Beyond Botball: A Software Oriented Robotics Challenge for Undergraduate Education

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Abstract

Beyond Botball is a thoroughly thought out robotics challenge that varies from year to year. The challenge does not presume specific equipment or software packages – there are many techniques that can be used to accomplish each of the challenge goals. The challenge is distributed freely and is meant to be used as an end of semester project in a robotics or programming class. An open Beyond Botball tournament is held every year in conjunction with the NCER conference. This paper describes the program in more detail and how it has been used in several classes.

What is Beyond Botball

To understand the origins of Beyond Botball one must first look at the Botball program. Botball (Stein 2003) is an educational robotics program for Middle and High School students offered each year by the KISS Institute for Practical Robotics (KIPR).[1]

Botball traces its origins to the MIT 6.270 contest[2] and the AAAI robot building labs (Kadie 1993), many of which were produced by KIPR. Botball grew out of these activities but includes simplifications to make it more age appropriate. Botball augments the technology to allow for a friendlier development environment and more advanced technologies such as robot vision and full PID control (LeGrand *et al.* 2005).

The basic format for the game is to pit two robotics teams against each other. The robots employed must start in response to a signal and operate autonomously thereafter, ceasing all activity when time has expired. By playing the game alone, a team can demonstrate robot performance. Playing against an opponent demonstrates robot survivability.

Beyond Botball is a Botball style of competition that provides Botball alumni and other adults the opportunity to continue to participate in a competition based on this kind of robotics.

The National Conference for Educational Robotics is a student oriented conference held annually since 2002. Along with typical conference sessions (talks, plenary sessions, etc), three different contests are also held at the NCER. The Robot Olympiad (Vernor, Ahlgren, & Miller 2006), the International Botball Tournament, and the Beyond Botball Tournament. Teams entering the Beyond Botball Tournament are strongly encouraged to submit papers describing their robots to the conference. Papers on other related research topics are also accepted. The chance to interact with dozens of groups that have addressed similar issues in robot design and construction is a very valuable experience for aspiring engineers.

Game Design

The Botball game challenge differs from year to year, sometimes radically, and the same approach is used for Beyond Botball.

While the overall objective is to provide a test of robot performance and robot survivability, the game design must also meet a set of pragmatic objectives (in no particular order):

- Have game objectives that
  - can be achieved within a 90 second window
  - sustain robot activity until game end
  - can support teams of robots
  - has a broad solution space not tied to a specific technique, sensor etc.
- Game board is made from low cost, readily available materials
- Fits within a 3-D space roughly 9’ x 5’ x 3’
- Keeps competing robots from getting tangled too soon and too easily, yet lets opposing robots interact directly
- Has levels of scoring of increasing difficulty
- Incorporates elements that discourage prior participants from recycling old designs.

For Beyond Botball, equipment is not limited to the Botball kit, and rules regarding what is allowed are relaxed, although still constrained enough to help ensure that availability of funds to spend on the robot is not the primary factor in team performance.

The 90 second time frame has proven to be short enough to complete a 10 team double elimination tournament in 90

[1] See www.botball.org.

[2] See web.mit.edu/6.270/www/about/history.html

minutes (on average a round consumes about 5 minutes to accommodate setup, scoring, and other logistics), and long enough for robots to undertake relatively complex tasks. This also works nicely for a class divided into 10 (or fewer) teams.

It is important to note that the rules of Beyond Botball support each team entering a team of robots (in aggregate the robots must meet the size and mass constraints). The ability to have several robots participate as a team lets the student teams more thoroughly learn the technology, and also allows for a distribution of key team roles (e.g., robot lead, system integrator, etc). Issues in multi-agent communication and collaboration can also be explored at both the human and robot levels.

The test of robot performance is achieved by playing the game without an opponent with the purpose of achieving a highest possible score (subtracting any points scored for the virtual opponent). It provides a reasonable performance test since the robot is dealing with a known world where any changes to its world are from its own initiative. In recognition that Murphy's law could have been written for robotics, taking the average of the best 2 out of 3 attempts is a fair way of arriving at a performance score. For 10 teams this requires 30 rounds, but since logistics are simplified in comparison to a tournament (teams simply take turns), a round can typically be completed in 3 minutes; i.e., the time is roughly the same as for the double elimination tournament. Performance scores also provide a natural way for seeding a tournament.

The test of robot survivability is achieved by playing the game in a double elimination tournament format (the use of double elimination is consistent with forgiving one performance round). The longer a team lasts in the tournament, the greater survivability they have demonstrated. Scores can be assigned based on the level reached by a team before being eliminated (level 0 is the first set of matches, at level 1, teams each with 1 loss compete and 1 is eliminated, and so forth). Note that it is not until the next to highest level that an undefeated team plays a team with 1 loss; i.e., the highest level is achieved only by the tournament winner.

The Beyond Botball game is developed each year by a committee of experienced game designers. The game meeting involves going through suggested scenarios from committee members and both solicited and unsolicited suggestions. The game design process involves mockups of boards, frequent trips to Home Depot and various hobby stores, and the vigorous movement of toy cars around table tops (accompanied by someone making appropriate engine noises).

After a preliminary game and scoring system has been created, the committee disperses and formal rules are created along with CAD models of the game board. These are vetted by the committee members and the game is released in the Fall for use in the Spring semester.

Using Beyond Botball in the Classroom

The Beyond Botball competition provides an effective course project for the hands-on component of a first collegiate course in robotics, or as an exercise for a more advanced course. It has clearly defined objectives and scoring criteria that provide final rankings much as one might grade other student work. Moreover, development of a robot for the competition lends itself to having a series of laboratories designed to explore robotics paradigms that have potential applicability to the term project. Each laboratory can be structured as a mini-competition for comparing performance for a more narrowly defined objective than those presented by the Beyond Botball competition. This approach enables peer learning since students seek better solutions than those they see being developed by classmates.

As with all robotics projects, there are a number of interdisciplinary aspects to a viable Beyond Botball entry. Faculty (known by the authors) in electrical engineering, mechanical engineering, aerospace engineering and computer science have used the Beyond Botball Challenge as a capstone project for their robotics courses. It has also been used as a team building exercise and as a technical management exercise for various engineering graduate programs.

In most instances, the last week of a class is the obvious time to have the competition, with seeding/performance taking place one class period, and double elimination the next. If time is limited, say to 50 minutes, then a 2nd game table can be used so that one team is setting up while the other is in progress, halving the time required.

Even an initial laboratory exercise such as following a taped line on a white surface can be used to introduce and illustrate different robotics paradigms based on hierarchical, reactive, or hybrid variations of sense-plan-act, and to contrast single sensor vs. multi-sensor solutions. If colored tape is used, then the options expand to utilization of color tracking (a digital camera for tracking up to 3 different color ranges is incorporated into the Botball kit used for Botball competitions).

Later laboratories can focus on obstacle avoidance using optical and sonic range finders, beacon navigation and mapping, and compound behaviors for approaching an acquired target. Exercises in mobility, kinematics and control can also be performed. Precision movement can be facilitated by using a controller such as the XBC which has built-in PID control using back EMF to close the loop. Alternatively, a simpler controller can be used in a controls class where the students are to devise their own motor control systems. Concluding each laboratory with a mini-competition (e.g., moving an exact distance; following a colored line the fastest; etc) eliminates being late as an option, and peer pressure to show well improves design quality. The added interest level also tends to improve the quality of lab reports, due the class period after the mini-competition so that they can include an experience report. For this approach to work, minimal performance criteria need to be established with means to distinguish performance quality (typically time and accuracy).

In the collegiate context, the available time can be devoted to introducing and illustrating concepts without having to devote a lot of time to equipment issues. An effective laboratory support environment can be based on the Botball kit (see (Miller & Winton 2004)). In contrast to Botball, Beyond Botball has the added advantage of not being tied to the current version of the Botball kit. Custom mechanics and electronics have often been entered as appropriate. CS classes may make use of premade platforms such as those by LynxMotion; or use an iRobot Roomba for mobility carrying a notebook computer. ME classes may use a lego RCX or a HandyBoard for computation on a custom chassis. An EE class may have home grown electronics. An interdisciplinary team may have everything be locally developed; while a system engineering class may try and use all COTS parts to explore interface/standards issues. LEGO and overnight deliveries from Digi-Key can fill any remaining gaps.

The authors' experience has been that the competition is a strong motivating factor. We have been able to increase its motivation even more by offering travel supplements to attend the Beyond Botball tournament at NCER for high performing teams.

Student response to questionnaires that ask about the competition element, including the mini-competitions for laboratory exercises, is overwhelmingly positive. This seems to be because they recognize it helps to keep them on task in addition to making the exercise more interesting. Establishing minimal performance objectives that more strongly affect the grade than competition outcomes contributes to the approach being viewed positively.

Game Example: 2006 Beyond Botball Challenge

The 2006 challenge is a typical example of the Beyond Botball challenge (though perhaps with less randomness than is often incorporated). The background story for the challenge is as follows:

> *Disaster has struck Botland. Billy & Betty have been placed in separate shelters, but yellow and green toxic loads are nearby, making the shelters unpleasant. Your job is to reunite Betty & Billy and put the toxic waste in the permanent disposal receptacle.*

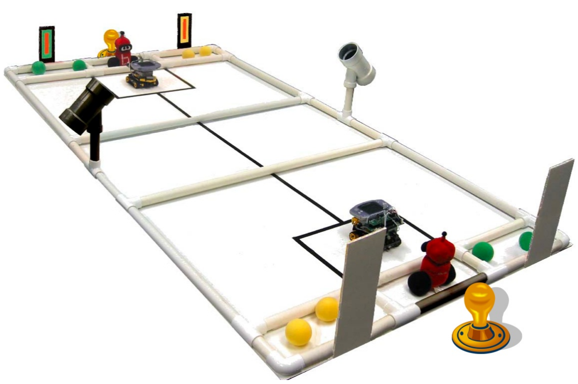

Figure 1: The 2006 Beyond Botball Game Board

Figure 1 shows the game board and major pieces. The teams score points by removing the colored balls from their side and placing them in the raised disposal bins at the middle left of the board. There are several types of partial credit. Some points are received simply for removing balls from their starting areas. More points are granted for getting them off of your side. There is (because of the competition setting) some advantage to putting the balls on the other team's side, and it is even more advantageous to your team to get them correctly sorted on the other team's side. However the biggest score is to get them into the disposal bins.

Figure 2: Lynxmotion 4wd base with 5 DOF arm

The plush dolls also have points attached to them. In this game your team gets a large number of points for having both dolls on your side, but is penalized if it just has one. Having no dolls means neither a bonus nor a penalty.

While these rules make for an interesting story, and interesting strategies, they are also designed to test different robot skills. Robots with good manipulation skills can place the balls in the disposal bins. Robots with good vision can track the plush dolls and decide whether to try and gather them both or dispose of theirs depending on what the other team is doing. Robots that can just scoop and push a little can also score points, though will have some difficulty getting the higher scores. Teams of robots that incorporate good navigation, sensing and manipulation can really shine in this task – though strategy will also play an important role.

As we'll see in the next section, sometimes the game inspires students to create robots with skills not even considered relevant by the game designers – and use them to good effect.

The Beyond Botball NCER Experience

As mentioned earlier, the Beyond Botball Competition provides an excellent opportunity for an interdisciplinary educational project. Such an approach to the competition can be used in an interdisciplinary robotics course (Weinberg *et al.* 2005) or as an extra-curricular experience as illustrated here by the team from Southern Illinois University Edwardsville (SIUE). Competing in the 2006 competition, the team from SIUE consisted of a junior in computer science, a senior in computer engineering, and an associate professor of computer science.

The team chose to use the Lynxmotion 4WD1 robot (www.lynxmotion.com) as the base. The decision to use

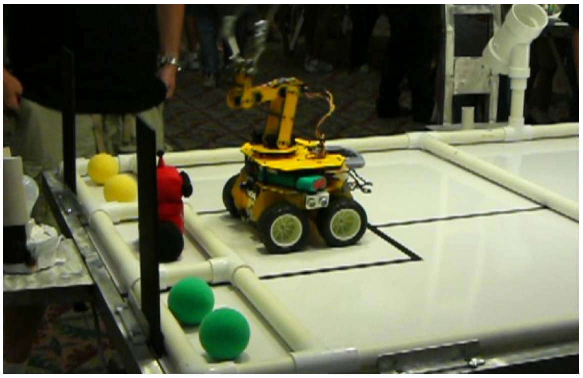

Figure 3: Robot going for the Botguy

this platform was made in large part to the availability of a 5 degree-of-freedom (DOF) arm that mounts to the top of the base (See Figure 2). The competition required retrieving different colored foam balls and a plushy robot, Botguy, which is the Botball mascot (See Figure 3). Placing these items in different areas impacted a team's score. The 5 DOF arm allowed for flexibility in placing objects. In addition, without the expertise of an ME to design a custom arm, having an off-the-shelf arm was important.

The XBC microcontroller with integrated camera was chosen as the robot controller. This is the same configuration that is included in the Botball Competition Kits. With the XBC controller the team chose to use Interactive C for programming, which includes a vision system for blob tracking. As an alternative, the team considered using C++ with a cross-compiler available from Charmed Labs (www.charmedlabs.com). The IC vision system has an extensive library for blob tracking that provides 3 color channels with unlimited blobs per channel allowing for calls to retrieve a variety of properties for a blob. Using the Charmed Labs C++ cross-compiler and a CMUcam2 with serial communication to the XBC instead would have allowed for direct calls to the camera API and additional servo ports available on the CMUCam2 board. While this would have allowed for direct calls to the camera API, it would have required reprogramming of the XBC's field programmable gate array, consequently increasing the development time. The color camera was used for object recognition and orientation. Back-EMF, sonar sensors, and optical range finders were used for navigation and obstacle avoidance.

The team adopted a behavior-based control architecture (Arkin 1998). This architecture allowed for different game strategies based on the opposing robot's actions. This choice also made it easy for modular development along the lines of the actions necessary for the various situations the robot might encounter. The team's division of development reflected the components of behaviors: Overall control and navigation, object recognition, and arm control. Individual team members could develop behavior components, but team interaction was necessary to ensure that components fit together to form complete behaviors.

The SIUE robot entry encompassed concepts that could be part of projects in an artificial intelligence course or an introductory course on robotics. As an interdisciplinary project it included computer science elements such as the control architecture and navigation. While back-EMF built-in to the XBC was used to aid navigation, interfacing the 4 wheel drive Lynxmotion motors to the XBC proved challenging. Alternatively the team considered mounting encoders and developing their own PID controller. This along with the kinematics control of the 5 DOF arm would be appropriate elements for a mechanical engineering course.

Having a computer engineer was necessary to interface the motors with the XBC. This was particularly true for the 5 DOF arm. One limitation of the XBC for the robot design was only having 4 servo ports available, while the arm required 5 servos. The team decided to control the claw of the arm using an available digital sensor port since it only had two states, opened and closed. The interface used between the digital port and the servo motor was a PSoC 29466 micro-controller. One bit from the XBC was connected to two input pins of the PSoC, which triggered a general purpose interrupt. One interrupt pin was posedge (close) and the other negedge (open) triggered, allowing it to receive each desired state. The PSoC then utilized a 16 bit pulse width modulator to send the appropriate signal to the servo.

While a simpler arm would have been adequate to pick up the balls and the plush doll, the high dexterity of the 5 DOF arm was put to good use. Rather than simply removing the balls, as most of the teams did, the SIUE team pitched them into the color appropriate bin on the opposing team's side. Considering the numerous uncertainties in the board and the shape and size of the ball, the SIUE robot had a surprisingly high success rate – very surprising to most observers. The SIUE team's entry did well in both the seeding (performance) rounds and the double elimination final. They only lost to a multiple robot entry consisting of three robots each engineered to do one specialized scoring task using an open-loop control. SIUE's single robot entry was unable to play offense and defense against three opposing robots.

Conclusions & Recommendations

Any course project has to be structured so that it can be accomplished by students within the time limitations imposed by course schedules. Courses involving robotics lend themselves to use of a game-based project that requires students to implement and integrate concepts covered in class.

Beyond Botball provides a game design that changes annually. More importantly, the design nicely fits with the constraints imposed by a course. A number of pragmatic objectives have been worked out to make Beyond Botball games well-suited for use in a course context. The fact that Beyond Botball games are designed to be addressed using a Botball kit (among many possible alternatives) means that a well-defined base of equipment is readily available, and at a relatively modest cost, supporting both course and project requirements.

An added advantage of employing the Beyond Botball game in this manner is that it can encourage students to extend their work, since it is very unlikely they will be satisfied with robot performance achieved by the end of the course.

Figure 4: The 2007 game board – before the reactor goes critical

This may be by organizing a local Beyond Botball tournament among classmates and other interested parties, or even better, by participating in the Beyond Botball tournament held annually in conjunction with the National Conference on Educational Robotics.

Addendum

One request we have received from participants of the Beyond Botball game is for there to be both random and predictable elements to the game. The 2007 game (see Figure 4) is set on a starship whose reactor is going critical. The task of the robots is to move the crew and hydroponic gardens into safe areas and then clean up the fissionables that are randomly distributed across the game board by the explosion (a mousetrap powered plunger launches 16 colored poms from the central cannister). The full rules and contest details can be found at the website[3].

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[3] http://www.botball.org/current-season/beyond_botball.php