Combining Robot Form and Behavior: Designing a Winning Botball Robot

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1 Introduction

This paper focuses on practical lessons learned in the process of designing a team of two robots intended for the 2013 Botball [1,2] challenge. While this paper displays lessons learned in Botball, these lessons and principles are common to the field of robotics in general, and to mechanical design at large. Through the experiences of our rookie team, we illustrate some of the most important basic principle of robotics: *the fact that the robot's mechanical design (its form) must be developed in parallel with its behavior design (its code) in order for the whole system to be effective*.

We also discuss a second principle, that *a successful Botball robot must be both effective and competitive*. A great robot design that works well in practice when the robots are alone on the table may not work at all when competing against an opposing team. We are not able to effectively simulate the actions of the opposing robots in practice, and often, a high scoring robot design that is competitive in theory may not be realistic or effective. Therefore, the design and planning process involves anticipating and predicting the strategies of the opponents and then modifying, and in some cases entirely redesigning, the robots' form and programs in order to be competitive.

The principles and ideas in this paper are illustrated through the actual design decisions and results of a solution that was ultimately very successful in a regional Botball 2013 competition, which involved a point-scoring game of collecting and transporting pom-poms and a Botball character into a designated area, and stacking plastic/PVC rings on tall poles, with the added challenge of stacking shuttlecocks on top of the rings as a way to multiply points [3].

2 Design Process, Designs, and Testing

In this section, we provide a chronological account of our design process, annotated with lessons learned along the way and culminating in the successful outcome.

2.1 Initial Design Process

To go about developing design ideas, our team laid out the available Lego pieces for building, along with all metal pieces, sensors, servos, etc. Each team member used a clipboard with paper and sketched basic robot design ideas and scoring strategies that were shared, improved on, and/or rejected by the other team members. Concepts were chosen or rejected based on their ability to be created with the Lego pieces available, their likely ability to perform the tasks presented, and the team's estimated ability to write the required code for the imagined mechanical design.

If a proposed design concept for the robots was relatively simple to build and program, as well as likely to be effective in scoring points, it was chosen as a viable design option by the group and set aside. Once the team identified several viable design concepts, favorites were chosen as the final designs to be evaluated. As will be seen later, *these were far from being the final designs, but that was one important lesson we learned along the way.*

Our overall two-robot design consisted of a robot built from an iRobot Create mobile base, and a custom-designed metal and Lego robot. It was decided that the former would move around and push scoring objects such as pom-poms (and possibly opponents) with a scoop, while the latter would be equipped with an effector (arm with a gripper) to grab PVC rings and transport them to scoring positions.

2.2 Examples of Rejected Design Concepts

To give examples of the qualities of rejected designs, here we describe two such designs. One of the rejected robot design ideas involved creating an overhead servo-controlled wall-like apparatus that would push scoring items such as pom-poms into an immobile scoop attached to the base of the robot. The robot would score by collecting items in its scoop and then parking itself in the loading area. The idea was rejected because too many servos would be required to build the arm, therefore this arm would be the only method available to score points, effectively rendering any scoring option, such as the rings, unavailable. It was likely that the arm would require more servos to build than we possessed in total, making the design impossible to actually build.

The second considered but rejected design concept (nicknamed "The Unicorn") was meant to score high points by levering rings onto stacks and adding shuttlecocks to top. The Unicorn would achieve this task by using a long rod-like servo-controlled arm to "spear" the rings and lift them. The robot would require a camera to detect color, a floating sensor to evaluate distance, and several servos to build the arm. The team anticipated at the time that the most difficult aspects of building this robot would be creating a servo-controlled arm that can move in the requisite ways. Another difficulty would be writing code for the floating sensor to keep the robot from bumping into the terminals, but still allowing it to get close enough to load onto them.

These rejected designs are good examples of overly complex concepts that were discarded. With time, the team learned that even our ideas for "simpler" and "doable" designs were quite complex and, as a result, not robust or effective. *As we discovered, the team was to reject many more designs after testing than anticipated.*

2.3 Initial Accepted Design Concepts

2.3.1 Drive Train for the Custom-Designed Robot

The drive train design we selected is shown in Figure 1 (on the right). We attached it to the metal robot base using two pop rivets for each motor. A wheel is attached to each motor, positioned to be parallel, making a direct drive system. There is a rolling ball-and-socket appendage secured to the front tip of the robot, allowing it to turn and keep its weight evenly balanced. Even without physical tests, we immediately eliminated the option of a more complex four-wheeled drive train. Such a design had the advantages of the robot being more stable and having heightened precision in maneuverability. However, it would require more complex programming for the simple act of turning, and the two added wheels and motors would take up vital space and supplies. The 2-wheel system was selected instead, as it is more compact and lends itself to more straightforward programming. This part of the robot design ended up being part of our final competitive system. *The choice of the simpler system ended up repeating itself as a valuable lesson throughout our design process.*

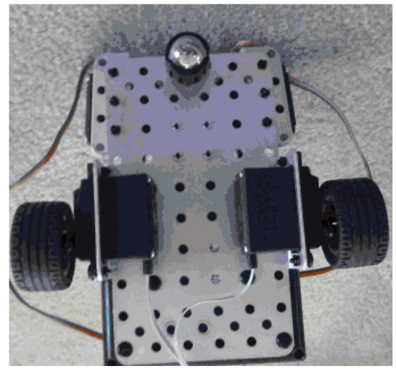

Figure 1: Drive train

2.3.2 Sensor Mount Design

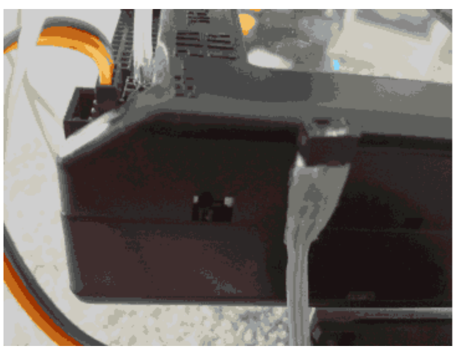

Figure 2: Sensor mount

Figure 2 (on the left) shows the light sensor design, used to turn on and begin the robot's program in the competition, when the starting light is turned on. The sensor was glued on with UGlu at a location that did not get in the way of any of the robot's moving parts; it could have been mounted mechanically with Legos, but using UGlu was simpler and robust, allowing for space and weight savings as well. This simple choice was a good example of a design decision that endured the process of necessary redesigns, unlike most other components of the original designs.

2.3.3 Initial Effector/Arm Design

The first accepted design concept for the robot effector was based on aiming for maximum points by going after high scoring parts of the challenge task: loading rings onto terminals and placing pom-poms in the loading area. Accordingly, there were two main components to this design. The first consisted of one robot arm controlled with servos that had two tires attached to it for the added friction when picking up PVC rings; the arm was to lift up rings and load/stack them onto the poles. The second component was an underhand claw, inspired by those found on bulldozers, designed to scoop up pom-poms. This component, combined with a color-sensing camera, was to seek out specifically colored pom-poms, scoop them up, and transport them to the target area. The team anticipated that the most difficult aspects of this design would be building the arm with a limited number of servos and designing the claw so that the pom-poms would be scooped in, instead of just pushed around.

Figure 3: Arm design

Figure 3 (on the left) shows the original effector (arm) design, with a pincer-like appendage, with two tires placed on each "pincer" to help the it pick up and keep hold of PVC pipe scoring pieces. The arm contained three servos: two at the base, and one that operated one of the pincers. The pincer section included two claws/pincers: one static and one mobile. A mini servo was attached to the mobile pincer with rubber bands, allowing it to manipulate the distance between itself and the static pincer. This was meant to allow the pincers to open and surround a PVC ring, and then close to grab and hold onto it so it could be lifted. We considered using a design with a joint in the arm, allowing it to bend, but that would require at least one if not two more servos. Such a design was possibly superior as it might have decreased the stress on the lowest servos, have higher maneuverability and accuracy in scoring, and allow for a more compact robot design. However, we decided against that design because of a lack of servos, the likely complexity of programming to control such a jointed robot arm, and the weight of the arm.

We performed an evaluation of the effector design by writing a test program to move the arm up and down. The program had the servos holding the arm parallel to the floor as a default start position, then lifted the arm until it was perpendicular to the floor, then lowered it to the parallel position again. Ten trials were completed, a failed test being if the arm did anything other than the function of slowly lifting and lowering to the desired target positions. The data, shown in Table 1 (below), represent the accuracy of the effect at the basic task of raising and lowering. The data show that the arm is too heavy to be effectively lifted to a position perpendicular to the floor needed for use in the competition and, while more effective at lowering, it was too have to be lowered properly in 40% of trials. Based on these tests, we concluded that we need to alter our effector so that it weighs much less or displaces some of the stress on its base servos elsewhere. As a side effect of completing these tests, we noticed the effect the weight of the arm had on our overall robot: the

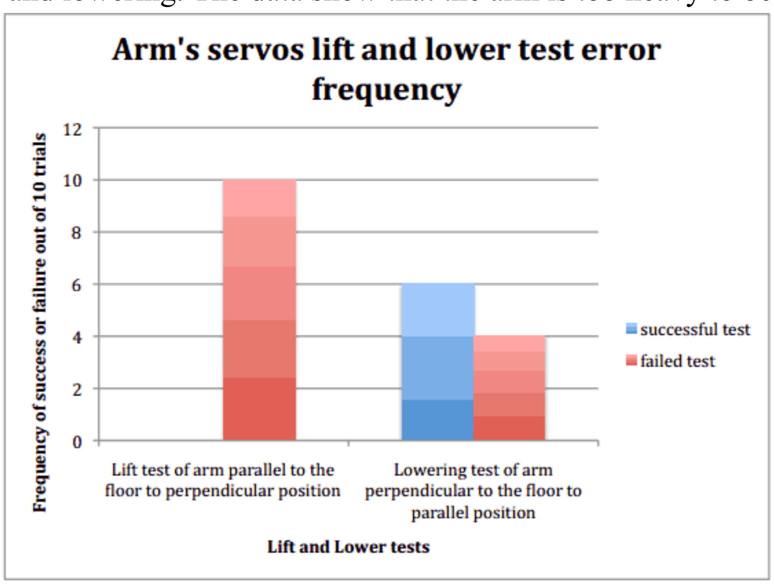

Table 1: Testing the effectiveness of the effector

balance was compromised and driving speed was lowered. While we knew we would be able to alter the weight of the arm, the balance of the our robot would only be fixed by changing the arm's length, which was not allowable by the contest rules.

The evaluation data were sobering and lead to the conclusion that the effector should be moved from the smaller, built-from-scratch metal and Lego robot to the second, larger, more robust and balanced iRobot Create robot. This meant that the planned roles of our robots would be reversed: our iRobot would use the effector to score points by loading rocket booster sections, and our built-from-scratch robot would be fitted with the scoop originally created for our iRobot, which would allow it to travel around the game board and push scoring pom-poms into our loading area.

2.3.4 Finalized Modified Systems

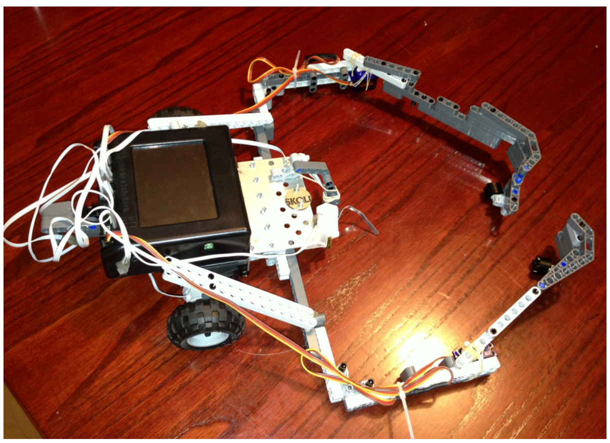

Figure 4: Finalized custom-designed robot

Figure 4 (on the left) shows the modified custom-designed Lego and metal parts robot. We took the idea of a pom-pom scoop from the iRobot Create and modified it to fit the custom-designed robot, and added servo-controlled arms that opened and closed to capture pom-poms. This robot's new main purpose was to scoop pom-poms and put them in the scoring area. IR sensors were attached to the front and back of the robot for game board navigation by line following. A touch sensor was affixed to the front of the robot that, when triggered, caused the servo arms to close around whatever scoring items were in the scoop and allow them to be dragged back to the loading area. This was the final competitive design used for the custom-designed robot. While the design remained unchanged from that point, the robot's program and general strategy for use had to be altered during the competition, once the system was tested on the competition tables.

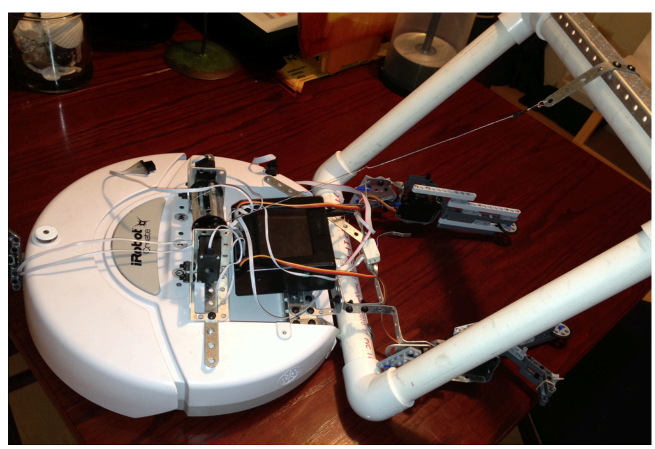

Figure 5: Finalized iRobot Create design

Figure 5 (on the right) shows the final design of the Create capture mechanism. In a first attempt, the effector arm was moved to the iRobot Create, but this did not improve its performance. There was a clear need to entirely reengineer the arm to be much lighter and more effective. Here is where the most important flash of insight occurred: rather than attempting to grab high scoring but also high-risk rings, the Create could be used to capture and transport other lower-scoring but lower-risk items in the competition, and deliver them to the destination. We recreated the highly effective arm capture system being used on our custom-designed robot with the pieces we had left, and then we designed a pulley mechanism that operated using motors and wire to lever a large square scoring multiplier box that could be lowered onto the collected pom-poms, allowing for maximizing scored points with minimal risk of pom-pom loss.

The two robots were programmed so that they were able to work together as a team. Each robot collected scoring items from its side of the table. Then, after a fixed amount of time, the custom-designed robot aligned itself to the Create. The purpose of this alignment was that so the pulley system--which operated on a purposeful delay so as to wait for the slower Create robot to get into position with its pom-poms—would drop the scoring multiplier box on top of the items collected by *both of the robots*. This design ensured that every captured point-scoring object had its value multiplied, effectively doubling to tripling the collected points through a combination of robot mechanical design and coordinated behavior.

3 Discussion and Conclusions

Through the process of designing, testing, and redesigning our two-robot system, we learned a great deal about system engineering, system integration, and evaluation. The well-established engineering principle of Occam's razor, or "keep it simple," repeated itself numerous times [4,5]. *The simplest mechanical and programming designs were the most robust and lowest-risk/highest scoring over time*.

Simplicity does not eliminate elegance; it may help to create it. Our Create arm scoop and pulley-controlled scoring multiplier design turned out to be high-scoring and highly effective because of its simplicity and robustness. It had very few instances of failure because it was uncomplicated and sturdy. For those reasons it was also accurate, repeatable, and unlikely to be broken by an opposing offensive robot.

As is always the case, our overall system design can still be improved. We are looking for ways to improve the custom-designed robot to make it more effective and complementary with the Create. We will not, however, change the Create design because we see no prospect of improving its elegant efficiency and robustness.

References

[1] C. Stein, "Botball: Autonomous Student Engineering Autonomous Robots", *Computers in Education Journal,* 2, June 2013.
[2] C. Stein, D. Schein, and D. P. Miller, "AAAI Hosts the National Botball Tournament!" *AAAI Magazine*, 23(1):51-54, Spring 2002.
[3] 2013 Botball challenge web site: http://www.botball.org/contests
[4] F. Martin, "Robotic Explorations: A Hands-On Introduction to Engineering", Prentice Hall, 2000.
[5] M. Mataric', "The Robotics Primer", MIT Press, 2007.