RoboCup 2021 Worldwide
Team Description Paper
Junior League - Lightweight Soccer

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Abstract

A great leap was taken from using pre-packaged sensors to open source sensors. Exclusive PCB modules for most of the components were developed for our soccer robots. A camera system, including a suitable cone mirror, was also added to the robot to detect the angle and distance of both goals for greater accuracy. I2C communication was covered in the system in order to boost into highest performance. Omni-wheels were also self-designed which were light and provided necessary friction.All the sensors were connected to the microcontroller and controlled using complex programs and algorithms.

Introduction

History

The Robotics Team of Cheung ShaWan Catholic Secondary School (CSWCSS) was established in 2008 and has since actively participated in multi-various local and international RCJ competitions. The present team was formed by 5 senior form students in 2019. In 2008, for the first time the robotics team qualified for the RoboCup International Championship and obtained the first runner-up. After a decade, our efforts have finally brought our club back to the world stage and three members will represent our club and country in this year's RCJ Soccer Lightweight League.

Past Achievements in previous RoboCup tournaments

Name	Award	Name	Award
RCJ Taiwan Open 2019	1st Runner-up	RoboCupChina Open 2019	2nd Runner-up
RCJ Japan Open 2019	3rd Runner-up	Virtual RoboCupAsia-Pacific 2020 (RCAP)	2nd Runner-up

Roles of Team Members

Name	Role	Name	Role
Lee Pak Nin, Marco	Captain, Software developer	Li Ping Yee, Benny	Hardware developer (Mechanical)
Li Chun Kit, Justin	Software developer	Ip Chit Long, Thomas	Hardware developer (Electrical)

Links

Instagramhttps://instagram.com/cswcss_robotics
Facebookhttps://www.facebook.com/hk.csw.roboclub

CAR	Lightweight							
Component	Name	Quantity	Cost/unit	Cost/car	Cost/car(HKD)			
PCB with all components soldiered						Assumption	1USD = 7.8 HKD	
Mainsheid		1	$ 36.86	$ 36.86	$ 36.86		1RMB =1.2HKD	
IR Ring		1	$ 19.57	$ 19.57	$ 19.57			
Grayscale		4	$ 5.03	$ 20.12	$ 20.12			
Xbee		1	$ 3.96	$ 3.96	$ 3.96			
Lidar		4	$ 4.21	$ 16.84	$ 16.84			
Compass		1	$ 3.67	$ 3.67	$ 3.67			
Components								
MTR	JMP-BE-3561	4	$ 575.56	$ 2,302.24	$ 2,762.69			
MTR board	BTN7971	4	$ 117.42	$ 469.68	$ 563.62			
Compass	MPU9250	1	$ 46.25	$ 46.25	$ 55.50			
Lidar	VL53L0X	4	$ 10.00	$ 40.00	$ 48.00			
Pro Mega 2560	Pro Mega 2560	1	$ 51.94	$ 51.94	$ 62.33			
Screen	OLED Screen	1	$ 12.00	$ 12.00	$ 14.40			
Camera	OpenMV H7	1	$ 470.00	$ 470.00	$ 564.00			
XBee	XBee S2C	1	$ 92.00	$ 92.00	$ 110.40			
Wheel board	Cut from acrylic board	12	$ 5.00	$ 60.00	$ 60.00			
Small wheel		48	$ 3.00	$ 144.00	$ 172.80			
Frame								
Carbon fiber		1	$ 200.00	$ 200.00	$ 240.00			
Cone mirror		1	$ 10.00	$ 10.00	$ 12.00			
Wire	XH-2.54 4pin	8	$ 0.35	$ 2.80	$ 3.36			
Wire	XH-2.54 5pin	8	$ 0.44	$ 3.52	$ 4.22			
							SUM	$ 5,424.34
	Courier	-		$ 650.00	$ 650.00			

Fig.1 Bill of materials

Robots and Results

Hardware- Sensors and Components

1. **Main controller - Mega 2560 Pro:**

    Compared to the Arduino Mega2560, the Mega Pro is an embedded controller with a smaller size (38mm x 55mm) than Arduino Mega 2560 (103mmx55mm). With the same number of ports as Arduino Mega 2560, yet 63% smaller in size, it was chosen as the main controller.

2. **Compass(GY9250):**

    GY9250 was used as the compass module of the robot. It is a 9-axis (Gyrometer, Accelerometer and Magnetometer) sensor. The size of the GY9250 is 15mm x 25mm and weighs 2.2g. Raw data is received from the magnetometer and it is transferred to the main controller through I^2C communication. With algorithms and calculations, the data is transformed into true bearing and could be easily used in the main program.

    GY9250 is chosen as the compass module due to several advantages:

    -1. Light- It weighs only 2.2g. Even if it is attached to the PCB,

    It is 6.6g only.

    -2. Sensitive- It can detect B-field within $\pm 4800\mu T$.

3. **LiDAR(VL53L0X):**

    Instead of ultrasonic sensors, such as HC-SR04 , LiDAR(VL53L0X) was used to determine ranges. It emits radiation which can detect up to 2 meter. The time used to measure distance is less than 30ms. The size of VL53L0X is 25mm x 11mm and it weighs only 1.2g. It communicates with the microcontroller using I^2C protocol. Unlike traditional LiDAR, VL53L0X can measure distance accurately up to 1mm.

    VL53L0X instead of HC-SR04 is chosen due to several reasons:

    -1. Lighter- VL53L0X weighs only 3.9g even with PCB while that of HC-SR04 is 7.8g

-2. Smaller size- Its size(25mm x11mm) is much smaller than HC-SR04 (46 mm x 21mm)

4. **Motor and Motor board(JMP-BE-3561 and BTN7971b):**

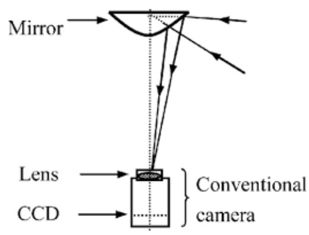
Stellar motors from ZMRobo were chosen. Each of them weighs 87g. Its operating voltage is 12V. The motors can run up to 1700 revolutions per minute. It was chosen as it can run at up to 1700 rpm and its performance is stable. In addition, it is light(87g). The motors are connected to the motor board, BTN7971 b. The size of BTN7971 b is 45mm x 31mm. Each BTN7971b can control one motor. As its operating voltage varies from 7.2V to 20V, it is suitable for the motors. BTN7971 can provide a more precise motor control. Its output current can be as high as 68A, thus it has got a high efficiency. Moreover, it is light in weight(15.1g). In short, they are the designated motors and motor boards we look for.

5. **Communication System(XBee S2C)**

Xbee module is a module of ZigBee wireless technology, which communicates with the microcontroller through inter and other serial devices. This module uses the 802.15.4 protocol stack and supports point-to-point communication. It can give a maximum communication speed of 250kbps. With the addition of the Xbee module, it is expected that there could be communication between two robots and more strategies can be developed, i.e. switch of roles.

6. **Camera sensor and Cone mirror (OpenMV H7):**

OpenMV H7 is used as the camera sensor. It is controlled by STM32H7, with a frequency of 480MHz. The usage of camera sensors allow our robots to detect the angle and distance of our own goal and the opponent 's goal. Robots will perform diagonal movement while holding the ball.

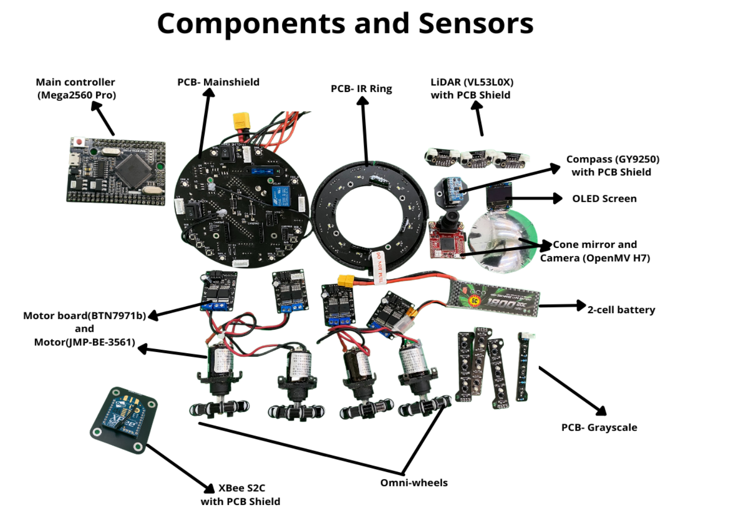


In order to provide a 360° field of view, a hyperbolic mirror is designed and made. It is 3D-printed with an elastic mirror sheet stuck on top of it.

7. **Omni-wheels**:

The robot can move in an 8-axis direction with stable movement with the installation of 4 omni-wheels. Each wheel consists of three layers of acrylic board, layered such that 12 small, 3D-printed wheels can slot inside and rotate freely.

Fig 2 . Components and sensors of the robot



PCB Board

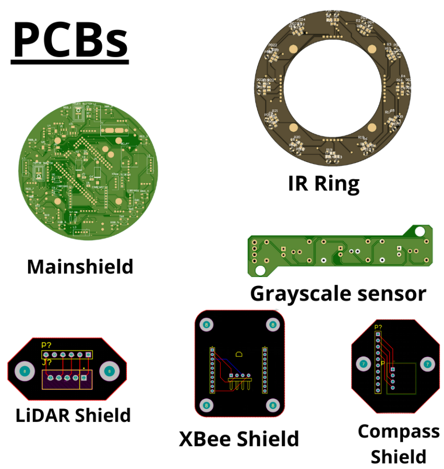
In total, 6 different PCB boards were developed over the course of the past year and a half, all with different purposes.

1. Mainshield

    The most important and the largest board out of the six, the mainshield houses 21 headers, used to connect the various components and sensors in the car to the microcontroller embedded in the middle of the board. There are several switches on the board: the most important two being the main power switch and motor power switch. Power is delivered to the mainshield via the XH60-M power socket, then distributed among the different components via the circuit board. Five LM1117_5.0Vs are used to lower the voltage to 5V to suit the sensors. A 15A fuse and several diodes are used to protect the circuit, while an indication light is connected to show whether the battery has been plugged into the power socket. A 2” OLED screen is used to display data. Moreover, the camera is directly plugged into the mainboard to send data to the microcontroller.

2. IR Ring

    The second most important PCB board in the robot, it is responsible for detecting the infra-red ball used in competitions. There are 12 pairs of photodiodes , each at an angle of 30°, as well as 12 LEDs to indicate the closest photodiode to the ball. It is plugged into the mainshield via two 8-pin and two 6-pin female headers.



3. Grayscale

There are 4 grayscale boards placed diagonally, each with three pairs of photodiodes and LEDs. They are used to detect the white lines on the field to prevent the robot from going out of bounds.

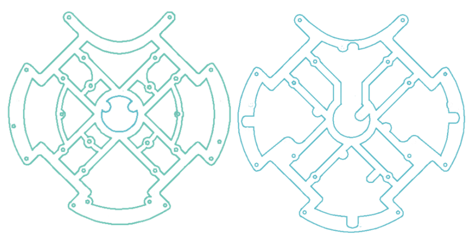
4. Lidar, Compass and Xbee shield

   Each of the three sensors have extra pins that are not used, and each of them need to be placed at different positions on the robot. As such, a shield is designed for each of them, consisting of a small PCB board and several female headers to provide an interface between it and the mainshield.

Frame

For the frame of our soccer robot, carbon fiber is chosen as the material as it is light but sturdy and durable, thus able to avoid unnecessary damage to the robots during the game. The board designs were drawn using Adobe Illustrator, then sent to factories to be cut out. In the front part of the frame, there is a ball capturing zone used for attacking. Handles are also added for more convenient pick up action.

Frame of Robot



Both layers were made by carbon fiber

Between the middle part and bottom part of the frame, the robot carries motor boards, motors and grayscale sensors. The upper part of the frame carries the LiDAR, IR ring, compass, camera sensor and mainshield.

Software

Arduino IDE was the main programming software. For the OpenMV module, OpenMV IDE was used. C language and Python are used in our robots. Here are some improvements of our algorithms.

1. Motor Control
   a. Advanced matrix calculations are used to perform 360 degree movements instead of eight directions. The 4 motors are divided into x-axis and y-axis. Vector and trigonometric functions are then used to calculate the rpm of each motor.
   b. PID controls are also included in our motor control algorithm. It is a control loop which is used to minimize the errors in automation. Proportional-Integral control, a.k.a PI control, is used to set the motor current proportional to the error calculated and changes the motor speed when the robot is far from the designated path.
2. Ball tracking
   a. IR lasers emitted from the IR ball are received by our self-developed IR ring. At the start of the program, readings will be collected from

each IR sensor. Data are compared with one another. Through calculations, each IR sensor will be calibrated in order to minimise the chances of error.

b. The IR ring consists of 12 IR sensors, which can detect the IR ball in all directions. In order to facilitate the ball tracking process, algorithms are developed to calculate the exact direction and distance of the ball. The 12 IR sensors are remapped into radian angles. We first find readings of the IR sensor with the largest reading and the two IR sensors near it. When the ball is between two sensors, the two nearby-values are used to determine which side the ball is closer to. The three values are multiplied by their corresponding angle n*30(n is the index of the IR sensor). It is then divided by the total value of IR readings as an addition to find the ball angle.
c. Wraparound algorithms are also used to calculate the shortest distance between the infra-ball and the robot. In order to capture the ball more accurately, it is divided into different states while tracking the ball. The rpm of motors is set to be proportional to the ball distance. If the ball is far away, it will move at a high speed. It is then reduced when the robot moves closer to the ball.
d. Our robots are able to capture the ball in a curved movement. A constant is added or minused by the ball angle according to the quadrant the ball lies in. The constant is determined by the wraparound algorithm.
e. It is found that the above method is not precise enough. Our previous algorithms are translated to a simple straight line equation, $y=mx+c$, where c is a parameter proportional to the ball distance.

3. Camera sensor
   a. OpenMV is used to detect the goals in order to increase the chances of scoring. When the ball is in the ball-capturing-zone, the robot will turn itself and move toward the side or centre of the goal instead of going straight forward.
   b. It is also used in our defending movements. The robots can ensure themselves stay in the defensive position with the data of goals, angles and directions. If the angle or distance is larger than a constant, the robot will automatically go backward. The pathway of backing defensive position is also determined by the lidars value.
4. Grayscale sensors
   a. The grayscale sensors are easily affected by environmental light and the colour of the white line. At the start of the program, the robot will move along the boundary automatically and continuously collect grayscale readings. It will then undergo different calculations and thus the grayscale value will be adjusted to increase the accuracy of detecting white lines.
5. Communication
   a. The communication algorithms between robots are still under development. We aimed to perform role exchange during competitions. For example, a signal will be sent to robot2 when robot1 captures the ball. Robot2 will then move back to the defensive position.
   b. If one robot is out-of-bounds, it will send a signal to the other robot to indicate its situation. If the defence robot is out-of-bounds or is

considered a “damaged robot”, the remaining robot will adjust its tactics in order to replace the other one. For example, the attack robot will be less aggressive if the defence robot is out of field.

Results

Cone mirror design

To provide a 360° field of view for the camera, omnidirectional vision systems using hyperbolic or spherical mirrors can be used. However, if a spherical mirror is used, the objects near the rim of the mirror will be represented by less pixels and as a result will have a lower resolution near the border of the mirror. If a hyperbolic mirror is used, the image acquired near the border of the mirror would have a higher resolution and thus create a clearer image when viewing more distant objects. Using the following equations and certain given parameters, an equation for the curve of the hyperbola can be obtained[1]:

$$y = \sqrt{a^2 \cdot \left(1 + \frac{x^2}{b^2}\right)} - \sqrt{a^2 + b^2} \qquad (1)$$

$$\phi = \frac{\pi}{2} + \arctan\left(\frac{h - 2\sqrt{a^2 + b^2}}{r_{top}}\right) \qquad (2)$$

$$b = h \cdot \sqrt{\left(\frac{a^2}{b^2} + 1\right)} - \frac{a}{b} \cdot \sqrt{h^2 + r_{top}^2} \qquad (3)$$

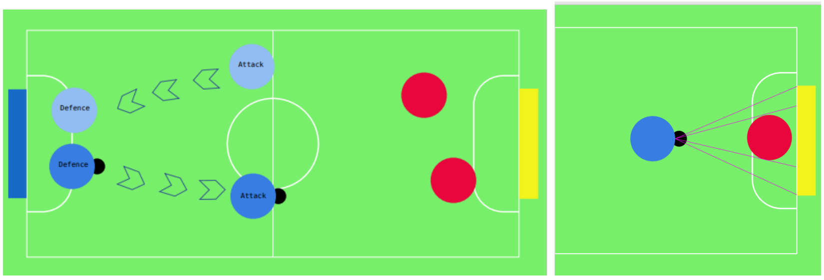
$$h = \frac{f \cdot r_{top}}{t_{pixel} \cdot r_{pixel}} \qquad (4)$$

, where f = focal distance of the camera, h = distance between the focal point of the camera and the top of the mirror, r_{pixel} = number of pixels of the mirror rim radius in the image, r_{top} = radial distance of a point located at the top of the mirror surface (mirror rim), and t_{pixel} = size of each pixel element in the CCD of the camera.

IR sensor cover

As the distance between each IR sensor is small, there were situations where the[1] difference in readings between the photodiode closest to the ball and the surrounding photodiodes were too small to be distinguished. Plus, the noise from the environment caused the reading of the IR ring to be inaccurate. Therefore, a 3D-print cover was made to reduce the impacts mentioned above and increase the accuracy of the ball tracking progress.

Strategy



[1] Please refer to reference 1 for a full report on hyperbolic mirrors.

a. One robot is responsible for defending while the other focuses on attacking.
b. Two robots will switch between attack and defence with the use of XBee communication.
c. The robots will determine the best angle to score a goal, which will bypass the goalie.

Conclusion

The robot had been successfully tested and developed. Most of the components and sensors were self-developed and performed well during testing. It was a great leap for us in R&D. The robot is expected to have more improvements in several fields. These features are expected to be added in the future.

Future work

1. Teammate/Opponent recognition

   In the future, it is planned to use camera sensors to detect teammates. Apriltags or color stickers will be attached to the middle frame of the robots. With tracking algorithms, every robot can know the relative position of one another which can be used to perform more precise corporations.
2. Installation of kicker

   The possibilities of adding a kicker to the robot had been discussed. The main issue with adding a kicker was that it is rather heavy. Moreover, a kicker would consume a lot of power, which may not be able to be supplied by the 2-cell battery. If so, a 3-cell battery may need to be used, which may cause the robot to become even heavier. Therefore, the plan of installing a kicker in the robot was suspended.

   However, if the weight of the other components in the robot can be further reduced, a kicker could possibly be added to provide more attacking options.
3. Self-development of motorboard

   The current motorboard is bought directly online. As such, it already has a certain design for connecting the motor, power supply and control pins, as well as board shape.

   To fully utilize the space within the robot, a plan of self-developing a motorboard has arisen. It is expected that the self-developed motorboard could be installed in our next version.

References

1.Valdir Grassi Junior, Jun Okamoto Junior, Vol. XXVIII, No. 1, January-Mach 2006, https://www.scielo.br/j/jbsmse/a/DsBwhLGNP3ZWGfTr4sQMQFy/?format=html

2.adafruit/Adafruit_VL53L0X, https://github.com/adafruit/Adafruit_VL53L0X