DLR SPACEBOT CAMP - THE EVOLUTION OF GERMANY'S SPACE ROBOTICS COMPETITION

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ABSTRACT

In 2010 Germany's Ministry of Economics and Technology formulated the goals for a competitive and sustainable space strategy[1]. One of these activities regarding planetary exploration rovers, the DLR SpaceBot Cup, was presented at ASTRA 2015[5]. In this follow up we describe the evolution of of DLR SpaceBot Cup into DLR SpaceBot Camp 2015 and its implications.

Key words: Planetary Robotics, Field Testing, Robotics Competition.

1. INTRODUCTION

Following the National Robotics Conferences in 2009 and 2012, the German Aerospace Center (DLR) developed and announced the DLR SpaceBot Cup as a national space robotics competition. The goal of this activity is on the one hand a better understanding of Germanys state of the art in academia and industry, relevant for space robotics. In its role as space administration, DLR has to know where strength, weaknesses, and technological gaps lie. On the other hand, DLR SpaceBot Cup is supposed to kick-start efforts to fuse singular technologies into working designs, ready to be benchmarked.
Compared to its premier in 2013[3], the DLR SpaceBot Camp 2015 implemented changes, for example in project scheduling (see figure 1), team support, and scoring approach, made according to conclusions from the lessons learned of the 2013 event and in comparison to other events. Competition rules and scoring in particular have a strong influence on team behaviour and the conditions the participants and systems perform under. Performance benchmarking and scoring was influenced and incorporated experiences made by several predecessors as e.g. the ESA Lunar Robotics Challenge[2], RoboCup and several EU projects (euRathlon, RockIn)[4].

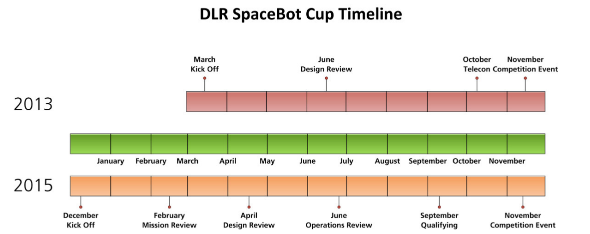


Figure 1: Timeline of the DLR SpaceBot Cups 2013 and 2015

2. DLR SPACEBOT CUP

DLR SpaceBot Cup came into existence as a probing tool for Germany's robotics community to identify the accessible state of the art. Since a major part of the desired capabilities for planetary exploration lies in the field of land robotics, the calls for participation were intentionally addressed at land robotics and not exclusively the space robotics community. In order to achieve validity, a series of requirements had to be fulfilled by both the competition environment and the teams: Exploring mostly unknown demanding terrain, perform mobile manipulation on known partly hidden objects, deal with a delayed and impaired communication link, and finishing in a limited time frame.

The result of this work was a mission design with a rather complex rule system, based on bonus points and penalties, and a demanding terrain with varying surface features (see figure 2). In the short period of just 9 month all ten teams designed, built, and prepared promising systems and arrived at the DLR SpaceBot Cup 2013. The results came back inconclusive. From case to case different and sometimes tiny malfunctions in the systems' complex designs allowed only a few teams to actually explore the surface to a reasonable extent in their respective competition runs. A follow up open field after the main competition showed very promising functionality of the systems. The subsequent analysis of the event[3] and lessons learned led to a major overhaul of the SpaceBot Cup for its continuation.

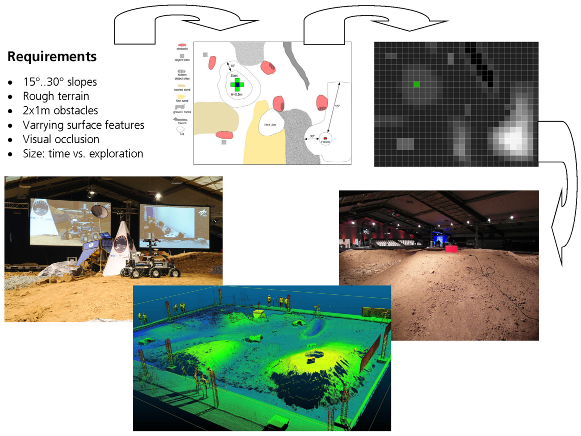


Figure 2: Building a Planet: The terrain of SpaceBot Cup 2013, Source: [Photos]DLR (CC-By 3.0), [3D Scans] RWTH Aachen MMI

3. DLR SPACEBOT CAMP 2015

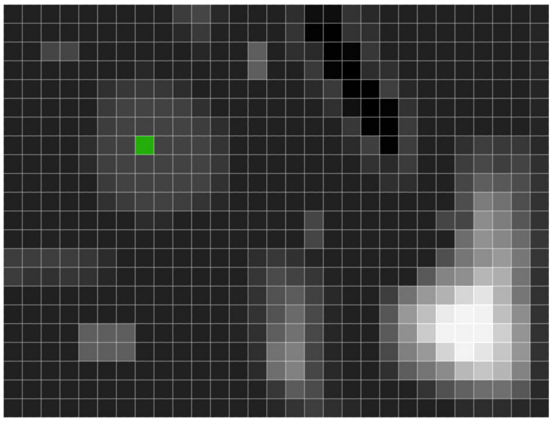
In mid-2014 DLR Space Administration announced the second round of the SpaceBot Cup. Out of a pool of applicants, ten teams qualified for participation: Uni Koblenz-Landau, DFKI Bremen, Uni Tübingen, Uni Kassel, TU Chemnitz, FZI Karlsruhe, Uni Bonn, DLR RM Oberpfaffenhofen, TU Berlin, hochschule 21 Buxtehude. The scenario inherits strongly from DLR SpaceBot Cup 2013[3].
As described before, the main updates are the schedule described in figure 1 with a rigorous qualification test, the chance to perform soil sampling as opposed to carrying a cup of water, and moving towards a crater like scenario, although many other changes were implemented as well. This section discusses some of the central aspects of the 2015 event.

SpaceBot Camp 2015

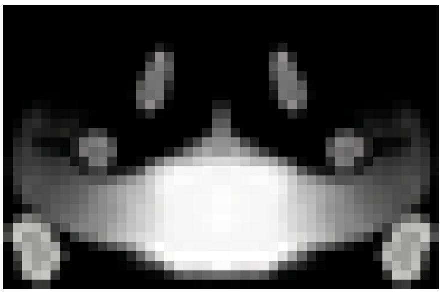
Figure 3: DLR SpaceBot Camp 2015, Source: DLR (CC-By 3.0)

3.1. Schedule and team support

The most noticeable change, compared to the 2013 event, is the pacing of events, as it can be seen in figure 1. Preparing an entire robotic system including electric, mechatronic, eletronic, and software subsystems, in some cases from scratch, can be hard and time consuming. This can lead to neglect in testing and subsequent poor performance during competition runs. Extending the time frame to work on their solutions from 9 to 12 months helped make room for exactly this. Testing effort increased and the number of non-recoverable system failures in qualifying and the competition basically dropped to zero. Other measures to promote strict project management and a clear understanding of the mission scenario were several on site reviews with each team (Mission Review, Design Review, Operations Review) and a half day workshop on tackling robotic operations under time delay and unreliable network conditions.



(a) Height map 2013



(b) Height map 2015

Figure 4: Comparison between SpaceBot Cup 2013 single field (top, 22 m x 29 m, 1 m resolution) and 2015 double field (bottom, 15 m x 23 m, 50 cm resolution) height map (black represents 0 m, white represents 2 m), Source: DLR (CC-By 3.0)

3.2. Terrain

Although the surface of the DLR SpaceBot Cup 2013 contained all aspects we wanted to see in a planetary exploration analogue scenario (size for exploration, several substrates, varying slopes, obstacles, etc.), from an organizational point of view it was too bulky and could not be exploited by most systems. The redesigned terrain still contained all the features, apart from surface area, to let the systems show their capabilities. At the same time, splitting the field in two halves allowed for interchanging performance runs on one half and preparation on the other half (see figure 4). This effectively let us shorten the event from two days into one while still allowing full 60 minute runs for each team.

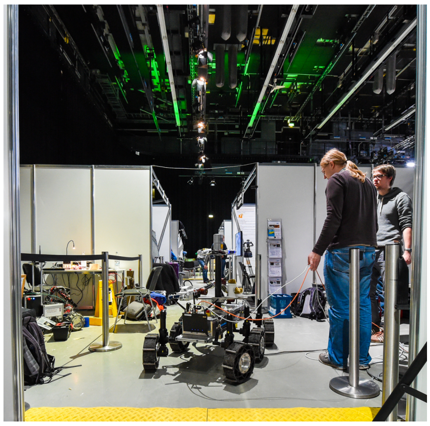
Figure 5: DLR SpaceBot Camp 2015 qualification event. Field size 10 m x 10 m, Source: DLR (CC-By 3.0)

3.3. Rules and scoring

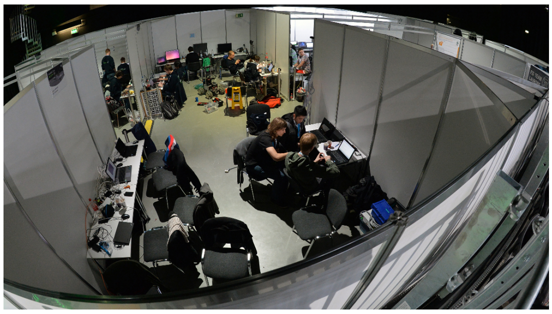
Scoring and benchmarking are ongoing activities, that need to be well refined to meet the requirements of the event and to give conclusive results from the robotic system test runs. The scoring system needs to be tuned to not evoke "score hunting" behaviour that deviates from the core mission. Since there was no official ranking in DLR SpaceBot Camp 2015, the teams behaved very mission focused. Another factor promoting mission oriented behaviour was that the self scoring sheet to assess mission success was simplified and reduced from five pages in 2013 to just one page. Successfully solved mission tasks scored one point, equal points could be compared against saved communication windows, run time and manual interventions. A derivative of this system is considered to be the base for any upcoming SpaceBot-like competition.

3.4. Qualification

The "pre-flight test" two month before the main event showed to be a true revelation. The positive outcome was that every team identified shortcomings in their systems that, to a great extent, could be mitigated for the November 2015 event. Further, the qualification event was designed to be a test that the systems could fail. The requirement to master all three demo tasks (motion/object identification, planing/gripping, pick up/transport) on a small test field (see figure 5) however showed to be a very hard limit that did not allow for even minor mistakes. Subsequently also very promising teams failed this test in one way or the other, only two teams managed to fulfil the whole scenario. The way the rules were set up, it was not possible to relax the requirements for qualifying in a fair and unbiased manner with the goal to have a meaningful competition event. It was finally decided to carry on all ten teams into a performance test without ranking, now called "SpaceBot Camp" and to carry the experience on into a more robust organizational structure for the future.



(a) Pit lane



(b) Work space

Figure 6: DLR SpaceBot Camp "pit lane" style ground control stations and work spaces, Source: DLR (CC-By 3.0)

3.5. Work environment

Although one could assume that teams arrive at a competition with ready-to-go systems, that is rarely the case. Since basically every aspect of the robotic systems is ongoing research, organizers have to acknowledge and accommodate for maintenance and testing on site. The approach for DLR SpaceBot Camp 2015 was to arrange for a "pit lane" (see figure 6), that combined work shop, ground control station, and storage. Nothing had to be changed from preparation to competition run since every booth could be connected directly to the managed time delayed "mission network" and had no direct line of sight to the fields. For the main event this also gave the opportunity for visitors to observe operations without causing too much disturbance. Additionally the teams had time for settling in and preparing their systems. Two days appears to be a good rule of thumb for this and comparable events.

3.6. Planetary analogue mission "SpaceBot"

The mission of DLR SpaceBot Camp 2015 can be considered the general "SpaceBot" scenario. Planetary rovers of up to 100 kg mass have to explore a sparsely known planetary surface (see figure 7a) with various features like slopes up to 30°, boulders, cobbles, pebbles, gravel, sand, and pits or trenches. Lighting conditions are favourable and an opaque fence limits the field. All systems have to connect to a ground control station through a managed network connection that introduces a 2 s time delay, port restrictions, and occasional black-outs. Earth specific navigation like GPS is not allowed. Under these conditions the teams had 60 minutes each to find and collect a cup with soil sample and a battery pack (see figure 7b), and carry them to a mock-up science experiment (see figure 7c). Optionally, teams could take the soil sample themselves with a chance of extra score (see figure 7d). The 2015 event showed that the design of the terrain, the rules, and the working conditions worked well together, so that all teams showed very good performance. Four teams could achieve all mission goals before time-out, which is another indicator that requirements and conditions were set closely to the given technological and organizational limits, without being unnecessarily hard.

3.7. Lessons Learned

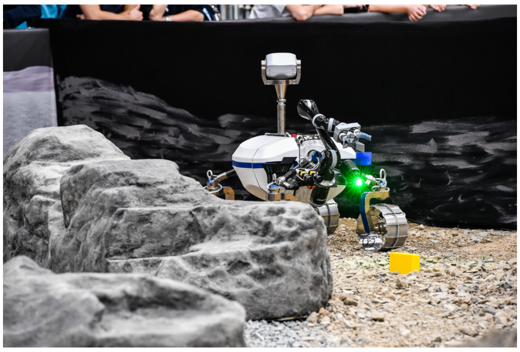
Working on DLR SpacBot Camp 2015 was an almost two year activity for DLR Space Administration and, including application phase, almost one and a half year work for the teams. Everyone benefited from the experiences of DLR SpaceBot Cup 2013, organizers, new entrants, and veteran teams alike. Yet, the learning curve for competitive robotics testing in planetary analogue environments is still steep. We selected a few valuable lessons that we will take as starting points for further improvement.

- The good...
  - Time - From our experience, 12 month preparation time can be considered a sweet spot for a large challenge event with complex mechatronic and computer science tasks.
  - Testing - Feedback from teams, documentation, and review meetings showed that every team devoted a sufficient amount of time to testing with the expected positive outcome regarding system performance.
  - Communication - A dedicated training event for the communications infrastructure and an open thought exchange between teams helped to solve all major issues with delay and bandwidth restrictions.
  - Qualification - Demand a ”hot fire” test that bears the risk of failure well in advance.
  - Work environment - Give teams space, time and resources to work on site.
  - Terrain - Although the terrain shrunk in size to 13 m x 15 m for each team, all necessary functionalities could be tested.
- The (kind of) bad...
  - Qualification - Having a hard limit on qualification is risky, in the end most of the entrants could fail if the rules are not well balanced. A mixed approach with fixed competition slots (best in, no matter the score) and extended slots (are added, if teams exceed a score threshold) seems to be a reasonable trade-off between mitigating organizational risk and high technological demands.
  - Single Use Terrain - The downside to the freedom of design of a single use terrain is cost. A significant amount of the event’s cost went into rent of the indoors venue and building the terrain. This could be mitigated by using a permanent controlled planetary surface environment like a large rover test bed or the upcoming ESA LUNA facility.
- The ongoing tasks ...
  - Scoring / Benchmarking - Rule books are hard. If rules are too specific and complicated, using loop holes becomes attractive to the teams. If they are too vague and maybe weak, the rules become unusable for judges and the results lose their significance. Give freedom, but define limits and scores precisely and comprehensively.

4. DLR SPACEBOT NEXT

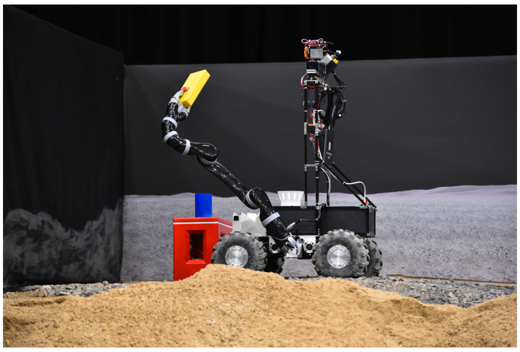
The results of DLR SpaceBot Camp 2015 are promising both on the technological and scientific side as well as the competition design side. A follow up event was designed to incorporate the lessons learned of the previous events to arrive at a point where the series of SpaceBot events would be lasting, sustainable, and inclusive. Every list made now cannot be exhaustive, but is rather a guideline. Starting point would be the design of the 2015 event regarding organization, rules, and environmental conditions as well as the lessons learned. The outline of a future SpaceBot competition would then be as follows:

- Establish a comprehensive qualification process - Adjust the qualifying event in a way that a subsequent competition event remains feasible. One way would be to apply a mixed ”best score + minimum score” slots approach as described in the previous section.
- Planet SpaceBot - Find / establish a permanent venue to fine tune environmental conditions and make results comparable from event to event.
- Get international - Organizational restrictions make it hard to host an international robotics competition as a national space agency. Nevertheless, a next SpaceBot-event would benefit greatly from European or even worldwide interest and participation. First steps would be to find partners and associations that promote robotics competitions and space robotics.
- Remain challenging - Any future event should adjust to technological advances in a reasonable way. If



(a) exploring unknown terrain

(b) identifying artificial objects



(c) assembling experiment setup

(d) taking soil samples

Figure 7: SpaceBot Camp 2015 - Mission tasks, Source: DLR (CC-BY 3.0)

one domain is solved to a certain extent, shift focus to harder tasks e.g. autonomous decision making, unfavourable lighting conditions, etc.

- Produce increasingly meaningful results - The scoring and benchmarking should mature over time in a way, that the gap between a system's performance in the artificial SpaceBot-test and actual working conditions get smaller each time.
- Be fair - A performance test culminating on a single point in time is intriguing, nonetheless can give misleading results about a concepts true capability. The competition should reserve room for mistakes and glitches. Multiple runs should be granted, if it benefits all teams and does not distort the test results.

The current design for the next event assumes usage of a facility like ESA's LUNA in cologne. The mission will be spread over three "mission days". On the first day, ten teams will compete in a cube rover challenge, that explores a system of underground tunnels. This task is supposed to act as the international outreach, since the demand on the hardware will not be as high and costly as for the SpaceBots. Second and third day are SpaceBot mission days, when ten different teams land their much bigger systems on the planetary surface. This gives us the opportunity to grant every team two runs, although they are basically working on one mission. Mishaps on day 2 can be mitigated for day 3.
Any future event, of course, has to be aligned with the needs and requirements of its stakeholders and play a beneficial rule in Germany's space program and the ongoing international space exploration effort.

5. CONCLUSION AND OUTLOOK

The DLR SpaceBot Cup evolved over two iterations into an efficient tool for probing Germany's robotics capabilities and more. It sparked development and educational opportunities in space robotics, brought the subject to a broad audience, and generated valuable insights for Germanys Space Administration. The observed increase in performance from 2013 to 2015, besides the actual skills of the participating teams, can be attributed to a more favourable competition environment and more comprehensive rules. Briefing the teams on the special communications environment and having their systems tested well prior to the event helped create a better understanding of the mission requirements.
In November 2015 the DLR SpaceBot Camp was conducted as a performance review. All in all, the main event and the 12 month that led to it had an insightful outcome for DLR Space Administration. We gained a clearer picture of what could be done with today's technology and state of research for planetary space robotics and where gaps lie that need to be addressed. Furthermore, the whole event acted as a kick starter for several working groups to push their robotics research into a direction, that serves space and terrestrial applications alike.
The number of scientific publications, graduating theses,

Figure 8: Participants of SpaceBot Camp 2015, Source: DLR (CC-BY 3.0)

and overall participants; the feedback from companies, research community, and involved staff; the well received public outreach; are promising indicators for the demand for robotics competitions and their benefit to technology and the community.
The next event has the potential to build on a matured competition platform to test planetary robotics and push the boundaries of integrated robotic systems through a demanding environment and collegial rivalry in the research community (see figure 8). Right now the feasibility of further events is being evaluated.

ACKNOWLEDGMENTS

Work conducted by the teams on their contributions to this competition is funded by the German Federal Ministry for Economic Affairs and Energy, grants 50RA1411, 50RA1412, 50RA1413, 50RA1414, 50RA1415, 50RA1416, 50RA1417, 50RA1418, 50RA1419, and 50RA1420

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