Designing Robot Competitions That Promote AI Solutions:
Lessons Learned Competing and Designing

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Abstract

Robotics competitions are an educational tool at the middle school, high school, and university levels. The layout, rules, and reward systems of these competitions galvanize students to a specific solution space. From our experiences competing-in and designing such competitions, open-loop, low feedback strategies tend to dominate the winner's circle. If we want competitions to emphasize solutions spaces that include AI-type robot control, contest designs need to favor closed-loop, high feedback strategies. Game elements that encourage such designs are discussed.

Introduction

Robotics competitions have long been a part of the national American Association of Artificial Intelligence (AAAI) conferences. These competitions have been dominated by universities that can afford high-end robots or have the wherewithal to manufacture their own robots. With the introduction of modestly priced microcontrollers paired with accessible mechanical building materials, robotics projects became a viable option for undergraduate artificial intelligence courses (Kumar and Meeden, 1998) , many of these taking their inspiration from the MIT 6.270 competition (web.mit.edu/6.270). Building on the experience of early adopters and the emergence of easy-to-use programming environments (e.g., Interactive C and Not Quite C) robotics competitions flourished as course activities and extra-curricular educational experiences. Some competitions are regional or national such as Beyond Botball (www.botball.org), the IEEE Regionals (www.2006ieeer5conference.com), and the Trinity Fire Fighting Competition (www.trincoll.edu/events/robot). Robotics competitions have also become educational and inspirational activities for middle and high school students, such as Botball (Miller and Stein 2000), FIRST Robotics (www.usfirst.org), and Best Robotics (www.bestinc.org) at the national level. Many schools and university also hold local level activities, for example, the competition held at Southern Illinois University Edwardsville (SIUE; roboti.cs.siue.edu).

The design of a robot competition determines the emphasis for participants. AAAI competitions (www.aaai.org) and RoboCup (www.robocup.org) have designs that emphasize some of the outstanding research issues in robotics and AI, such as human-robot interaction, multi-robot coordination, and navigation in unknown environments. Other competitions emphasize the educational experience by challenging students to develop creative solutions in one or more of the multidisciplinary aspects of robotics, such as the IEEE Regionals, which appear to focus on the development of custom mechanics and sensors.

Within the specific emphasis of a competition, the design of the rules and the reward system of points and penalties determines the *gameplay* (Rouse 2001). Gameplay, a term most often used in the design of computer video games, defines the way a participant can interact with the components of a game and promotes strategy choices for accomplishing goals. Applied to robotics competitions, gameplay impacts the solution space that teams will explore for their robot designs.

One of the dangers in designing competitions is crafting gameplay that is not balanced (Laird and van Lent 2001). Unbalanced gameplay results in a strategy that is dominant over all other strategies. From our experience in competing and designing, the gameplay of competitions appears to favor *open-loop* control designs, specifically control designs that have little or no sensor feedback. If we want competitions to emphasize solutions spaces that include AI-type control, gameplay should favor *closed-loop* control structures, specifically control designs that use sensor feedback to make decisions with regard to immediate strategy and, possibly, higher level tactics.

Competition Experience

Competitor's Perspective

Recently, we have competed in two university-level robotics tournaments. The IEEE region 5 robotics competition involved a mini warehouse setup (see Figure 1) with the robots acting as automated sorters. Cans of four different colors were placed at random in rooms 1, 2, 3, and 4 (the four lower rooms in Figure 1). These cans were to be sorted and delivered to the correct room: red in room A, green in room B, blue in room C, and yellow in room D (the four rooms at the top of Figure 1). These cans always started within a black circle; likewise, they were to be delivered into the corresponding black circle located within the appropriate room.
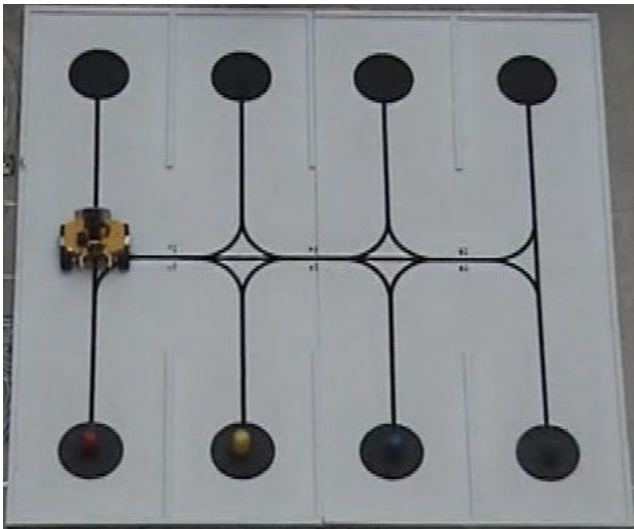

Figure 1: Layout of IEEE region 5 competition.

The goal of the 2006 Beyond Botball competition was to have competitors rid the arena of all "toxic waste" and save Billy and Betty Botguy (plush robot seen in Figure 2). The toxic waste, represented by green and yellow foam balls, was to be removed from the bins and placed either in the middle (neutral zone), off of the table, onto the opponent's side (negative points awarded to the opponent), or into the appropriate hopper within the neutral zone (bonus points). Billy and Betty could be removed in the same manner or could be reunited on your side for additional points.

Our Designs. Typically, our robots include a sensor array consisting of sonars, infrared range finders, light sensors, and a color camera; we try to find a nice medium between complexity and simplicity while attempting to maintain a closed-loop strategy.

At the IEEE competition, the robot consisted of three light sensors to perform simple line following as it's navigation technique. In addition, two laser mice accurately tracked odometry. This competition included complex line intersections; the mice approximated when intersections were reached, thus reducing dependence on the three light sensors. Front sonar, in combination with a color camera, identified the colored cans. This allowed the robot to locate the object using the sonar and, using the color camera, process an image to guarantee that it had found the correct object (identically colored obstacles were also on the field of play). An arm capable of five degrees of freedom was used to manipulate the environment; this added complexity to grabbing static objects. The basic strategy of the robot involved line following to a room, detecting an object's position with the sonar, processing an image from the camera, grabbing the sensed object, and then line following to the correct storage room for delivery.

Figure 2: One half of the Beyond Botball arena.

In the Beyond Botball 2006 national competition, sonar and infrared range finders were utilized as a means to safely navigate the course. This strategy overcame orientation errors introduced by the four-wheeled platform design. The wheels introduced significant turning errors similar to tank-tread platforms; this approach was simple, yet robust in establishing robot orientation with respect to the arena. The robot relied heavily on image processing to find the colored foam balls, as well as to localize on the orange sign posts (found near the foam balls). We, again, utilized the five degree-of-freedom arm, which was advantageous because the robot could accurately throw the foam balls great distances; in this case, onto our opponent's side. The design of the control architecture adopted a behavior-based approach (Arkin 1998). Behaviors included removing foam balls from either side, pitching them to the opponent's side or dropping them off the table, removing the Botguy, dropping the Botguy off the table or placing him in any of three blocking positions in the neutral zone, placing a ball in the hopper, and blocking the hopper with the grabber. The modular nature of the behaviors allowed us to choose the set of behaviors that we considered the best combination to offset the strategy of the particular opponent we were facing during any particular round.

Competing Designs. One of the wonderful experiences of participating in robotics competitions is observing the diversity of robots and ideas that come from competitors. People always find interesting and different methods to complete the same task.

At the IEEE contest, there were very similar designs that dominated the finals. One part of these designs that appeared to work best was the use of many light sensors for line following. These robots all had, at a minimum, five light sensors; some had as many as twelve. This large array of sensors allowed them to handle the complex line intersections with little effort and, thus, navigate the lines very smoothly. They also utilized large claws fixed to the front of their robot chassis. This allowed them to quickly grab an object without any searching. After sweeping the area with the large claw, they applied a simple color check, taking advantage of the fact that the object was now directly in front of them. This design was capable of completing the course very quickly and efficiently without having to spend a lot of time sensing or thinking.

At the Beyond Botball competition, the winning design was a highly engineered platform built specifically for this game. It utilized three robots, each built for a specific duty; there was no communication between the robots. One robot would collect the balls from one storage bin and carry them to the opposing side. Another would collect the balls from the other bin and attempt to score them in a hopper. The third would grab the Botguy from the center bin and remove it. The successful navigation of each of these robots relied heavily on intentionally running into walls to trigger touch sensors, which in turn let them know when to turn or grab. The digital touch sensors were the only sensors on all three robots. These robots were programmed to drive forward until a touch sensor was triggered by a wall, turn approximately 90 degrees, run into an adjacent wall to straighten out, and then repeat, fully utilizing the static environment.

Results. In each of the competitions, similar outcomes resulted: open-loop design dominated the robot designs, and the teams that managed to develop reliable open-loop designs did well overall. At the IEEE competition, the vast majority of the robots utilized this methodology; the winner was simply the one with the fastest claw and motors. The Beyond Botball tournament had a similar flavor: the three robots of the winning team each utilized reliable, open-loop control designs. The division of labor was an effective strategy. Making defensive moves against three robots while making offensive plays within the time constraints proved to be too difficult. Experience has shown that in competitions which, for all intense and purpose, are assumed to have static or near-static environments, the successful robots involve little feedback and decision-making. It seems that more AI-type control designs take too much time gathering and processing sensor data, and are, quite possibly, overkill in competitions such as these.

Designer's Perspective

Each year, SIUE hosts a competition using the LEGO Mindstorms robots. Seeding rounds for freshman engineering students and local area high schools are held over the course of a few days, culminating in a head-to-head competition between the top ten qualifiers from each group.

In SIUE's Robo Pong 2003 (based on a design in Martin 2001), robots were to get as many ping-pong balls as possible onto the opponent's side of the arena; each side was its own inclined plane (see Figure 3). Though much effort was made to emphasize the use of sensors, the clear winning strategy was to simply fling balls randomly over the incline and, because of the physical characteristics of the arena board, let gravity do the rest. By the time qualifying robots had returned for the double-elimination rounds, nearly all of the entrants had modified their designs to utilize this strategy to its fullest potential.
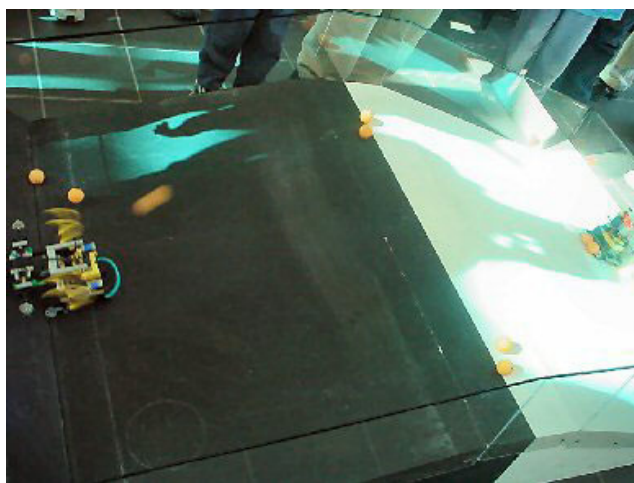

Figure 3: Robots fling ping-pong balls in Robo Pong.

Similar tactics were demonstrated in RoboCraft 2004. Robots were given the task of gathering resources (represented by golf balls) to be delivered to various goal locations (see Figure 4). Though the environment added more complexity than that of the previous year, a dominant strategy was still identified and exploited. In the final round of the double-elimination tournament, the top two robots were nearly identical in design, taking advantage of an open-loop control strategy that depended on the known locations of game objectives.
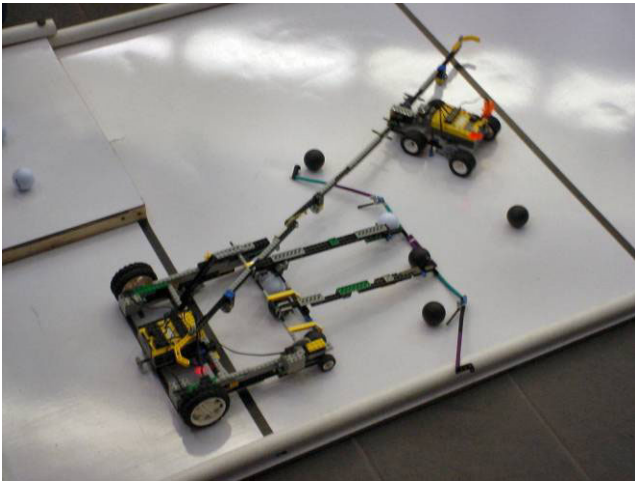
Figure 4: Two robots become entangled in RoboCraft.

Components for Emphasizing AI Solutions

In the aforementioned robotics competitions, many of the winning robots demonstrated a single dominant strategy that was a direct result of the rules of the contest itself. The nature of gameplay encourages participants to make use of an open-loop design as the control method for the robot. The importance of intelligent decision-making based on sensory feedback is not adequately stressed and, thus, concepts utilized do not extend well into higher-level applications where robots may need to react to unexpected events in a potentially dynamic environment.

Given the specifics of a competition, teams generally assume a known layout of the arena, as well as the locations of objects and goals; consequently, they program actions to be taken when the robot reaches these locations with the assumption that no changes have occurred in the initial arena configuration. In order to promote the use of closed-loop designs, one or many degrees of uncertainty must be deliberately included in the rules of the game. Incentive must also be offered to encourage the use of planning and re-planning based on interactions with the environment as well as with other robots. Intelligent decision-making may take a significant amount of time, which is not currently offered by many competitions.

Mapping
The closed-world assumption appears to be the largest assumption that is made in regards to the physical environment (Murphy 2000). The robot is programmed to navigate and interact with a static environment where all relevant information is known a priori. A first step towards requiring sensory feedback is to not specify or at least not be as specific with the characteristics of the field of play. RoboFest (www.robofest.net) has such a component, in that they do not give the dimensions of their arena boards prior to the competition. This simple lack of detail forces participants to rely on sensory inputs to successfully traverse the course. In the same competition,

robots must interact with or attempt to remove a wooden barrier blocking off an area of interest on the game board. It follows that a game in which the environment itself can be obstructive, but also interactive, will present robots with interesting situations not yet seen in competition.

Localization
Even in current formulations of competitions, it is important for a robot to maintain a sense of where it is within the world. The most common form of localization is known as dead reckoning. This approach is adequate for these competitions; however, when the dynamics of the game require robots to cover much of the arena board in order to accomplish tasks, the unavoidable error intrinsic to dead reckoning quickly accumulates. It would be advantageous for a robot to verify its location based on observations, such as distance readings and landmark sightings, within the environment. This provides the robot with an accurate and robust system for determining its spatial position and orientation while navigating the world to meet its objectives.

Object Recognition
Within the domain of the game, robots are given a series of tasks to complete. These tasks often include the manipulation of objects within the world, moving them from one place to another. However, these tasks rarely require an actual search procedure in order to find the desired objects; if the locations of these objects are given, there is no need for a search within the environment. Likewise, if their positions were not specified, but rather placed randomly throughout the field of play, then participants would be encouraged to utilize sensory capabilities to best locate and approach the objects.

Navigation and Planning
If the locations of objects are unknown, a robot will have difficulty relying on a fixed navigational strategy. Navigation involves avoiding obstacles while attempting to reach some destination. Path-planning becomes crucial in these situations. Even low-budget robots with limited computational power can perform basic path-planning (Mayer, et al. 2004). In the case that a robot was to interact with certain physical elements of the environment, planning would be required for object manipulation.

Interactions
While a game may include various intended obstacles that a robot must overcome, the most influential obstruction on the field of play tends to be another robot. This could be an opposing robot or a robot from a team's own multi-robot entry. Many competitions allow for, and sometimes encourage, interactions between competing robots. Though these interactions are likely to happen, most robots are not designed to react to such an encounter; often the result is entanglement (see Figure 4) or, if the robot is merely clipped, failure for both robots to perform their

tasks because the assumptions made in programming their open-loop control strategies have been violated. The competitions at SIUE address this by incorporating restart rules for robots deemed immobilized by a judge (e.g., RoboCraft 2004). In Botball, robots were not permitted to cross onto an opponent's side for some duration of time, thus reducing the risk of collisions early in the game; robots that violated this rule were subject to penalty. In head-to-head competitions, contact between robots should be expected, and the structure of the game itself should promote the use of sensory feedback to predict an oncoming interaction to avoid or handle these collisions.

Time

All of the aforementioned AI topics require one key element—time. Sensing the environment and making decisions based on this feedback is a time consuming process. Our experiences in competing in various robotics competitions have shown that this overlooked factor constrained AI-type strategies the most. In both the IEEE and Beyond Botball competitions, teams that attempted complex sensing and interactions within the environment often failed to complete the tasks given. It is after identifying this limitation that many teams tend to adopt the open-loop strategy. If the game were played out over a longer period of time, robots could carefully examine their surroundings and calculate appropriate responses.

An Example

At SIUE, a multidisciplinary robotics course is taught that presents students with an introduction to mobile robotics from an integrated systems perspective (Weinberg, et al. 2005). With slight modification, the final project of the class can be extended into the realm of a robotics competition. We will depict it here as an example that addresses many of the AI topics discussed.
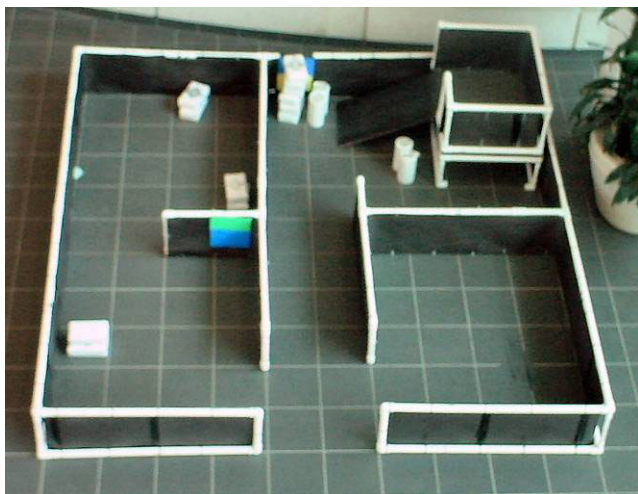

Figure 5: An overhead view of the search and rescue arena.

The project is in the domain of urban search and rescue, using a 10'x10' arena to represent an earthquake-damaged warehouse. An initial layout of the arena is given, but the conditions inside are unknown (see Figure 5); the collapse has left various obstacles in the paths of the robot rescuers. Each team must design and build a robot that can explore the arena and search for victims (all wearing red uniforms). As the robot traverses the environment it should sense objects. If an object is an obstacle, the robot must avoid it, often altering the robot's navigation plan. If an object is a victim, the robot must approach it as closely as possible (see Figure 6), again, altering its path plan. The robot must also indicate that a victim has been found by making a signal, either auditory or visual, and marking the estimated location of the victim within a map of the arena. Thus, a robot must also maintain its own global position and orientation. While dead reckoning remains the main localization method for the project, colored landmarks at known locations and unique tone emitters offer the robot an opportunity to recalibrate its odometry information within the environment. This information becomes exceedingly important when the robot must traverse up a 20 degree incline to search a room on the second floor of the arena. The entire search effort must be completed within a 15 minute time period.
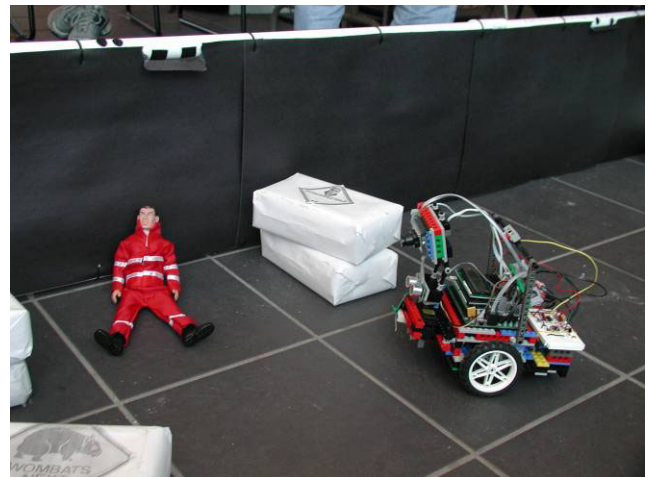

Figure 6: A robot rescuer identifies a victim.

The search and rescue project promotes robots to utilize closed-loop control and the AI elements of mapping, navigation, object recognition, planning, and localization, all within a reasonable amount of time. Though the project is implemented on a smaller scale than the application domain, the techniques utilized provide an adequate introduction into higher-level challenges, such as the AAAI Robot Scavenger Hunt Challenge (www.aaai.org/Conferences/AAAI/2006/aaai06robots.php #exhibition) and the Urban Search and Rescue Competition run by NIST (www.isd.mel.nist.gov/projects/USAR/).

Conclusions

In order to encourage teams in robotics competitions to explore design spaces that include close-loop and AI-type control structures, the gameplay of the competition must encourage such designs. The arena environment and rules must reward robot designs that react to sensory data, alter strategy for immediate tasks, and, potentially, encourage higher level decision-making in overall strategy and tactics based on the opponent's actions. Some important elements of the gameplay to consider include unspecified arena dimensions, random placement of game objects, navigational and planning dynamics, and time constraints. The competitions designed to explore AI solutions can be a good intermediate step for students intending to continue studies in these areas and possibly competing in higher level competitions such as the AAAI and RoboCup challenges.

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