Team Raffles TDP

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Abstract. Team Raffles has made numerous changes to its hardware and software designs across multiple years to improve robot performance in RCJ Soccer. This paper highlights the notable changes found in our 2021 design, including an improved brushless motor dribbler with spring damping and no gearing, and strategies centered around Bluetooth communication.

1 Introduction

1.1 Team Background

Team Raffles began when Raffles Institution students Teng Yi, Mun Hin and former member Ruihan built Soccer Lightweight robots from scratch in 2019. At RoboCup SG Open 2019, the team placed 1st and represented Singapore at RoboCup Sydney, placing Individual 5th and Superteam 1st. In 2020, the team switched to Soccer Open joined by our senior Samuel, but the national open was cancelled. In October, Harmony and Yi Lin joined the team, and we worked on building improved robots for 2021, with Harmony and Teng Yi on hardware, and Mun Hin and Yi Lin on software.

Fig. 1. From left to right: Mun Hin, Teng Yi, Harmony, Yi Lin, our robot

1.2 Current Year's Highlights

Hardware: Improved dribbler, LiDAR and camera systems

Software: Bluetooth role-switching and ball data transmission, camera-based aiming

RoboCup Singapore Open 2021: Best Presentation, Logbook and Engineering (Hardware and Software)

2 Robots and Results

2.1 Hardware Improvements for 2021

Table 1. Bill of Materials (for one robot, blue – upgraded, green – added)

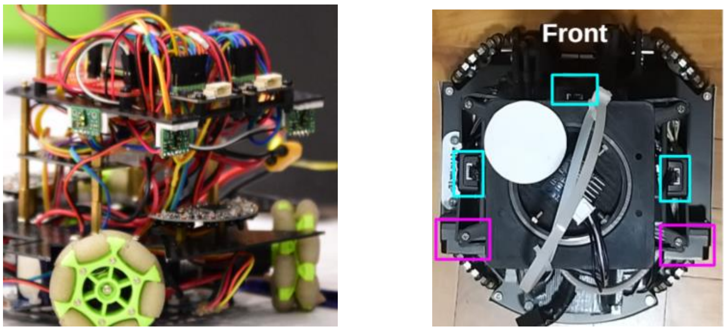
Function	Manufacturer	Part	Qty	Unit Price (SGD)
All	JLCPCB	Printed Circuit Boards (Bottom, Middle and Top)	1	$21.00
	-	Assorted Building Materials (e.g. Spacers, Wires)	1	$40.00
Control	PJRC	Teensy 3.5 Microcontroller ↳ 2nd Teensy upgraded from Pro Micro	2	$40.00
	-	Rocker Switch	1	-
	Gateron	MX Keyboard Switch	3	$0.60
Power	Turnigy	3S 3000mAh 40-50C LiPo Battery	1	$36.00
	Matek	XT60 Power Distribution Board	1	$16.00
	Pololu	U3V50AHV 9-30V Step-Up Voltage Reg ↳ Upgraded from XL6009 Boost Converter	1	$26.00
	Pololu	D36V50F5 5V 5.5A Step-Down Voltage Reg ↳ Upgraded from D24V50F5 5V 5A Step-Down	1	$30.00
	Pololu	13.2V, 15W Shunt Reg	1	$10.00
Movement	JoinMax	JMP-BE-3561 12V 1700RPM Motor	4	$130.00
	Elechouse	50A Motor Driver	2	$44.00
	GTFRobots	GTFRobots 50mm Metal Omniwheel ↳ Upgraded from JoinMax Omniwheel	4	$60.00
Line Sensor	WorldSemi	WS2812B SMD RGB LED ↳ Upgraded from 3mm White LEDs	16	-
	CJMCU	TEMT6000 Analog Light Sensor	18	$1.00
LiDARs	Benewake	TF Mini Plus LiDAR TF Luna LiDAR ↳ Both upgraded from VL53L1X LiDARs	2 3	$73.00 $33.33
Camera System	OpenMV	OpenMV H7 Camera ↳ Upgraded from OpenMV M7 Csm	1	$87.00
	-	Vinyl Chloride Mirror Sheet (Thermoformed into hyperbolic mirror)	1	-
Orientation	-	GY-951 IMU	1	$21.00
Dribbler System	Surpass Hobby	2212 C2830 750kV Brushless Outrunner Motor ↳ Upgraded from TT Motor	2	$18.00
	Tamiya	4WD Sponge Tire	2	$2.50
	AWD RC	80mm RC Shock Absorber	1	$4.19
	LittleBee	20A BLHeli-S ESC	2	$6.13
Kicker	SparkFun	SparkFun Logic Level Converter	1	$4.00
	-	5V Relay	1	$1.30
	-	JF-0826B Solenoid	1	$5.00
Comms	-	HC-05/HC-06 Bluetooth Module	1	$16.00
Total Price:				$1,564.54

*More in-depth assembly of the robot can be found in our 2021 Hardware Report

LiDAR System. In 2019, our VL53L1X LiDARs (Fig. 2a) had a 27° field of view (FoV). With a 27° FoV, the LiDARs (at 0.15m height) would start sensing the floor rather than the walls when placed 0.64m from the walls, resulting in less accurate readings. In 2020, we narrowed the VL53L1X's region of interest in software to reduce its FoV to 15°. However, using this fix, a smaller sample size of SPAD receivers is used, leading to greater variance in readings. To fully resolve this issue, our upgraded TF LiDARs (Fig. 2b) have much narrower FoVs (Mini Plus: 3.6°, Luna: 2°) which will not sense the floor when placed anywhere within the field.

The VL53L1X have a polling time of 33ms. In 33ms, at full speed the robot can move 31.5cm (enough to fully cross the line) without the LiDARs detecting it and slowing the robot down. To solve this issue, our LiDARs have lower polling times (Mini Plus: 1ms, Luna: 4ms) so they are more responsive to changes in position for strategies which rely on accurate readings for localisation. For Singapore Open 2021, the robot was able to swiftly move to each neutral point with this improved system.

For Superteam matches in Sydney, our robot's localization was limited by the VL53L1X's 4m range, rendering our robots unable to find their precise position. Our new LiDARs can range across the full length of the Superteam field (Mini Plus: 12m, Luna:8m), improving Superteam gameplay in this aspect.



(a) 2019: 5 VL53L1X LiDARs

(b) 2021: 3 TF Lunas (blue) and 2 TF Mini Pluses (purple)

Fig 2. 2 LiDARs facing South, 1 LiDAR facing North, West and East each

Orientation Sensor. Our orientation sensor is used to point the robot North. This is important as if the robot is rotated away from North and the opponent pushes in the direction of the ball, the robot will torque and lose possession.

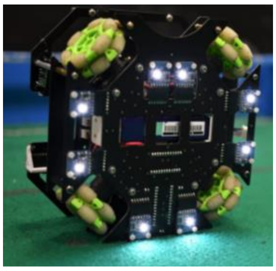
In 2019, we used a JoinMax magnetometer. However, it gave poor readings at Sydney due to heavy magnetic interference. One solution to this is using an inertial measurement unit (IMU), where multiple sensing modes (acceleration, gravity, and magnetic field) are collected and fused to provide more reliable orientation data. This year, we used a GY-951 IMU containing each of these sensors.

Fusing the final orientation values takes up compute time, adding ~8ms of latency with each reading. However, the GY-951 has an onboard ATMEGA328P to run the sensor fusion at 100Hz, so there was no performance loss on our main Teensy.

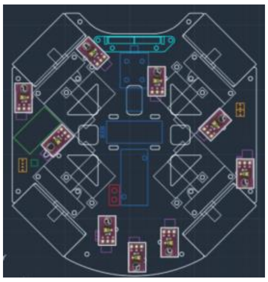
Line Sensor. Our line sensors are fail-safes for when the robot is pushed by other robots into the line. In 2019, we used 8 I2C color sensors (Fig. 3a). One problem with this arrangement is that when moving past the lines, both sensors cross the line at the same time, creating unnecessary redundancy. To solve this, in 2020 we scattered the sensors (Fig 3b) such that each sensor has a unique XY position on the PCB, so that when crossing the vertical or horizontal lines, each sensor would cross the line at different times, maximizing the chances for detection.

Another downside of the 2019 system was that with the integration time of the RGB sensor and added latency from the I2C multiplexer, each sensor had a polling time of 3ms (timed on Pro Micro). In 3ms, the robot could travel 10.5cm at full speed, more than enough for the sensor to cross the 2cm line. After 2020, we switched to TEMT analog light sensors directly wired to the secondary microcontroller to reduce this polling time to <1ms.

However, one separate downside to the 2020 system is that the area covered by the sensors is not optimal. The smaller the area, the less time for the robot to detect the line at high speeds since it crosses the area more quickly. We decided on a circular ring shape to push each sensor to the edges of the robot, maximizing the area covered. We used 18 sensors such that the gaps between their sensing cones are less than 2cm (thickness of the line), leaving no blind spots despite some redundancies. To avoid delays from using multiplexers, we used a Teensy 3.5 with 18 analog pins so every sensor could be directly wired.



(a) 2 I2C color sensors on each side of the robot



(b) 9 TEMTs with unique XY positions

(c) 18 TEMTs arranged in a circle

Fig 3. Light Sensor systems from 2019 to 2021

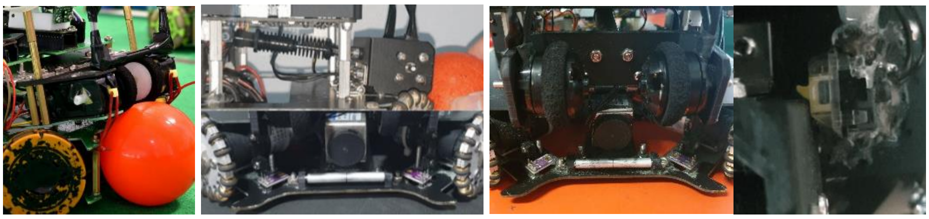
Dribbler System. The dribbler is necessary to gain possession of the ball at high speeds without knocking the ball away (which happened to us without a dribbler in 2019). In 2019, our seniors doing Open used 2 brushed motor gearboxes (300RPM), which were fixed to hinges and tensioned with rubber bands (Fig. 4a). One advantage of their design was that their Tamiya 4WD sponge racing tires had a high coefficient of friction to transfer more energy to the ball, while having a slight damping effect to reduce small vibrations, so we kept using them.

But one problem with the 2019 dribbler was that the rubber bands' tension was hard to adjust. Hence in 2020, we were inspired by team Ri-one Nano[2] to use an oil spring shock absorber instead (Fig. 4b), so we could easily adjust the tension and damping.

Another problem was that the spinning rubberized ball rubbed against the bottom PCB, losing energy to friction, and lowering efficiency. A ball roller was also added in 2020 to reduce friction from the ball rolling against the bottom plate.

Additionally, our gearboxes would jam occasionally in 2020. Therefore, for 2021, we directly drove 2 brushless motors without gears (Fig. 4c) to reduce the number of moving parts and hence possible points of failure. To ensure the motors had enough torque to spin the ball, we bought 20A brushless motors with lower kV (750 RPM per volt).

It was difficult for the camera to consistently detect the ball in the ball capture zone, so in 2021 we added a ball capture sensor (Fig. 4d), which triggers when the dribbler is pushed up, allowing the robot to reliably determine when the ball has been captured.

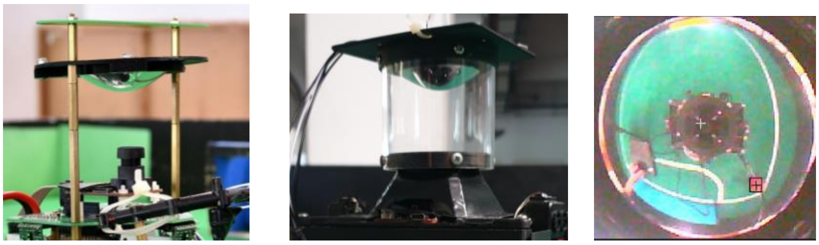


(a) 2019: Gearboxes with Rubber Bands (b) 2020: Oil Spring Damping and Ball Roller (c) 2021: Brushless Motors (d) 2021: Ball Capture Sensor

Fig 4. Dribbler from 2019 to 2021

Camera System. We use a camera and a hyperbolic mirror for omnidirectional vision of the ball and goalposts. In 2019, the hyperbolic mirror was mounted on standoffs (Fig. 5a). However, the standoffs created blind spots where the camera could not detect the ball. For 2021, we replaced the standoffs with a clear acrylic mirror tube to remove the blind spots. There are some IMU wires visible from the tube, since the IMU had to be mounted on top to avoid magnetic interference from the motor drivers. However, they are thin enough for the ball to be detected anyway (Fig 5c).

In 2019, the 2 mounting points holding the mirror were insufficient to secure it in a 3D space and it tilted easily, affecting the ball angle and position readings. Hence, for 2021, the clear acrylic tube was mounted using a friction-fit ring mount (Fig. 5b).



(a) 2019: OpenMV M7 Mirror Mounted on 2 Standoffs (b) 2021: OpenMV H7 Mirror Mounted on Clear Acrylic Tube (c) OpenMV detecting ball past IMU wires

Fig 5. Camera systems from 2019 to 2021

2.2 Software Strategies

We run a striker - goalie configuration, with one offensive and one defensive robot. The striker goes out and attempts to score goals, while the goalie stays behind to prevent the opponents from scoring. This was chosen over the double striker configuration which we tried at Sydney. It left our defense weak as the strikers could not capture the ball fast enough, and they clashed with each other while ball tracking, resulting in a 0:10 loss.

Compass Correction. The robots often unintentionally rotate due to factors such as collisions with other robots. To keep the robot pointed North for previously mentioned reason, we use a rotation factor determined by *TurningRate* = *CompassError* * *Kp*, where $K_p = 1/\alpha$ and α is a chosen constant. However, this alone was ineffective in keeping the robot's heading pointed North due to speed variations. As movement speed increases, less correction is needed, and the required K_p decreases. Hence, we calibrated α at multiple fixed speeds such that it eliminates oscillations and undercorrection, after which the data points are used to plot a best fit cubic equation (Fig. 6).

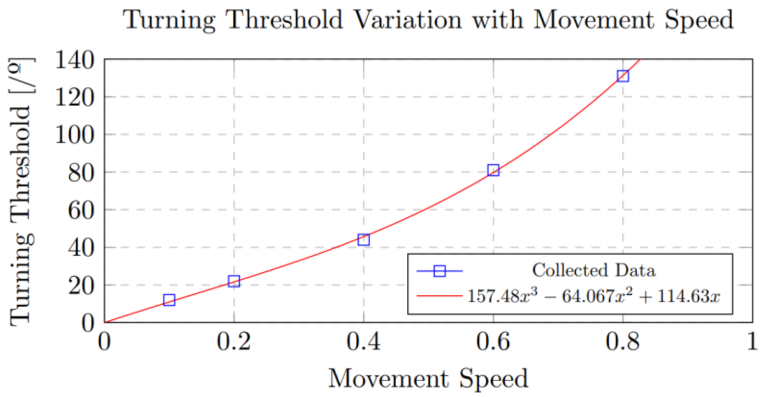


Fig. 6. A calibrated compass turning threshold (α) curve (R^2=0.9994)

Staying within Boundaries. At the 2019 Nationals, our robots relied on 4 color sensors to detect the white line. Coupled with its high speeds, this meant that our robots a) did not detect the white line and b) were unable to react in time, causing them to go out of bounds. The "double out" rule in place at Nationals meant that opponents were immediately awarded a goal once both of our robots went out, and we conceded 10 goals across 5 matches to this alone. Additionally, even more were conceded from our goal being left open after our robots' removal for 1 minute every time they went out.

Several measures were implemented to ensure that the robot would always slow down enough to react to the white line in time. The first is a position-based slowdown. The robot's movement speed was decreased in cases where it nears the borders of the field. When it is not close to the border, it can continue to move at higher speeds so that scoring ability is not affected.

However, this relies on accurate position information, which is not available if the robot happens to be blocked. The next solution is a confidence-based slowdown. We use confidence as a measure of how sure we are of our position, calculated using the size of the bounding box of possible positions where the robot could be. This is calculated using the LiDAR readings (Fig. 7), with the actual position assumed as the center.

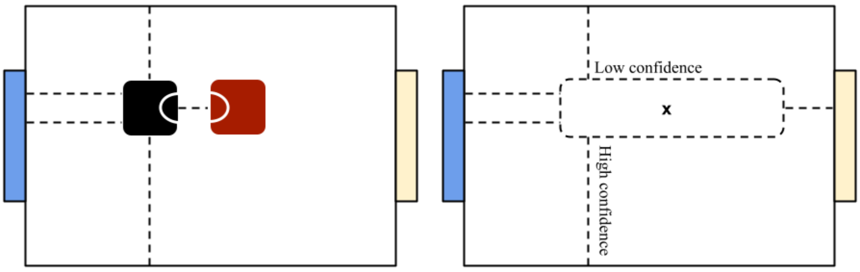


Fig. 7. Bounding box generated during localization

When the LiDARs are blocked, the size of the bounding box increases, decreasing confidence and movement speed. This was split into the 2 axes to allow the robot to continue moving on the axis blocked to a lesser degree. When one axis is almost fully blocked, movement speed along it is slowed down to near 0, ensuring that the robot can react to the white line in time. Since movement speed is also greatly reduced, the robot does not move in the wrong direction when trying to move back towards the center of the field. Using both strategies together proved effective at the 2019 Internationals, where our robots rarely went out (except when damaged).

Striker Strategy. When our robot was trying to score using LiDARs alone, it was often unable to avoid the opponent's goalkeeper. This year, a camera system allows us to avoid obstacles when scoring and is prioritised over the LiDARs.

Another issue with scoring occurs when the robot tries to score from corners near the opponent's goal. If it moves straight towards the center of the detected goal, it hits the goalpost from the side, and is also unable to kick and score since the ball capture is pointed North. Thus, we implemented a strategy which allows it to move backwards in such cases before moving towards the goal, so it can get a direct shot to score.

Goalie Strategy. To defend, our goalkeeper strafes left and right on the white line in front of the goal depending on where the ball is. The ball is sometimes suddenly relocated to the neutral point far away from the goalie, so to reduce its reaction time, it should stay between the goalposts. However, it often overshoots the edges when goalkeeping, wasting precious time. It thus slows down to stop before the goal edge using localization. Goalpost detection using differences in back LiDAR readings is used as a failsafe when localization is inaccurate.

Bluetooth Strategies. Our previous strategies leave us vulnerable to opponents which hide the ball from our robots, for example by using a back dribbler. By implementing Bluetooth ball data transmission between robots, the goalie can continue defending if the striker can see the ball, and vice versa. Having both robots switching at the same time allows us to maintain a striker-goalie configuration.

The goalie is often able to get possession of the ball simply by defending. To increase our scoring opportunities, the goalie switches roles to become a striker when the ball is stationary or captured by the dribbler, also allowing it to pass the ball responsiveness test. When the ball is stationary, it often means that there are no other robots fighting for the ball, likely because they have left the field. In this case, we are unlikely to be scored against while attacking.

At the 2019 Internationals, when our goalie was removed due to damage, our goal was often left undefended by the remaining striker. To solve this issue, both robots ping each other at fixed intervals when turned on in the field, and the striker switches roles when it cannot detect the goalie's "heartbeat".

We are also looking into setting the striker to be the robot closest to the ball or further from the goalpost, to improve scoring and goalkeeping. At the 2019 Internationals, we found that there were many cases where the striker was stuck behind the goalie, such as when they were relocated due to double defense. Both robots were stuck clashing with each other when the striker tried to move forwards while the goalie wanted to move backwards, limiting our scoring and goalkeeping ability.

3 Conclusions and Future Work

3.1 Learning Points from This Year

Strengthening 3D-Printed Parts. Initially, we had problems with prints flexing and snapping. We learned to add chamfers, more points of reinforcement and use finite element analysis to find the best wall thickness to reduce flex and prevent snapping.

Code Modularity. In 2019 and 2020, our strategy code was all in one file. However, this proved problematic when debugging specific strategy components. To improve the debugging experience, we split the strategy into libraries that can be tested individually.

Foresight. This year, we built the robots and filmed footage early as we did not know when schools would close and we would lose access to the field. This footage proved useful in our submission for the National competition.

3.2 Future Hardware Modifications

More Powerful Kicker. Despite boosting the solenoid supply voltage to 30V this year, our kicker failed to overcome increased backspin from the dribbler. While goals can be scored with the added momentum from dashing forward, stationary kicks are unfeasible. We plan to test kicking at various voltages to find the most efficient but still sufficiently powerful kicker next year.

SMT Motor Driver. In planning an 18cm diameter design for the 2022 Open season, our robots' design must be more space-efficient. We plan to integrate SMT motor drivers into the middle PCB, saving 3D space for the battery.

3.2 Future Software Modifications

Opponent Detection. If both robots cannot see the ball but can track opponent robots, the goalie can continue to goalkeep based on the location of the opponent, rather than returning to a set home point, further increasing our chances of successfully defending goals if the opponent is hiding the ball.

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