The Role of Competitions in Advancing Intelligent Systems: A Practitioner's Perspective

Elena Messina
National Institute of Standards and Technology
Gaithersburg, MD 20899-8230
+1 (301) 975-3510
elena.messina@nist.gov

Raj Madhavan
National Institute of Standards and Technology
Gaithersburg, MD 20899-8230
+1 (301) 975-2865
raj.madhavan@nist.gov

Stephen Balakirsky
National Institute of Standards and Technology
Gaithersburg, MD 20899-8230
+1 (301) 975-4791
stephen.balakirsky@nist.gov

ABSTRACT
In recent years, the number of competitions in the robotic domain has increased tremendously. This growth is spurred by the appealing nature of robots, the flexibility that they afford in competition themes due to the practically unlimited applications, and by the recognition that competitions can yield advances in a technological domain that is immature. The National Institute of Standards and Technology has supported a variety of competitions to help stimulate innovation in certain critical technologies and capabilities needed in robotics. In this paper we present some general views of competitions and discuss the experiences NIST has had with robotics competitions as catalysts for advancing the state of intelligent systems. This paper is a lead-in to others in a special session organized at the 2010 Performance Metrics for Intelligent Systems (PerMIS) workshop that describe in more detail how competitions are used to advance intelligent systems.

Categories and Subject Descriptors
F.2.3 [**Theory of Computation**]: Analysis of Algorithms and Problem Features – *Tradeoffs among complexity measures.*

General Terms
Measurement, Performance Evaluation, Performance Metrics, Intelligent Systems, Robotics

Keywords
Robotics, Competitions

1. INTRODUCTION
Robot competitions are becoming increasingly popular, serving a number of goals that range from primary education to stimulating technological advancements for real-world applications. Competitions can be categorized in many ways. In this paper, we view them through a prism of three dimensions: motivation, objectives, and evaluation techniques. Note that these usually have some form of interdependence.

The spectrum of motivations for robot competitions ranges widely. On one end, robot competitions are pure entertainment. There have been several popular television shows featuring robot combat, for instance, such as Robot Wars[1] and BattleBots [1] [2]. These types of competitions exercise the creativity of the contestants, but are not designed to specifically advance the state of the art. Education is another popular motivation for competition. The For Inspiration and Recognitions of Science and Technology (FIRST) competition was specifically created to inspire young peoples' interest and participation in science and technology [3]. A third major motivator for competitions is to stimulate progress in the technology itself. One-time "grand challenges" are an example of this. Some competitions blend education and technological advancement. One instance of this is the RoboCup array of competitions. In this paper, we briefly present an overview of the spectrum of objectives and methodologies employed in robotics competitions. Certainly, all forms of competitions involve performance measurements, making them useful to examine in the context of performance metrics for intelligent systems.

2. THE BEGINNINGS: MICRO-MOUSE

It has been over three decades since the first mobile robot competition made its debut. The Micro-mouse maze contest, announced in 1977, was first conducted in 1979 and is considered the first such competition [4]. The initial task was simple: a robot mouse was to drive from start to goal through a maze in the least time. Over the years, the rules evolved to create greater challenges to the intelligence of the "mice." In the first contest, the robots were simple wall-huggers. An early rule change was to have the mouse start in a corner of the maze and end up in the center. This change forced more intelligence in the path planning. Another later rule change required the mouse to explore the entire maze and then compute the shortest path. Even this earliest competition illustrates the basic premise of this paper: that carefully crafted competitions (and their rules, which should evolve) can steer research advancements. According to Braünl [5], by 1999 the electronics, sensors, and software problems of the micromouse were solved, with only mechanical improvements still possible.

[1] Certain commercial equipment, instruments, or materials are identified in this document. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology nor does it imply that the products identified are necessarily the best available for the purpose.

3. SPECTRUM OF COMPETITIONS

Since the micro-mouse beginnings, robotics competitions have flourished, for a variety of purposes and reasons. Robots are inherently appealing to youngsters. Therefore robot-centered competitions are useful for attracting students to science, technology, engineering, and math (STEM). Competitions can expose students to many aspects of STEM and encourage them to pursue studies in these disciplines. Notable examples of STEM-oriented competitions are FIRST and BotBall [6].

At the college level, a number of competitions are designed to bolster engineering education by providing a systems design and integration challenge. For example, the Association for Unmanned Vehicle Systems International (AUVSI) has a wide range of robotics competitions spanning ground, aerial, and aquatic domains [7]. The challenges posed are representative of missions that robots currently cannot complete in the military or commercial world, but the emphasis is on education. A recent AUVSI International Aerial Robotics Competition (IARC) had fairly detailed scoring, allotting points for effectiveness measures, such as avoiding all obstacles without collision, and for specific mission tasks such as retrieving a specific object, as well as subjective measures, such as elegance of design and safety of design to bystanders. There are even points allotted for the quality of a journal paper submitted by the team and for best tee shirt design. The mission design for each competition builds on the prior ones, increasing in difficulty with each year.

High risk, high payoff competitions have been staged to advance the state of the art in targeted applications. This "grand challenge" model is used to introduce a community to a compelling and major technological goal that can only be attained by concentrated and often collaborative efforts. A recent example is that of the United States' (U.S.) Defense Advanced Research Projects Agency (DARPA) competitions for driverless vehicles. These competitions have offered prizes of a million dollars and above to teams that successfully complete a course autonomously. The impetus for this competition is the U.S. military's stated goal of having one third of ground military vehicles autonomous by 2015. The first challenge was off-road, and none of the robots completed more than 11.78 km out of the 20 km length course in the first year. By the second year, all but one of the contestants went beyond 11.78 km and five teams completed the entire course [8]. For the third year, the competition turned its focus to urban driving environments and required the vehicles to follow traffic laws. The competition featured multiple vehicles on the course simultaneously. Six teams completed this challenge [9]. Another dimension of competitions is the set of objectives for victory. Yanco proposed a taxonomy for determining competition outcomes that includes ranked competition with subjective scoring, ranked competition with objective scoring, and non-ranked competition with technical awards [10]. In this paper, we augment Yanco's perspective. Some robotic competitions may require the contestants to complete a successful task. The Association for the Advancement of Artificial Intelligence (AAAI) has held several competitions at its annual conference, many of which have been credited with fostering advancements in robotics. For the "Hors d' Oeuvres Anyone?" competition, robots served food to attendees at the conference's banquet. The scoring for this competition included an audience vote component, along with the successful completion of the task of serving food (including restocking the serving tray). The Hors d' Oeuvres event drove research in manipulation, navigation through dynamic worlds, and human-robot interaction [11].

Some competitions are based on team contests. Various leagues within the RoboCup Soccer organization pit two teams against each other on a range of soccer fields. The RoboCup initiative's goal is to "foster artificial intelligence and robotics research by providing a standard problem where a wide range of technologies can be examined and integrated" [12]. The soccer competitions were begun in 1997, with several leagues designed to challenge different aspects of the overall robotics problem. For example, the small-size (below 18 cm diameter) robot league focuses on the issues of multi-agent cooperation with a hybrid centralized/distributed system, whereas the humanoid league encourages mechanical and electronic advances in physical bipedal robots, as well as in the planning and perception software. The abilities of the robots have steadily – even dramatically – improved over the years. Robots can detect the ball, goal, and opponents as well as teammates much more quickly than in the early years and can apply strategy and adaptive techniques. The sensing and planning have evolved tremendously [13]. On the hardware front, there has been significant progress for humanoid robots. They have increased bipedal stability and can move with greater agility each year. The progress is evidence that an ongoing, well-defined set of challenges can inspire innovation.

Other competitions use performance-based models, pitting the robots against a baseline measure. Such is the case with RoboCup Rescue. In 2001, the RoboCup organizers expanded their competitions to include disaster rescue [14]. Viewed as an important challenge in robotics, wherein large numbers of heterogeneous agents collaborate within hostile environments, there are multiple competitions and leagues in this application area [15]. The multi-faceted goals of RoboCup Rescue are "to promote research and development in this significant domain by involving multi-agent team work coordination, physical robotic agents for search and rescue, information infrastructures, personal digital assistants, standard simulator and decision support systems, evaluation benchmarks for rescue strategies and robotic systems that are all integrated into a comprehensive system in the future" [16]. The competitions in the physical robot league pit a robot or team of robots against a disaster environment, called the arena. The robot is to explore the space, map it, and identify victims within a fixed time period. There are many mobility challenges, and areas where fully autonomous operation is required (teleoperation is allowed in many parts of the arena). Robotic hardware designs, as well as software algorithms and sensors have shown tremendous progress in the past decade. Innovations introduced by teams that prove successful are quickly replicated by others, disseminating good designs and accelerating progress. Robots can tackle terrains that were deemed impossible a few years ago. They produce maps of better quality with each passing year. The competition's rules and scoring metrics are revised each year in order to ensure that the challenges grow increasingly complex and more reflective of reality. For instance, there are areas of the arenas where robots must operate exclusively autonomously and new manipulation tasks (e.g., opening doors) are being introduced.

A virtual competition for rescue offers larger, more complex environments and stresses collaborative planning of teams of robots [17]. Teams are required to address elemental tasks that include the autonomous distribution of up to eight robots to form communication repeater networks, autonomous multi-vehicle mapping, and multi-vehicle tele-operation. These skills are then brought together in a simulated full rescue scenario. As in the physical rescue league, the tasks and rules are modified as teams become more capable. This competition also provides an open source coding environment and the requirement that a team's source code becomes open source at the conclusion of the event. This assures that new teams are able to quickly become competitive and that good ideas propagate throughout the community.

RoboCup Rescue has evolved over the years to directly tie the competition to performance standards being developed for response robots. In a NIST-led project funded by the Department of Homeland Security, individual test methods are being developed to measure how well a robot meets certain requirements, which have been defined by end users [18]. Examples of requirements entail mobility over terrains of varying difficulty and the ability to aim or direct cameras and other sensors in a purposeful way to identify victims or relevant items in the environment. Individual test method elements are incorporated within the physical competition arenas. Thus, the research community is presented with real-world challenges against which they can pit their ingenuity and thereby advance the state of the art in robotics.

The success in stimulating innovation in the rescue robotics community via the RoboCup competitions led NIST to establish competitions in other domains. A virtual manufacturing automation competition (VMAC) strives to promote advancements in robotic algorithms, especially in sensing and planning, for factory operations [19]. Recent advances in microelectromechanical systems have enabled the development of mobile microrobots that can autonomously navigate and manipulate. This technology is expected to be critical to numerous applications, including sensor networks, medical diagnosis and treatment, and micro-assembly. Since there are many challenges, such as in locomotion, NIST has organized performance-based competitions for mobile microrobots to help coalesce the research community. Both the VMAC and the microrobotics competitions have been adopted by the Institute of Electrical and Electronics Engineers' annual International Conference on Robotics and Automation. The RoboCup organization hosted microrobotics demonstrations for the first few years.

Recent advances in the design and fabrication of microelectromechanical systems (MEMS) have enabled the development of mobile microrobots that can autonomously navigate and manipulate in controlled environments. It is expected that this technology will be critical in applications as varied as intelligent sensor networks, in vivo medical diagnosis and treatment, and adaptive microelectronics.

However, many challenges remain, particularly with respect to locomotion, power storage, embedded intelligence, and motion measurement. As a result, NIST has organized performance-based competitions for mobile microrobots that are designed to: 1) motivate researchers to accelerate microrobot development, 2) reveal the most pressing technical challenges, and 3) evaluate the most successful methods for locomotion and manipulation at the microscale (e.g., actuation techniques for crawling).

4. CONCLUSIONS

We have discussed a sampling of robotics competitions and the various objectives possible. This is not meant to be an exhaustive list, as there are too many competitions (and the number is growing annually). For example, [20] gives several examples of how mobile robot competitions can foster advances on many fronts. Clearly, robotics competitions are useful mechanisms to serve many purposes, ranging from entertainment to education to stimulating innovations. According to Yanco, "Competitions often influence the direction of research in robotics, which can be used to great advantage" [10]. Incorporating ways of measuring performance in particular tasks or missions has proven to be a useful means of helping the research community better understand the problems to be solved. Having annual competitions with evolving challenges as technologies mature is an effective way of motivating the creativity of the international robotics community towards useful, real-world solutions and advancements in the technologies for robots.

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