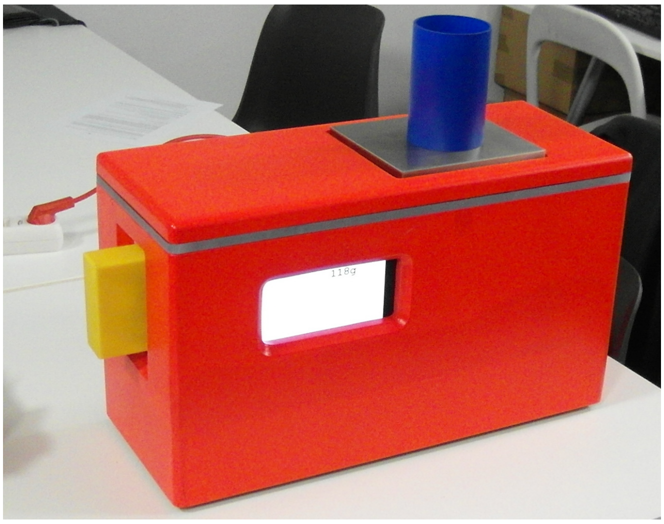

Fig. 5 The fully mounted object assembly in goal configuration: Battery pack (Length x Width x Height: 200 mm x 40 mm x 100 mm) inserted, cup (Diameter x Height: 80 mm x 120 mm) placed on scale on top of base object (LxWxH: 400 mm x 200 mm x 300 mm). Source: DLR (CC-BY 3.0)

inside an open cavity of one of the artificial boulders. After exploring and collecting the objects, the simulated battery pack (yellow cuboid) had to be inserted into a hole in the base object. The cup of water (blue cylinder) had to be placed on top of the base object, to measure its weight. The goal configuration is shown in Figure 5. The final task was to flip a switch on the base object. Successful return to the landing site or running for 60 minutes concluded a competition run.

3.2 Competition

During the two days of the competition, every team had to struggle with some sort of unforeseen errors, glitches, and malfunctions. In the end, six teams were not able to move away from the start zone successfully. Four teams accomplished a considerable distance of travel, without completing the mission. The two teams using aerobots (quadcopters in this case) managed to start them, though nominal operation was not established. One team was able to pick up one of the artificial objects. One team had to quit due to mechanical malfunction. A first feedback session showed that there seemed to be not one singular failure mode for all systems, but very individual sets of influences, which resulted in an overall draw. The jury did not derive a ranking.

3.3 Open Field

The second day was concluded by one hour of open field operation, where every team had the chance to test their vehicles with direct access. Here it showed that all systems had the capability to accomplish most of the tasks set in the DLR SpaceBot Cup 2013.

4 Conclusion and Future Work

The jury decided that the teams presented impressive and capable systems. Nevertheless, the performance on the field was too diverse to derive a proper ranking, so the teams were honoured as participants of the DLR SpaceBot Cup 2013. This resembles a similar decision, made after the 2004 DARPA Grand Challenge, where only a few contestants managed to leave the start area. For the DLR Space Administration and the teams, the competition and the concluding event were a valuable experience and gave important directions for future work. Currently, the event is being analysed to shape a proper way of exploiting the results. An impression of the work done by the teams and the event can be found on the SpaceBot Cup website [11] and the DLR YouTube channel [12] (German language).

Thilo Kaupisch received his B.Sc. and M.Sc. in Systems Engineering from the University of Bremen in 2008 and 2010. After having worked on underwater robotics, electric mobility, and space robotics at the German Research Center for Artificial Intelligence (DFKI), he is now a project manager at the Department for General Technologies and Robotics at the Space Administration within the German Aerospace Center (DLR).

Daniel Noelke received his Diploma (M.Eng.) in Mechanical Engineering with specialization in Aerospace from the RWTH Aachen University in 2002. During six years of working as scientific engineer at the Institute of Lightweight Structures at the RWTH University in the fields of structural optimization and space debris, he extends his expertise in this fields. He was able to gain a position as project leader of different scientific projects at the institute and leads interdisciplinary scientific working groups in the field of aerospace at the university. After this he joined in 2009 the Department of General Technologies and Robotics at the Space Administration within the German Aerospace Center (DLR) as project manager.

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