Mobile Robot Competition

Underground Mining: A Challenging Application in Mobile Robotics

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Abstract—**This paper presents the history, current position and future aspirations of the mobile robot competition. It has been run for a number of years in the past under the guidance of National Instruments as an undergraduate competition for National Instruments based software and hardware. By 2011 it has expanded to include all levels of academia, is no longer limited in the hardware or software architecture or supplier, and also includes postgraduate students. There has also been an interest from hobbyists and industry to participate and the 4th Robotics and Mechatronics Conference of South Africa has agreed to play host to the competition.**

As underground mining is such an important research field for robotics in South Africa, the competition has taken on an underground mining theme, and is being coordinated by the Council for Scientific and Industrial Research's Center for Mining Innovation. As such, all the Tasks are indicative of a Task that an underground mining robot could feasibly execute. The competition aspires to grow in subsequent years in size and complexity as the universities and their teams grow in capability. In this way, the human capital moving into mining robotics will grow in number and capability, so supplying an expanding market.

Keywords- mining robots; robot competition; academic competitions; ROBMECH 2011

I. INTRODUCTION

Competitions form a valuable tool for academic institutions in directing their research and scholarly endeavours. They provide clear guidance for students and have a fixed deadline by which a working prototype must be presented. Famous examples are the now discontinued Darpa grand challenge [1] and Robocup [2], the international competition for soccer and urban search and rescue (USAR). The Cyber Junkyard competition by Siemens [3], Festo and Lappcable is focusing on renewable energy autonomous vehicles in 2011, and is supported by eight local university and college teams and three international teams. There are annually more than 133 robot competitions globally [4] ranging from aerial, to ground-based, on water and underwater. It is of significance that while the winning team does get much recognition, all the competing teams benefit and contribute to the progress in robotics research [5], often extending beyond the life of the competition [6].

The Mobile Robot competition aims to provide such direction and motivation to South African robotics research institutions by presenting a competition to be held on November 24th 2011 at the Robotics and Mechatronics Conference of South Africa (ROBMECH 2011 [7]) at the Council for Scientific and Industrial Research's (CSIR) International Conference Center. As mining, particularly gold mining, is struggling with increasing costs mainly because of decreasing grades and increasing mining depths, there is an opportunity to use mining as a focus for this competition and thus promote mining robotics in South Africa. This will enable both the development of technology to meet the challenges facing deep level mining, and also generate the human capital to meet what will become an expanding market in an already skills-scarce mining industry.

The Mining Houses' vision of what future mining holds supports the need for a focus on mining robotics. The words used by them focuses on automation and remote control or tele-operation where the operator is no longer near the vehicle, but instead needs sensors on the vehicle to indicate what the environment looks like, potentially assisting with the execution of actions, such as following a tunnel as the Sandvik Automine product [8] is designed to do.

Angle American has a vision 2030 strategy [9] that describes what they feel are the important areas that need focus. Technology forms a significant portion of this vision, and automation and remote control comprises one of three focus areas. The end goal is a mine where intelligent autonomous robots are standard and intelligent machines perform the activities.

Anglogold Ashanti has also launched a significant initiative in the development of a continuous mining system, with people-less stopes, that mines every day, all day [10] which will be needed to make deep mining sustainable in the future. They are attempting to achieve this through a world-wide technical consortium to introduce automated blast-free continuous mining at the Mponeng gold mine, the deepest mine in the world .

II. History

A. The Start by National Instruments

National Instruments (NI) held its first robotics competition in 2008 with the aim of supporting the marketing and implementation of their equipment in South African academic institutions. It was arguably the most successful one to date with six teams competing on the day. The University of Johannesburg (UJ) and North West University (NWU) each had two teams, while a single team from each of The university of Pretoria (UP) and Tswane University of Technology (TUT) had robots at UP's High Performance Center, where the competition was held. The rules of the competition remained unchanged in 2009, and the same institutions were invited to send teams to that years' competition. For various reasons, only teams from TUT and NWU were able to present robot entries at the CSIR campus in Pretoria where the competition was hosted as part of an NI symposium.

The rules remained unchanged for the first three competitions, 2008, 2009, and 2010 as well. The entries were limited to undergraduate students completing their engineering degrees, and their contribution to the competition therefore usually formed the foundation of their final year projects, as required by most South African universities.

B. Center for Minning Innovations becomes involved

The 2010 competition was held at a mobile robot symposium in Melville Johannesburg [11], hosted by the CSIR's Center for Mining Innovation (CMI). The symposium was convened specifically to host the competition, with the goal of presenting some current research on mobile robotics in the morning session. The teams then unveiled their robot entries in the afternoon session with a 10 minute presentation before competing.

Presentations were given by J Green (from CMI) on Mining Robotics as a South African research opportunity [12,13], F du Plessis on the Solar challenge 2010 entry by UJ, and Wayne Du Preez from NI presented a suitable hardware and software architecture for the robot, together with demonstrating a data logging remote controlled vehicle.

Each team was required to present their robot, together with a short presentation about the work, before attempting to execute the Tasks of the competition. The Tasks were of a materials handling nature involving uniformly-sized boxes. Barcodes uniquely identified each box which needed an action performed on it. The Tasks ranged from weighing and stacking lightest to heaviest, to a speed test moving a box between stations, to inserting a box into a pigeon hole defined by the barcode.

A DebTech/CMI demonstrator robot from 2010 showed what could be achieved at low cost for the platform [14] and lunch time attention (with some late nights close to the demonstration). This robot used the NI robot platform with the 180 day license for all the tool boxes needed for the robotic application. Lego Mindstorm was used for the additional structures needed, and a web cam and netbook were used for the programming and image processing with NI Labview software.

Figure 1. Demonstration robot by De Beers, DebTech and CMI in 2010.

C. Learnings

During the three years of competition, it became apparent that the universities struggled for continuity from year to year. Each year new students were put onto the project. They elected to start from a clean sheet of paper, rather than build on the previous year's efforts. The limitation of the competition to final year students encouraged this approach, hence the shift in 2011 to include post graduate team members. This clean slate approach was also encouraged by keeping the Tasks the same from year to year, and maintaining the relative simplicity of the Tasks, implying that building on prior experiance was not required. These points fed into the formulation of new competition criteria that would encourage post graduate participation, and encourage more tertiary education institutions to take part as the competition grows.

III. Current format

The competition in 2011 has taken on a number of new aspects. The move away from an NI-based platform is perhaps the most significant. All hardware and software architectures are now able to enter. The hope is that more suppliers of equipment suitable for entering the completion will begin to partner with universities and teams, thus expanding the support and funding to the competitors.

The expansion to include post graduate team members is the next most significant change to the competition format. The rationale behind this change is to begin to create some continuity at the universities so that the team can grow from strength to strength yearly. The multi-year commitment of post graduate students enables a transfer of knowledge amongst students, thus enabling a multiyear research effort to be successful. The complexity and difficulty of the competition can then also grow as the teams master the initial challenges presented to them.

A third significant change is the theme of the competition. Materials handling, the previous theme, is already a global robotics focus area. South Africa, as a relatively small and fledgling robotics research participant, cannot start competing

globally against established much larger and better funded research teams. Mining robotics, however, is an area where there is potential to add to cutting edge research, particularly in underground robotics which has received little attention by the rest of the robotics world. South Africa has a unique need for small automated machines to work underground in the extremely dangerous and dirty environments of the deep hard rock mines [15]. The mines are getting ever deeper it is speculated that and with current mining methods they will no longer be profitable by 2020 [16]. This is a unique opportunity in robotics that the rest of the world had no need to solve. We have a unique South African problem requiring a unique South African solution.

CMI has realized this and is now a significant supporter of the competition. The support will be multiyear to drive the research into mining robotics. The intention is not only to develop technology that could be transferred into the mining environment, but also to develop the human capital needed to sustain the underground mining robotics industry as it grows and flourishes.

A. Criteria for entry

While the competition is primarily aimed at academic institutions in Southern Africa, it seeks to be inclusive rather than exclusive. Any robot fitting into the arena will be welcomed into the competition to attempt one or all of the Tasks. If a competitive entry is not suitable, i.e. from a company and not a university, then a demonstration robot can be presented during the ROBMECH 2011 conference. This was the case in 2010 when De Beers (DebTech) and CMI entered a demonstration robot (shown in Figure 1) into the competition.

The competition is no longer exclusively for NI equipment and software. All hardware architecture and all software for control are welcome to submit a competitive or demonstrative entry.

B. Competition classes

There are two competitive classes of entry in 2011:

- Autonomous: where the vehicle executes the Tasks independently of human control. Potentially with a restart between Tasks to execute different software algorithms for each Task.

- Tele-operation: or remote control, where the operator will not have direct sight of the vehicle, and the vehicle does not control its movements independently. The operator needs to rely on robot sensor feedback via wireless communications, to determine the control actions to take to execute the Tasks.

The autonomous entry attracts double points for successfully achieving a Task without human intervention. This is achieved by the imposition of a 50% point penalty for any human intervention required in the execution of the Tasks (i.e. as in tele-operation).

C. The competition arena

The competition field will be approximately 5m x 5m. The intention is that the robot will have control feedback onboard, as well as some autonomy, so the exact dimensions of the field will not be divulged. An approximate map will be available for use in path planning, and for Task 5 if Task 4 is unsuccessful (see Section III.D for Task descriptions).

The purpose is to ensure that the robots do not use dead reckoning as the sole navigation method in the execution of all the Tasks.
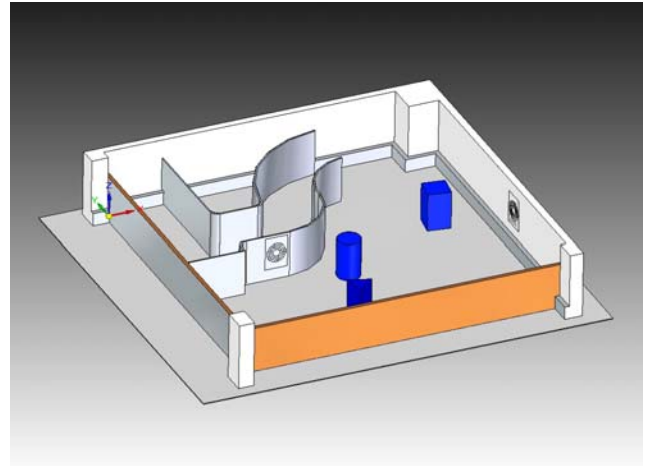

Figure 2. Arena approximation

The sides of the arena will be at least 400mm high, and may be the side of a room as in Figure 2. The starting area will be a cordoned-off area in one corner (far left in Figure 2), with a curved exit that the robot will need to find and follow. This 'tunnel' will exit into the rest of the arena. The arena will have a wooden floor, enabling skid steer and tracked robots to operate.

Obstacles will be randomly scattered in the area for the robot to navigate around. They will be repositioned for each team and will be round, square and triangular and at least 400mm high. Contact with the obstacles, while not attracting penalties, will move or knock over the obstacle resulting in a potential incorrect map in Tasks 4 and 5, as well as undetectable obstacles lying on the floor that could hamper further locomotion in the arena.

The targets for tasks 2 and 3 will be pasted at random positions on the walls of the arena, different for each team. More details are provided in Section III.D.

D. Competition tasks

There are five tasks for the competition. They can be attempted in any order, and can be completed in parallel, i.e. Task 4 could be completed first, while Task 5 is in essence executed in parallel with all other tasks, completed when the last of Tasks 1,2 and 3 are completed.

Should a task be failed, either because the time limit is exceeded for that task, or the robot has become 'stuck', the team can physically move the robot to a new position, and

reset/restart it for the start of the next task. This is subject to the overall time limits of 20 minutes in the arena, and the associated penalties for human intervention.

1) Task 1

The first task starts with the robot in the starting pen which has only one exit. It will need to locate the exit of the pen, which is the entrance to the tunnel, and follow the tunnel into the larger arena area.

This simulates a mining robot moving autonomously along an underground tunnel. Contact with the tunnel walls attracts penalty points for each occurrence. This task has a 10 minute time limit.

2) Task 2

Once in the arena, the robot will need to locate the four targets randomly located on the walls. The targets will be repositioned for each team at the beginning of the task. The target will have four concentric circles with 15, 20, 25 and 30cm diameters. The robot then needs to make a mark on each of the targets as close to the center as possible. The targets will all be identical, but will be at varying heights on the wall, with centers between 15 and 25 cm above the floor. Teams may provide their own targets meeting these criteria to ensure minimal problems with image segmentation.

This simulates a mining action of the robot, mining out a pre-marked portion, or drilling in a pre-defined position. The robot will need to identify the target, determine how to approach it and then execute the planned path.

3) Task 3

Task 3 will involve marking a grid onto an A2 sized sheet of paper that is on a pre-defined area of wall in the arena. The grid must be 3 X 3 dots and simulates the autonomous marking of drilling holes on the mining wall. The exact dimensions of the marks are not important, but they need to be evenly spaced, marked one at a time, and larger that the pre-defined minimum. (10cm between holes).

4) Task 4

The penultimate task will be to create a map of the arena environment. This can be executed while completing the previous tasks, or as an additional task, potentially completed first using a random wandering exploration algorithm.

5) Task 5

The final task will need to be completed while the other Tasks are being executed in that the path travelled for Tasks 1, 2 and 3 needs to be recorded and plotted on a map (either the map completed in Task 4, or onto the approximation supplied upon confirmed entry to the competition).

E. Task grading

Tasks will be graded as follows:

There is a 50% penalty for human intervention in Tasks 1, 2 and 3. i.e. tele-operation immediately attracts a 50% penalty. For autonomous entries, if, for example, the robot gets stuck against a wall, the operator can enter the arena and 'rescue' it incurring a 50% penalty (see note at end of this section).

Task 4 and 5 outputs need to be submitted 15 minutes after the end of the 20 minutes in the arena to allow for post processing of stored data (especially necessary in the case of tele-operated entries).

1) Task 1: Tunnel Navigation - 40 points

Points will be awarded in Task one as follow:

- Successful identification of the exit - 10 points.
- Successful entry into the tunnel (no part of the robot left in the starting enclosure) – 10 points.
- Successful navigation though the tunnel - 20 points awarded in 5 point increments. 1 point penalty for each wall collision, to a maximum of 20 collisions, i.e. 0 points for this portion of Task 1.

Human intervention will result in a 50% points penalty for all points earned subsequent to the intervention.

2) Task 2: Marking the targets – 40 points

Points are awarded for each of the four targets, i.e. 4 x 10 points

- successfull identification of the target - 4 points
- accuracy- 0,1,2, 4, or max 6 points depending on the accuracy of the mark on the target (Figure 3).

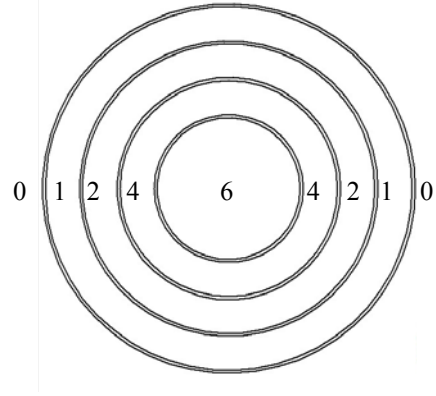0 1 2 4   6   4 2 1 0

Figure 3. Approximation of the target. Six points for a bulls eye with reduced points allocation for consecutively larger rings. Largest ring is 30cm

The mark must be such that it can be evaluated at the end of the competition (i.e. not a laser pointer, it must leave a lasting impression).

3) Task 3: Grid Marking – 40 points

Points are awarded for successfully making each of the nine required marks in the grid pattern. Three points for each of the nine marks for a total out of 27. The remaining 13 points are awarded for the evenness of the grid pattern, keeping to the minimum of 10cm between marks. I.e. The minimum grid must be at least 30 x 30cm in size and the largest must fit onto the supplied A2 paper for evaluation after the competition.

4) Task 4: Map Creation - 40 points

This will be determined as a ranking system for all the teams competing. The best map will achieve 40 points with subsequent teams in five point decrements. 1st=40, 2nd=35, 3rd=30, 4th=30 etc. If more than eight entries are received, the encrements will be adjusted accordingly. There will be no penalty for tele-operation in this Task. Late submission past the

allocated time limit will attract points penalty of 5 per minute to a minimum of 0 points for the Task.

5) Task 5: Course plotting – 40 points

As with Task 4, this will be a ranked task with decreasing points awarded for each position, the best result scoring 40 points. There will be no penalty for teleoperation in this task.

NOTE: Human intervention implies any assistance from a person. Tele-operation for Tasks 1,2 and 3 is classified as human intervention. A team can decide to conclude the task prior to 'rescuing' a stuck robot for an autonomous entry. This will not be classified as human intervention, rather a robot preparation for the next task. It will count in the 20 minutes allowed for the Tasks – not the 10 minute preparation time allowed (for further information on timing see Section III.F.2).

F. Additional restrictions and requirements

1) Audience consol

Each robot needs to provide feedback for the audience to interactively see what the robot is doing. This will be in the form of a projector attached to the team's remote computer. For tele-operation, this will be a duplication of the operator's consol. For autonomous entries, this must be a representation of the robot's actions, as would be used in debugging.

For Example, for Task 1 it may be a representation of the data from a laser scanner together with a graphic representation of the identification of the starting pen entrance, as well as the wall following algorithm's identification of the walls. Currently there are no points assigned to this requirement – it is simply to enhance the competition experience for the audience. This is expected to be a point scoring task for the 2012 competition.

2) Time limits

Each team will be allocated a 30 minute slot to set up their entry and attempt the five tasks. 10 minutes are assigned for setup and testing, then 20 minutes are allocated for attempting the tasks. There is also a 10 minute limit to any single task before the team must manually move onto the next task, forfeiting any further points available for that task.

Teams may also decide themselves whether to forfeit remaining points and declare a particular task complete, then proceed onto the next task without suffering the human intervention penalty, noting that the tasks may be completed in any order.

There is a time limit of 15 minutes after the completion of the arena time during which the team needs to submit the results of Tasks 4 and 5. This allows for post processing of gathered data.

G. Prize money

Teams compete for glory, and in many cases the work is the product of their academic degrees. There is a small cash incentive kindly donated by NI of R2000. There is however a minimum qualification standard for the prize of 100 out of a possible 200 points.

IV. FUTURE ASPIRATIONS

With the relative success of 2010 and the current support for 2011, there are great plans for the mobile robotics competition. It will depend on the continued support from the participating universities and, as such, the format and presentation will be subject to their contributions in the future.

The underground mining robotics theme of 2011 will be continued into 2012 and beyond with continued support from the CMI as well ROBMECH 2011, with which the competition is associated. The exact format of the tasks, the timing, points and requirements will be amended based on feedback from the 2011 competition so as to ensure that the mobile robotics competition is as inclusive as possible in the Southern African robotics research groups. It is envisaged that the competition will establish a panel to run it consisting of one member from each of the participating institutions.

The complexity and difficulty of the competition is expected to increase in the following years as the universities develop competency and capability. The development of functioning equipment platforms will also enable the associated research work to expand, building upon previous years successes, and eventually progressing beyond Masters level work into Doctorate quality research in underground mining robotics.

Industry support for individual teams is encouraged, and NI have already indicated their willingness to support specific teams and not the competition as a whole.

V. CONCLUSIONS

The mobile robotics competition has survived for four years and has undergone a significant change in scope and applicability in an attempt to expand the appropriateness of the outcomes. More universities are participating in 2011 than previously, and industry is beginning to show interest in the exposure that the competition is giving to underground mining robotics.

Competitions have in the past been used internationally in academia to guide research, and provide boundaries for applications that are useful in determining the extent of work to be covered in graduate and post graduate research. Having a deadline and a definite goal have an important impact in driving researchers to deliver working prototypes quicker than would otherwise be the case.

The need for research into underground robotics has been alluded to in that South Africa has a real challenge on the horizon of keeping gold mines open in the face of increasing costs, increasingly difficult deposits to mine, and a pressure to improve safety statistics. The method that the major mining houses of Anglogold Ashanti and Anglo American have proposed to achieve this, is to develop a new non-blasting continuous mining method that is small enough so it only mines the gold and not unnecessary waste rock as well. The safety imperative has driven them to state that the mine of the future will have people-less stopes. This all points to a robotics solution. One that does not exist at present, and one that is unique in both size and deployment due to the unique gold deposits that South Africa posses.

The robotics research opportunity presented needs to be embraced and supported by all parties with a vested interest. Equipment suppliers that will eventually supply these mini-miners will need a paradigm shift in their mining equipment manufacturing, from building elephants, to building ants. We stand at the cusp of this effort.

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