Leopard RoboCup 2021 Team Discription Paper

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Abstract. This paper describes the unique hardwares and softwares that Leopard developed to participate in RoboCup 2021 Junior Soccer Open. Our goal is to make robots play more human-like soccer. In order to realize this goal, we introduced five new main technologies to our robots this year: multi angle kickers, LiDAR, an optical motion sensor, a new ball-following algorithm and a new line algorithm. In addition, it also describes the technologies that support these five and also introduces the experimental procedure and tools used in those development processes. Finally, we also discuss the future development of these technologies.

1 Introduction

Our team(Fig.1) was formed to aim for the world championship of RoboCup 2021. Each member participated in the former RoboCup and achieved good results. Especially Yuta participated RoboCup 2018 Motréal and got Best Innovation Award. Kyohei and Togo belonged to one team in soccer Lightweight at RoboCupJunior in 2020. In order to compete in the Open, Kyohei and Togo made major changes to their plane. Yuta is in charge of the offense robot, Kyohei is in charge of the hardware of the defense robot and Togo is in charge of the software of the defense robot.

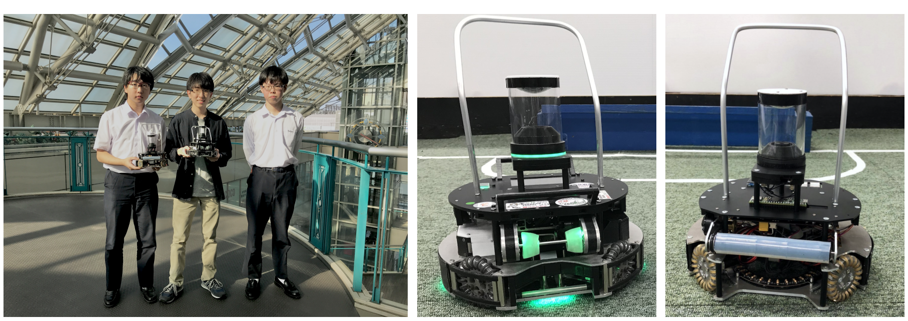


Fig. 1: Team Photo

To score even a momentary chance, we developed multi angle kickers. LiDAR enabled robots to dodge the opponent robot accurately. And the new ball-following algorithm can be used for the moving ball, by ball localization using an optical motion sensor. The motion sensor is also used to improve the accuracy of the multi angle kicker. A new line algorithm makes it easy to recognize even curved white lines.

2 Hardware

Expanding the capabilities of the hardware enables new software strategies. Then we have developed what shown in following sections. Our robots consist of sensors and mechanisms shown in Table 1.

Table 1: Parts List

	Offense	Defense
Motor	4×maxon RE16 + GP16A (19:1)	
Motor Driver	4×self-made one using DRV8701E	4×Pololu G2 18v17
Wheel	4×Self-made omniwheels	
Kicker	2×Solenoid CB10370100	BLDC SURPASS 2204 1400KV
Dribbler	2×BLDC SURPASS 2204 1400KV	-
Main Controller	STM32F446RET6	Teensy 3.5
Sub Controller	ATMEGA328P for distance sensors 4×ATTiny828 for line sensors	-
Distance Sensor	2×Ultrasonic sensor HC-SR04 1×ToF VL53L0X	3×IR sensor GP2Y0E03
Line Sensor	44 independent elements	16 circular placed elements
Camera module	OpenMV Cam M7	OpenMV Cam H7
LiDAR	5×ToF VL53L0X	
Motion Sensor	ADNS-9800	-
Ball Encoder	2×AH1751 1×ATTiny84A	-
IMU	BNO055	

We used a 3D printer and a CNC to fabricate the parts. The 3D printed parts were designed using Fusion360, the CNC machined parts were designed using AutoCAD. PCBs were designed using KiCAD and soldered by hand.

2.1 Multi Angle Kickers

Offense robot has multi angle kickers that can kick in any direction. A multi angle kicker consists of two solenoids and two linear motion mechanisms, one on each side. The linear motion mechanisms intersect vertically to give the ball two orthogonal force components. By controlling powers of solenoids of each side, various direction of diagonal kick is available. The solenoid power control is achieved by energizing time. We have developed a multi-angle kicker for the back side as well as the front side. For weight reduction and miniaturization, solenoids are shared between the front side and the back side (Fig.2). The multi angle kicker also enables straight kick while moving laterally by kicking in a direction that cancels the velocity of the robot obtained by an optical motion sensor. Moreover, by combining back kicker and back dribbler, it is also possible to perform magic shoot using backspin in which the ball cannot be seen from the opponent robot.

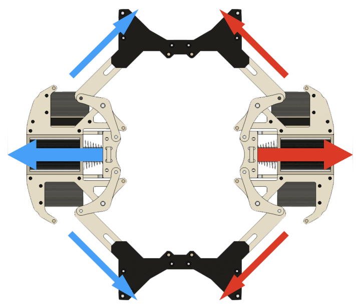


Fig. 2: Multi Angle Kickers

2.2 Self-Made LiDAR

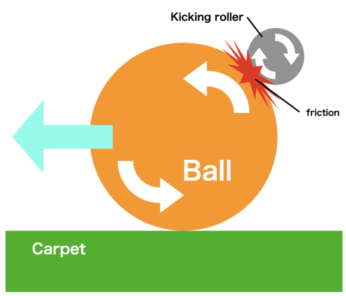
To avoid the opponent robot with high probability and shoot, it is necessary to detect the robot directly. Off-the-shelf LiDAR has high performance, but requires advanced processing and is difficult to install on small robots. Then we developed self-made LiDAR with five ToF distance sensors. The VL53L0X was small enough to be placed in a limited space, and ideal for multiple installations. Five distance sensors are placed at 20 degree intervals in front of the robot.

The threshold is set to a value slightly less than the average of the five sensor values, and objects are recognized to be in the direction where the value is less than the threshold.Instead of recognizing non-goal areas as opponents, LiDAR can be used to directly recognize the opponent robot and dodge the opponent without relying on vision systems.

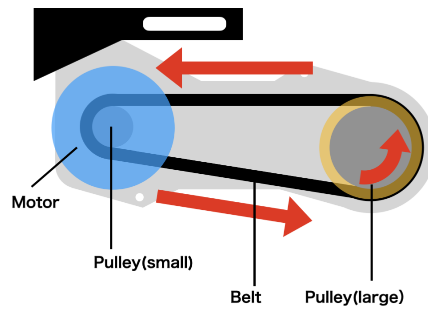
2.3 Top Spin Kicker

This mechanism is for defense and did not need to capture the ball. We have developed a top spin kicker which bounces the ball back [2]. This kicker differs from the conventional kicker that uses a solenoid to directly impact the ball, and is a mechanism that spins the kick rollers to spin and bounce the ball(Fig.3a).

This kicker module is a belt-driven type, which means that it consists of only one motor, two pulleys, a belt, and a drive shaft, making it possible to reduce weight(Fig.3b). Each pulleys have two different diameters, large and small. The pulley directly connected to the motor is small, while the pulley in contact with the ball is large, allowing the ball to be rotated with a torque stronger than that of the motor. For the purpose of reducing friction loss and improving durability, we installed the ball bearings on both sides of the drive shaft. The deformation of the silicone rubber at the contact between the ball and the roller causes energy loss, so we inserted a core material made by a 3D printer to minimize the deformation of the silicone rubber.



(a)



(b)

Fig. 3: Structure of Kicker

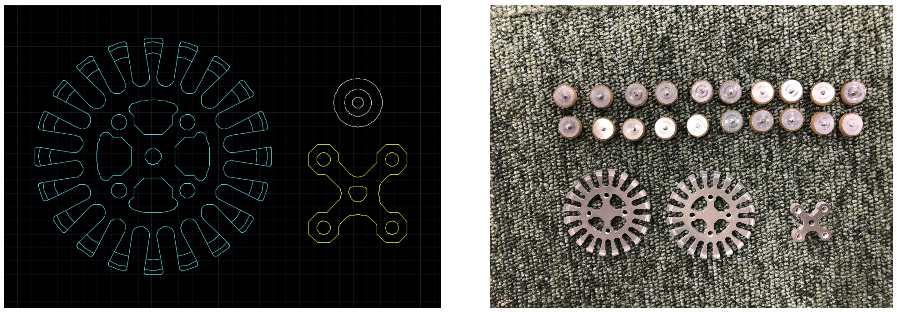
The advantage of this kicker is that the ball can be pushed back the moment it enters the ball capture zone. We were able to reduce the number of ball sensors. It is now possible to kick from the penalty area and score on the enemy's goal. We also needed to increase the width of the ball capture zone to maximize the benefits of this kicker. We made it possible to increase the width by changing the position of the motor.

2.4 Vision System

We built our own vision system. By using an omnidirectional hyperbolic mirror, the robot can see in all directions, so it finds the ball anywhere[1]. We designed the mold of the hyperbolic mirror using Fusion360, and then fabricated it using a 3D printer. The mirror was easily formed by heating a PVC mirror sheet and pressing it against the mold.

2.5 Fabrication of Parts

We used a CNC milling machine to process a variety of parts, and because it can cut exactly as designed in AutoCAD(Fig.4a), we were able to process a wide range of things, from our small parts to chassis(Fig.4b). We also used a laser cutter to process the urethane rubber used for the side wheels. By using many kind of processing machines, we were able to create a variety of gimmicks.



(a) Design in AutoCAD **(b)** Disassembled Omni Wheel

Fig. 4: Omni Wheel

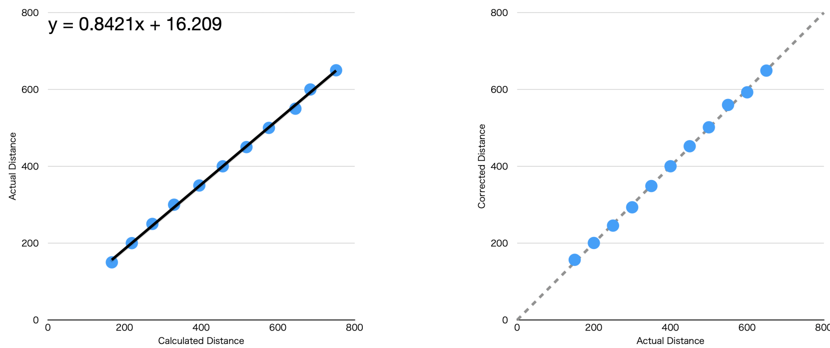
3 Software

Our source code is huge for advanced processing. So the main controller program is written in C++, and the source code is split into multiple files to make the program easier to read. The offense program was developed in Xcode using mbed. The defense program and sub controller program were developed with Arduino. And Vision system was written in Python using OpenMV IDE.

3.1 Distortion Correction of Hyperbolic Mirror

As the vision system, we made hyperbolic mirror ourselves [1] that is easy to correct distortion with software. We deal with position of the ball in mirror in polar coordinates, so we corrected the distance from the center linearly.

However, due to insufficient fabrication accuracy, there was an error between the actual value and the measured value. So we conducted an experiment to correct the error. We placed a ball every 5 cm and obtained the relationship between the actual distance and the calculated distance in the front, back, left and right directions. We plotted the average of the calculated distances at each actual distance on a graph to get the equation of the trend line (Fig.5a). Using this equation, the error between the calculated distance and the actual distance was reduced (Fig.5b).



(a) Before Correction

(b) After Correction

Fig. 5: Relationship between Actual Distance and Calculated Distance

3.2 Robot and Ball Trajectory Visualization System

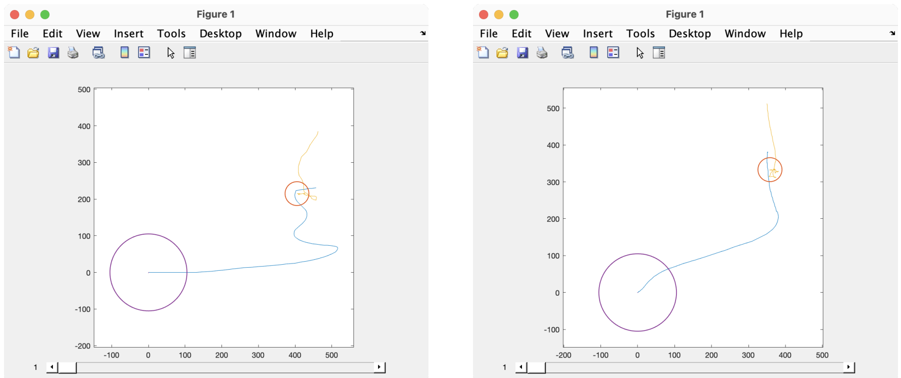
When developing ball position estimation and velocity calculation described in following sections, we created a system that visualizes the position and velocity of the ball and the robot, in order to improve development efficiency. This system consists of serial communication reception program written in Python and visualization program using Matlab. To utilize this system for strategy development, robot sends data using a protocol that can complement missing data in order to enable wireless communication(ZigBee) between the robot and the PC. Python program receives and complements data, and exports it in CSV format. Matlab program visualizes the trajectories and displays the velocity vector at each point by moving slider.

For example of utilizing this system, we adjusted parameters of control to follow the ball. We were able to analyze in detail the positions and velocities of the robot and ball at each point when designing the control to move smoothly as shown in Fig.6.

3.3 Ball Localization Using Optical Motion Sensor

To get absolute velocity of the ball for use in following section, absolute position estimation of the ball is necessary. We realized coordinate estimation of the ball using the initial position of the robot as the origin using an optical motion sensor. An optical motion sensor gets the changes in robot's position. By integrating it considering posture of the robot, the coordinates with the initial position as the origin are determined.

By adding the relative coordinates of the ball to the absolute coordinates of the robot, the absolute coordinates of the ball are obtained. To perform this operation, we converted the units of those coordinates to millimeters. The conversion coefficient of the motion sensor was obtained by repeating the operation of moving 300 mm in the positive and negative directions of the X-axis and the



(a) Control with Bad Parameters **(b)** Control with Adjusted Parameters

Fig. 6: Trajectory of the Robot and the Ball

positive and negative directions of the Y-axis four times each.The relative coordinates of the ball have already been obtained in millimeters in the previous section. Since the update cycle of the camera is more than twice as long as the control cycle, the position of the ball is updated only when data is received from the camera, and the absolute velocity of the ball is calculated by measuring the interval.

3.4 Ball Following Control Using Ball Velocity

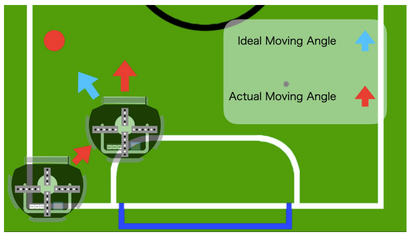
A control that does not take into account the velocity of the ball can follow a stationary ball smoothly, but not a moving ball. So we implemented a control that takes into account the velocity of the ball.

First, calculate the velocity of the robot to follow the ball assuming the ball is stationary. Then, by adding the velocity of the ball to the calculated velocity of the robot, the robot can be controlled in the coordinate system where the ball is stationary. When the ball is stationary but the robot is moving, the coordinates of the ball fluctuates a little. Then if the sum of the standard deviations of the X and Y coordinates of the ball of the last five times is smaller than a certain number, the velocity of the ball is considered to be zero.

This control allows the robot to smoothly follow a moving ball as well as a stationary ball. Not only can the robot reach the ball quickly, but it also be expected to follow the movements of the opponent robot to dodge the own robot.

3.5 Line Algorithm with Circular Placed Sensors

We have changed line sensor from the conventional cross shape to a circular shape to adapt to the new rules starting this year. The circular shape makes it possible to determin exactly what condition the robot is on the line. In a cross shape line sensor, cannot accurately determine the direction in which the robot should move (Fig.7a). In a circular shape line sensor, the exact direction in which the robot should move can be determined exactly (Fig.7b).



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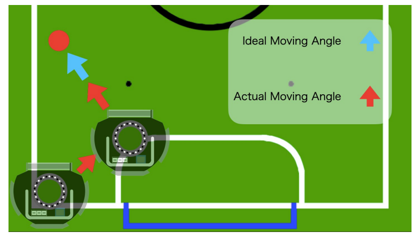

(b)

Fig. 7: Line Algorithm

The current court has additional white lines in front of the Goal. So, with a cross shape line sensor, it is difficult to defend Goal in the left and right side of the Penalty Area.Because many patterns are required depending on how the front, back, left, and right four are on the line.However, circular shape line sensor checks the distance between the sensors on the line and determined the angle, so it can defend the goal with fewer patterns and even on lines with complex shapes [3, 4].

4 Conclusions and Future Work

In this TDP, we presented mechanisms with potential for development and high-precision sensing technologies. Through these developments we leaned that advanced control techniques are required to demonstrate capabilities of complex and interesting mechanisms while those systems enable new strategies. However, the power of the current multi angle kicker is weak and there is room for improvement to make it more powerful. We also got able to combine information from multiple sensors to get one accurate data. By applying this technology, it may be possible to realize more accurate sensing using conventional sensors.

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