Lightweight Soccer Robot with Dribbler, Kicker, and Vector Projections: Orion 2021 ⋆

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Abstract. This paper provides an explanation of mechanical, electrical, and software aspects of the autonomous soccer robot built by Orion, a competitor in an international autonomous soccer robotics competition. To our knowledge, we are the first lightweight RoboCupJunior team whose robots each have a kicker, a dribbler, an omnidirectional camera tower, double layered omniwheels, and four motors. The robots are programmed to strategically switch roles, scoop the ball from out of bounds, and kick the ball precisely into the goal.

Keywords: RobocupJunior Soccer Lightweight · High School Robotics

1 Introduction

Orion consists of four high school students who share a passion for robotics. The team was founded in 2018. Our first robots were built with commercial electrical components and manually sawed polycarbonate plates. That year, we scored more own goals than proper goals. In 2019, however, we built improved robots which won first place in the US RoboCupJunior competition and competed in RoboCup 2019. At Sydney, we studied the features that were most effective in winning matches. Over the past two years, we have redesigned our robots from scratch and made numerous improvements over our older robots.

After RoboCup 2019, we founded the Princeton Soccer Robotics Club, which now has five RoboCupJunior teams. We regularly hold meetings, in which Orion teaches CAD, electrical, and programming in order to help students build their own robots.

Although the pandemic brought many challenges, we have been able to continue working on our robots due to Orion's flexible workflow. Our team members, Danil Korennykh, Keiji Imai, Niklas Austermann, and Mark Ogata, specialize in software, mechanical, vision, and electrical, respectively. In 2018, Keiji Imai moved from Princeton, NJ to Newton, MA, forcing us to adapt to remote collaboration before the pandemic. Keiji uses his 3D printer to build the robots

⋆ All authors contributed equally to this work.

and mails them to Princeton, where Mark programs the robot remotely with Danil and Niklas. Even when COVID limited in-person meetings, we were able to develop our robots at full speed.

Fig. 1. In row major order: Mark Ogata, Keiji Imai, Niklas Austermann, Danil Korennykh.

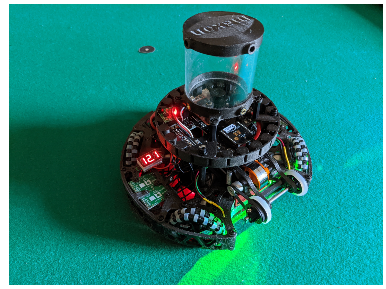

Fig. 2. Our soccer robot

Quantity	Part Name	Purpose
4	Maxon DCX19 9V	High acceleration drive motors
4	Double-layered omniwheels	High traction, low profile, lightweight omniwheels
1	CB1037 Solenoid	Kick the ball past goalies
1	A2208KV1100	Lightweight high rpm dribbler motor
1	Conic mirror	360 degrees of vision for goal recognition
1	Acrylic Tube	Rigidly support the mirror
1	Admiral 1300mAh 3S Lipo	Provide required power until half time
22	Custom 3D Printed Parts	Lightweight, cheap, and durable parts
2	Custom PCBs	Reduces weight, space, and points of failure
1	Teensy 4.1	600 MHz Cortex-M7 processor with 42 I/O pins
1	OpenMV Cam H7	Programmable and lightweight camera
24	TSSP4038	Infrared Sensors to detect the ball
16	SFH 5701	Photodiodes to detect white lines
5	MCP3008	Convert 40 analog signals into one SPI bus
1	XL6019	Boost IC to convert 12V to 60V
1	LM2575	Buck IC to convert 12V to 5V
1	XBee	Wireless communication between robots
1	BNO055	Compass sensor for absolute direction

2 Mechanical

Our robot has many features while being under 1100 grams because each part is designed to be as light as possible. We used four motors rather than three because we saw at RoboCup 2019 that speed and pushing power is essential to winning matches against top teams. Similarly, we used dual layered omniwheels to increase our robot's traction, thereby improving acceleration. We also added a solenoid kicker to further accelerate our scoring. The robot has an omnidirectional camera so that it can aim its kick towards the goal. To make our robot's scoring more reliable, each robot has a ring of 16 line sensors and 24 ball sensors. The compliant, lightweight dribbler applies a backspin on the ball to maintain firm control during maneuvers.

2.1 Omniwheels

Our omniwheels are unique because they have high traction, a low profile, and only weigh 12 grams. The high traction comes from two layers of silicone rollers. We used silicone tube in our rollers because silicone has a high friction coefficient and tubes are more durable than o-rings. Our design was inspired by OP-AMP's omniwheels [1]. Our rollers consist of an acetal dowel, two 3D printed spacers, and a silicone tube. We cut the tube to size using a 3D printed jig. Each layer of 18 rollers is sandwiched between two 3D printed plates that have slots for the roller pins. In previous iterations we used circular slots, which allowed rollers to pop out of their positions by plying the two plates apart. We remedied this issue by tightening tolerances with the part shown in Figure 3. This small test part allowed us to rapidly experiment with different tolerances. We also replaced the circular slots with square slots, which make it more difficult for rollers to spread the plates apart.

As depicted in Figure 4, we made our wheels slim by moving the set screw from outside of the wheel into the center of the wheel. We tighten the wheels by inserting an Allen key through a hole above the set screw. Older iterations of our wheels used heat set inserts for the set screws, but we found that our motors were so powerful that the inserts were pushed out and the D shaped hole wore out into an O. Now we use a captured nut that is much more robust.

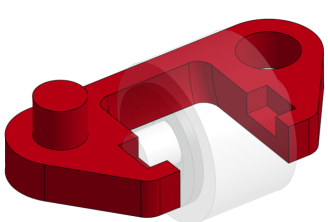

Fig. 3. Tolerance Test Part

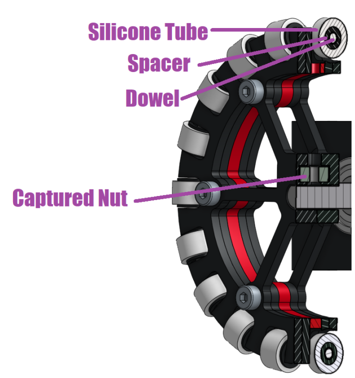

Fig. 4. Omniwheel Cross Section

We made several design changes to reduce our omniwheel weight to 12 grams. Old iterations of our wheels weighed up to 24 grams, but we reduced our wheel's weight significantly by replacing our steel dowels with acetal dowels. Since there are 128 rollers and acetal is 10 times less dense than steel, this lightened the wheel considerably. We further lightened the wheel by removing unnecessary material.

2.2 Dribbler

The dribbler mechanism maintains a strong grip on the ball and weighs only 70 grams. We took inspiration from Team Transcendence's dribbler [2], but made design choices to conserve space and weight. In order to absorb shocks from the ball, the mechanism pivots and is held down by two springs. Some dribblers have a single roller, but we chose to use two separate rollers in order to center the ball and increase our grip. We used a silicone tube for the dribbler to maximize the rollers' traction with the ball. While most dribblers weigh between 150 and 300 grams, our dribbler only weighs 70 grams. We achieved this by using a lightweight brushless motor and a timing belt, instead of a brushed motor with gears.

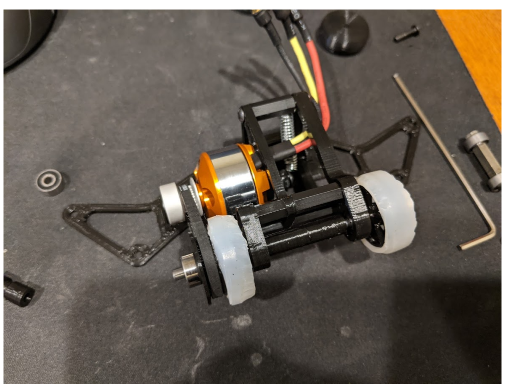

Fig. 5. Old unbalanced dribbler

Fig. 6. New dribbler

Another concern when designing the dribbler was compactness, as the circuit board is above the mechanism and we wanted the robot to have a low center of mass. Multiple prototypes and design iterations helped us determine the optimal pivot point and roller location for ball handling and compactness. An early dribbler iteration, shown in Figure 5, used a single spring and a cantilevered motor. This design caused the ball to favor one side of the dribbler, causing wear, because the tension from the spring and the belt put the roller shaft at an angle. Our current design, Figure 6, solves these problems by shortening the motor shaft cantilever and adding a second spring to balance the downwards force.

3 Electrical

We use PCBs on our robots to minimize space and weight of components. Our PCBs have custom white line sensors and enhance the structure of the robot. By integrating power management systems, logic, and sensors into two PCBs, we sacrifice modularity for efficiency, space, and weight. The PCB located near the top of the robot houses the logic and ball sensors of the robot. The Infrared sensors are processed through a low pass filter to turn the digital pulse signal to an analog signal, which is much easier to process.

3.1 Kicker

A solenoid allows the robot to kick the ball, increasing the acceleration the robot can apply to the ball. The extra acceleration helps score against teams with goalkeepers and avoids pushing penalties[5]. Our solenoid has a low resistance of 10 ohms because the lower the resistance, the lower the voltage needed to achieve optimal kick strength. Our current design charges a 2200uF electrolytic capacitor at 75V. To minimize noise to the rest of the PCB, the control circuit consists of two optocouplers controlling an N-channel MOSFET and P-channel MOSFET that separates the solenoid and capacitor from the rest of the circuit when triggering. We use MOSFETs over relays because they are more reliable and lighter. A boost circuit and a voltage doubling circuit produces an output of 24V to 100V. The boost circuit takes about 10 seconds to fully charge the 2200uF capacitor and we are investigating ways to decrease that time.

3.2 Line Sensors

To create a circular pattern of line sensors, we used an alternating pattern of red LEDs and photo resistors with about a 1cm gap between each of them, which ensures that at least one sensor will always see the line when the robot is on it. We found that 33k ohms is an optimal resistance when used in the voltage divider with photo resistors to produce an analog output. The readings from the voltage divider are reliable and no capacitors were needed on the output to smooth the signal.

4 Software

Our robot features an innovative line detection algorithm and strategic role switching. For instance, when the ball is near the white line, our robot can smoothly scoop it from out of bounds without completely crossing over the line. We use vision from our omnidirectional camera to curve the ball towards the opponent's goal to line up a kick. The robots alternate between goalie and striker roles depending on the position of the ball, allowing our striker to get past the opposing striker in some situations. Finally, we use an orbit and dampen function to efficiently move behind the ball without knocking it away.

4.1 Line Detection

Unlike most RoboCupJunior teams, our robot can smoothly scoop the ball from out of bounds. Our line algorithm starts by selecting the two most distant triggered line sensors. Adding the vectors associated with the two sensors gives us a vector pointing straight towards or away from the line. This vector is stored to be used in the next tick of the program. When the difference between the current vector's angle and the previous vector's angle is greater than 90 degrees, the robot's center has crossed over the line and the robot flips its recovery vector.

We built a wireless debugger, shown in Figure 8, to check for edge cases in our line avoidance algorithm. One of these cases is when the robot would rotate while moving over the line, causing disorientation and making the vector switch trigger too early. We solved this issue by storing the compass readings for the previous tick to offset the recovery vector. Another edge case we ran into involved the field's corners. If there are three clusters of triggered line sensors, then a corner has been encountered. In this case, the current tick's recovery vector is determined by offsetting the previous tick's recovery vector with the compass data. A third edge case occurred when the active line sensors are exactly in the middle. In this situation, the recovery vector adds to (0, 0), so we use the previous recovery vector and compass offset to calculate the current recovery vector.

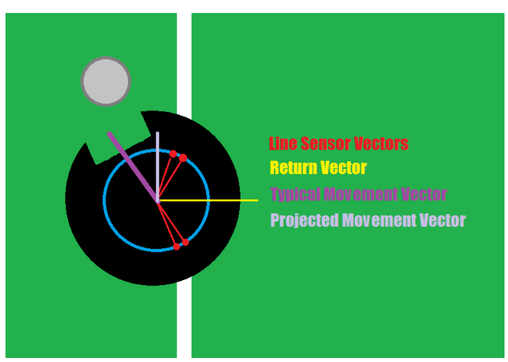

Fig. 7. Vector projection diagram

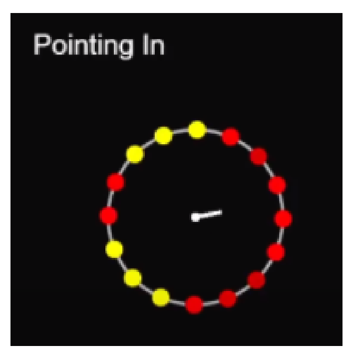

Fig. 8. Wireless line detection debugger

We have seen many robots with jittery motion near field boundaries because the robot moves towards and away from the line repeatedly. In order to scoop the ball from outside of the field, the regular motion vector should be projected onto a line parallel to the detected white line. An example vector projection is illustrated in Figure 7. This method allows our robots to smoothly grab the ball from out of bounds without losing momentum. Vector projections are risky because if the robot is moving at a high speed towards the line, its momentum could send it out of bounds. We are working on gradually slowing the robot's horizontal speed as it approaches the line to minimize this risk.

4.2 Role Switching

An RCJ team comprises of two robots. Our robots are identical in design and dynamically switch roles between goalie and striker to capitalize on situations when the goalie is in a better position to score than the striker. The robots send each other the approximate distance to the ball and the closest one is assigned to offense while the other is the goalie. Wirelss communication also allows us to monitor the robot remotely.

4.3 Vision

The OpenMV H7 camera and conic mirror tower provide rich data, but extracting accurate information is difficult. Our robots are able to aim their kicks and defend the goal effectively using vision analysis. We thermoformed our mirrors out of PVC mirror foil over a lathed wooden mold, shown in Figure 9. We previously machined a polished aluminum cone using a lathe, but it was too heavy. We support the mirror using a 3.2 mm thick acrylic tube because its stiffness prevents the mirror from wavering.

Fig. 9. Thermoformed Mirror

The most fundamental use of camera is determining the robot's angle to the goals. This allows the striker to aim towards the goal and the goalie to maintain its position between its goal and the ball. The algorithm utilizes OpenMV's blob detection function. Before each match, we calibrate color thresholds to account for varying lighting and goal colors. Our algorithm finds the rectangle of best fit for both goals and uses inverse trigonometric functions to estimate the angle from the robot to the center of the goal.

Furthermore, our striker recognizes the position of the opponent's goalie so that it may kick past it. This is accomplished by utilizing the OpenMV's merge parameter in goal detection, which merges color blobs that are close together. Since the goalie only blocks a small portion of the goal, the pixels present in the merged image but not in the unmerged image represent the goalie.

5 Conclusion

Our robot has many innovative features despite weighing less than 1100 grams. Four double layered omniwheels and Maxon motors provide fast acceleration, while a kicker and dribbler allow our robot to outmaneuver the opponent when scoring. Our omnidirectional camera is used to estimate the angle to each goal and the location of our opponent's goalie, helping our robot to line up a good kick or defend our goal.

Next year, we will participate in the Open league with new and improved robots. In addition to keeping our lightweight design and low center of mass, we want to add a second dribbler on the back of the robot as many successful Open teams have done. We are experimenting with 2D LIDAR for detecting opponent's robots, but we are unsure whether it is worth the additional weight. We look forward to the prospect of challenges related to the integration of SSL rules in the RCJ league, such as changed kickers, field, ball, and more.

6 Acknowledgements

First, we thank our sponsors, Maxon, Robomov, and OpenMV. We are also greatly appreciative for our parents, who have supported us in every way. Finally, we thank the teams M&A[3] and Sky Crew[4] for answering our questions and their helpful websites. Team Transcendence's fantastic website[2] was also very useful.

7 Appendix

We used Onshape to CAD our robot and a heavily modified Creality CR10 3D printer to 3D print parts. Our 3D-printed parts are made of NylonX, a carbon fiber reinforced filament. Our PCBs were designed using Autodesk Eagle and manufactured by JLCPCB. We used C++ to program the robot and Python for the camera.

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