

OUT OF THE BOX: FOOTBALL . . . WITH ROBOTS?

Applying the fundamental concepts of engineering learned during their studies at Purdue University Calumet and South Bend, three students team up to describe their participation in the annual Intercollegiate Robotic Football competition at Notre Dame. Ben Weiss created a competitive quarterback while Zach Nava and Chris Markovich's receiver joined the fray. Students who participate in competitions like this one are able to learn a broad range of skills in mechanical engineering, computer engineering, and electrical engineering.

INTRODUCTION

The play is started and the quarterback passes the ball to the running back. The running back moves the ball down the field, only to be tackled by an opposing player, ending the play. It sounds like a stereotypical football game—except these players aren't human.

Since 2012, Notre Dame has hosted an annual Intercollegiate Robotic Football competition in which many schools participate. Robotic football is inspired by American football, closely resembling the game and played with a quarterback, receivers, running back, linemen, and a kicker, but its participants are robots, controlled by humans, on a small field with a souvenir-sized football. The competition includes two different events—the combine and a full game. The combine is a meeting of different schools to demonstrate their progress in creating robots for the competition. In addition, the combine serves as a track-and-field day for robots, including a multitude of events to test a robot's skills, such as agility, pushing power, and throwing abilities. A full game is played with eight robots on the field, with the ninth robot serving as the kicker. This is akin to a typical game of American football, but with fewer players and played on a sectioned basketball court.

Students from Purdue University Calumet and the Purdue College of Technology South Bend decided to try their hand at the game and brought some innovations with them. Ben Weiss, a freshman at Purdue South Bend, alongside his fellow teammates, worked toward creating a quarterback for the competition. Zach Nava and Chris Markovich, seniors at Purdue Calumet, worked on a competitive robotic receiver for their senior design project.

In order to be eligible for competition, robots must adhere to a set of constraints put forth by Notre Dame. While the full constraints list is quite long, a generalized version is as follows:

- 16"x16" base length and width, maximum 24" height for robots (with following exception), 16"x24" base length and width, maximum 24" height for kicker
- 30 pounds maximum weight for robots (with following exception), 45 pounds maximum weight for quarterback and kicker
- Any single voltage source (typically a battery) 24 volts or less
- A robot status indicator light (for example, to show if a robot is running or tackled)

Once these constraints are taken into account, there are several aspects of the machine that need to be designed to both meet these standards and successfully complete specific tasks on the team.

QUARTERBACK

As in American football, the quarterback is a focal point of any team. This player must be precise in order to effectively pass the ball to the receiver. The machine's throwing system design mirrors professional football throwing machines. Two wheels spinning at a high revolutions per minute (RPM) rate make contact with the ball and propel it from the machine. In order to produce the spiral effect that results in accurate football throws, the two wheels are pitched at an exact angle over a center line that is parallel with the ball's ejection angle.

To maximize the forward throwing vector for the force supplied by the wheels, this quarterback design utilizes a smaller pitch for the wheels, which proved most effective. The minimal pitch still provides the ball with a spiral that maintains ball stability during a throw. After accurately calculating projectile motion and wheel calibration, the quarterback can effectively throw the ball to an exact distance. Given the size of the 90- by 48-foot field, the

maximum effective range for a quarterback is 60 feet to allow for a long "Hail Mary" pass from the furthest first down line to the touchdown zone. To make a long distance throw, a launcher angle of 45 degrees offers the best distance with the least force necessary.

To reach the desired 60-foot distance, calculations were made to determine required force and initial linear velocity of the ball. The velocity of the ball was then taken as the linear velocity of the wheels. This was used to determine the angular velocity of the wheels, which have a diameter of 4 $\frac{1}{8}$ inches. This is found by taking the necessary linear velocity divided by the radius. A motor was selected that is capable of producing the required RPMs to reach the desired angular velocity of the wheels. To adjust for different passing distances, the voltage supplied to the motors changes to affect the RPM. The energy transfers to the ball.

The completed machine revealed an average of just 7.6% error in the maximum distance thrown—much less than was expected considering the effect of air resistance or the heavy vibrations of the imbalanced wheels. The final product also revealed two new challenges to overcome when developing future models. The first challenge was that the two wheels did not make contact with the football on the same area of the ball. This resulted in curved throws, which launched in the direction opposite of the wheel the ball touched longer. To resolve this issue, the loading system requires a redesign. The second challenge, dubbed the "Gyro Effect," resulted in a longer pass being more stable with a better spiral than a shorter pass. The Gyro Effect occurs because longer distances require a higher linear velocity of the throwing wheels—and thus higher force—which produces a better spiral. The lower velocities of each wheel required for the shorter passes do not provide enough linear velocity, which results in unstable passes. To resolve this issue, a new way to vary distance (such as changing the launch angle) and to produce the best overall results must be determined. With proper funding, the quarterback can be improved into an effective, fully functional, mechanically precise machine that will compete in upcoming years.

RECEIVER

While a quarterback is central to a football team, it essentially is useless without a receiver to whom it can pass. Several changes were made to previous teams' designs to provide an advantage and optimize the receiver's functionality.

The catching system was redesigned to allow the receiver to move, which maximizes the target area the quarterback has to hit. The new design includes a slanted opening as seen in Figure 1. A secondary net was added to cover the area underneath the primary catching net, which increased target size.

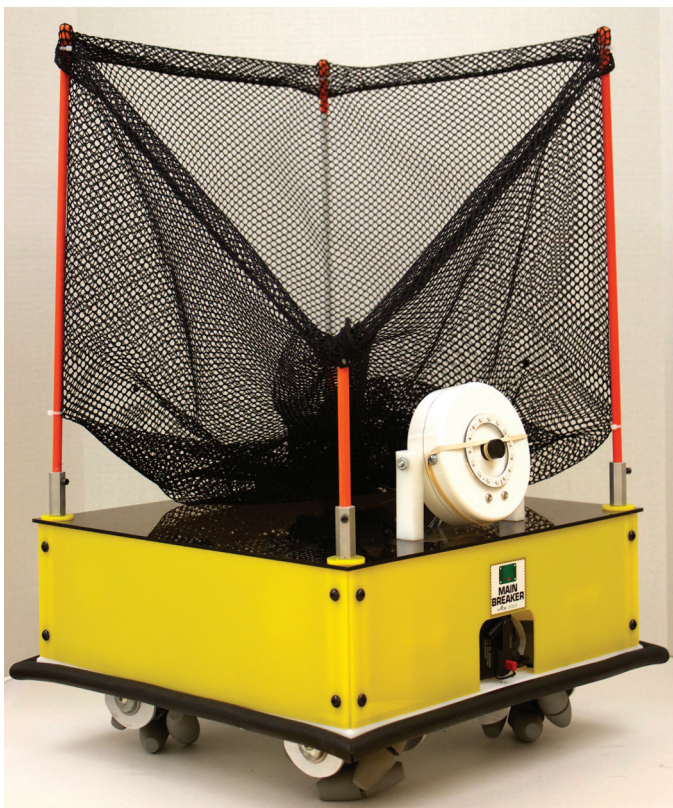


Figure 1. An angle shot of the wide receiver robot. It shows the top-end gameplay system (including camera and net), as well as the wheels.

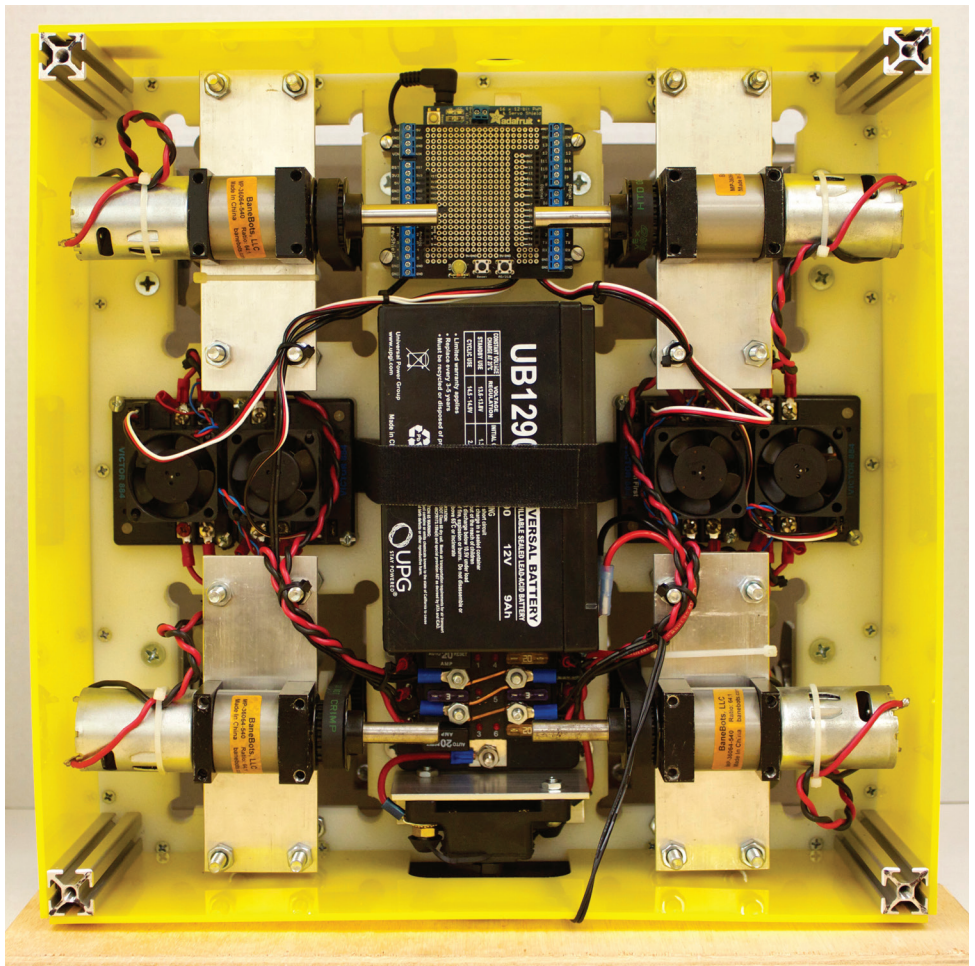


Figure 2. An aerial shot of the inside of the robot, with the top panel off, displaying all components including the motors, gearboxes, battery, and other components.

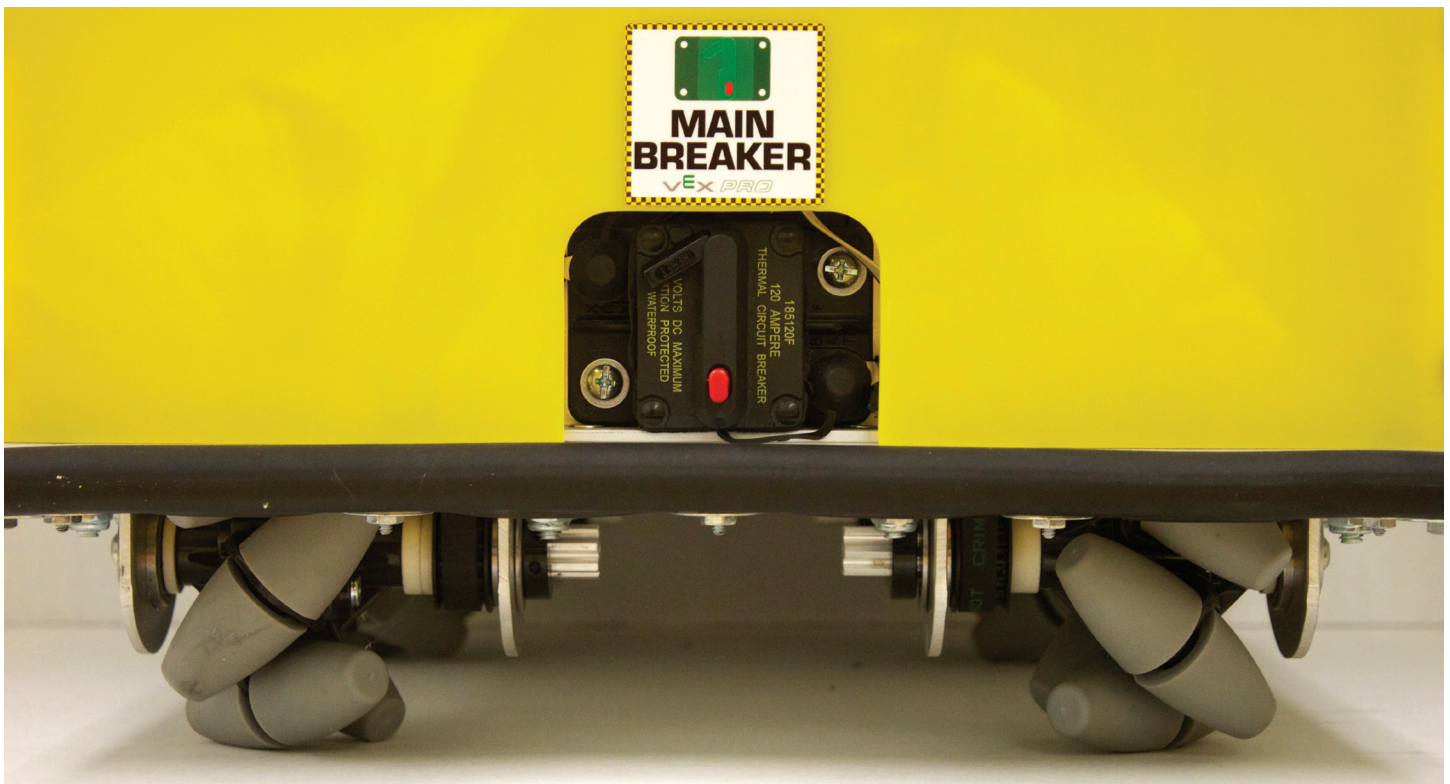


Figure 3. A close-up shot of the wheels, demonstrating the rollers. The main breaker is visible in the front.

The drive base also was changed to a highly maneuverable design, which maximizes the machine's ability to find an open position to catch the ball. A well-designed drive base system can be applied to all machines on a team. This cuts down maintenance costs and compatibility issues by making fixes simpler. The drive base also serves as the foundation for the machine, which is a determining factor in the machine's capabilities. Several drive bases were weighed, but the Mecanum drive was selected for optimal machine functionality. Though more expensive than the often-used differential drive, the Mecanum drive offers an additional degree of movement, which allows forward, backward, left, and right movements that permit autonomous control and joystick interfacing. This added maneuverability maintained the receiver's orientation to the quarterback, which allowed the design to include a football tracking control system.

An advanced control system was added to the robot that includes football tracking and proportional integral derivative (PID) to significantly improve the potential for a successful catch. To track the football, the robot uses a Pixy CMUCam5, which processes the image and sends the Arduino controller coordinates and dimensions. This camera, which remains oriented toward the quarterback, allows the receiver to look for the football; once found, it tracks the ball left and right to ensure the football is centered on the catching net. This setup allows the receiver to be two to three times as efficient at successfully catching a pass by creating a larger target as compared to other machines. To track the football, a green LED ring on the camera lights up and reflects off the retro reflective tape on the football, which reflects the light back to the camera. Since the ball now appears as a bright green circle, dimming all other ambient lighting effects, the machine can track this green circle. This tracking system is effective at a maximum distance of up to 20 feet.

This system offers significant potential for the future of Purdue's contributions in the Intercollegiate Robotic Football competition by laying the foundation with its drive base design and control system setup. After extensive testing and continuous calibration, these systems can effectively play their respective role on a robotic football team. With the implementation of several of these technologies, an entire new dynamic will be introduced to the robotic football game.

CONCLUDING THOUGHTS

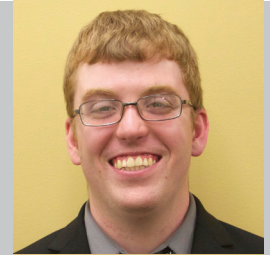
Robotic football is an excellent application of fundamental engineering concepts. It allows students to learn a broad range of skills in mechanical engineering, computer engineering, and electrical engineering. With these two robots, Chris Markovich, Zach Nava, and Ben Weiss hope to inspire other students to innovate and bring changes to

robotic football, creating a more competitive game, and to expand the game by introducing the competition to other students throughout the area.

Markovich, C., Nava, Z., & Weiss, B. (2015). Out of the box: Football . . . with robots? *Journal of Purdue Undergraduate Research*, 5, 104–107. <http://dx.doi.org/10.5703/jpur.05.1.10>

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Ben Weiss is an undergraduate in the Purdue University South Bend pursuing a BS in mechanical engineering technology. The quarterback robot was built as part of his project for the Controls Society under the direction of John Piller.



Mentors

John Piller started teaching full time at Purdue in the fall of 2011 after many years spent working in the public sector. Piller holds a master's degree in electrical engineering technology from Purdue University.



Don Gray is a professor of electrical engineering at Purdue University Calumet. He completed his PhD at the University of Notre Dame. He specializes in control systems, electronics, large-scale dynamical systems, and artificial networks.

