2021 Team Description Paper: NT

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Abstract. This paper describes the hardware and software of Team NT for RoboCup 2021 WORLDWIDE, and our research on the OmniVision. The paper also presents how we tried to contribute to the RoboCupJunior (RCJ) community last year with the absence of the competition.

1 Introduction

1.1 Team Background

Team NT was formed in 2019 by Hiroya, Shuta and Akitoshi.
Hiroya and Shuta participated in World Robot Olympiad (WRO) in 2 years and Akitoshi participated in RoboCupJunior (RCJ) in 4 years. We selected our working theme based on our specialties so that we are able to improve each other's ability. Akitoshi is the team leader and responsible for general hardware. Hiroya is responsible for software. Shuta is responsible for "theoretical analysis", which is a very unique part of our team.

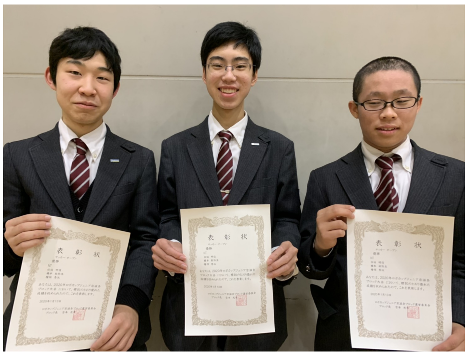

Fig. 1. Our Team

Our motto is "create new". We would like to explore a research topic no one has done before and apply our research results as new technology.
In 2019 we participated in RCJ's ScccerOpen league for the first time. We won the regional competition and were nominated to JapanOpen, but due to the COVID-19 pandemic, both JapanOpen and the world competition were cancelled.
We wanted to do something to contribute to the RoboCup community, even if we couldn't participate in the competition. Therefore, we started to publish the program and design data, and to post them on my blog [1]. We won the Most Popular Poster at the RoboCupJunior Soccer Virtual Poster Session 2020, which was held as an alternative to the world championships, and participated in the RCJ-sim preliminary competition in January, 2021.

We also researched a topic of hyperboloid mirrors during these period and won the third prize of the 64th Japan Student Science Award[2] for the paper summarizing the research results. We think this is the first time in Japan that a high school student team submitted a technical research paper for RoboCup.

1.2 Current year's highlights

This year's robot has evolved a lot from the robot we used in the last competition (2019), and become much cooler.
We did research on OmniVison last year when the World Championships were cancelled, and during the off-season this year. This is a topic that no one else in the Junior League has tried, and the research outcome has very high potential. The details of the robot and the OmniVision are described in Section 2.

2 Robots and Results

2.1 Hardware

Overview: The configuration diagram is shown in Fig.2. We aim to create a "smart" robot with as little visible wiring and circuit boards as possible. We also aim to design the robot in such a way that it can obtain a lot of information from the OmniVison, instead of the number of sensors for measurement.

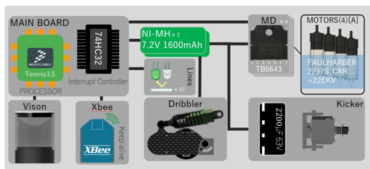

Fig. 2. Hardware overview

Omni-wheels: We use two-layered omni-wheels to ensure smooth running and good grip. By stacking 18 small diameter wheels (18x2), the thickness of the wheel is reduced. The outer periphery is made of aluminum alloy (A2017) to provide shock resistance. To reduce the weight of the robot, polylactic acid resin (PLA) is used for the internal structure. We sandwich a bearing between the motor mount and the wheel. The sandwiched bearing can prevent the wheel from tilting against the axis and reduce the radial forces on the axis. It is this kind of ingenuity that allows our robot to move so smoothly.

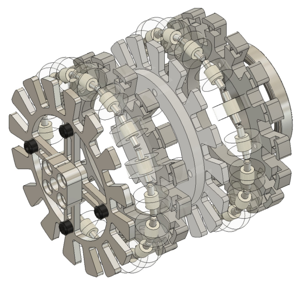

Fig. 3. Exploded view of the omni-wheel

Dribbler: Our robot has two dribblers, one at the front and the other at the back. With a dribbler behind the robot, the robot can shoot "Macau" in front of the goal. There is an advantage that one can score a goal without letting the opponent recognize the ball.

The heaviest part of the robot is the motor. The second heaviest part is the dribbler. It is difficult to reduce the weight of the motor, so if we want to have two dribblers, we have to reduce the weight of the dribbler. Many people make their dribblers out of aluminum alloy. Alternately, we have adopted Carbon Fiber Reinforced Plastics (CFRP) to reduced the weight of the dribbler.

3D printing: We use 3D printers to manufacture most of the parts used in our robots. This is very rare in Japan and is a new challenge. 3D printing technology enabled us to create parts with more complex shapes than Computerized Numerical Control milling machine (CNC) and reduce cost.

2.2 Software

To move in the right direction: The motors can move only forward and backward. We assume a straight line of motors as a vector line. Assuming that zero rad is the direct advance line of the robot and θ [rad] is the direction of the robot's movement, we get $\theta - \frac{\pi}{4}$, $\theta - \frac{3}{4}\pi$, $\theta - \frac{5}{4}\pi$, $\theta - \frac{7}{4}\pi$ for angles of each motor (θ can be used even if it is negative).
When we resolve the vector of the direction where the robot is advancing, we get $\sin(\theta - \frac{\pi}{4})$, $\sin(\theta - \frac{3}{4}\pi)$, $\sin(\theta - \frac{5}{4}\pi)$, $\sin(\theta - \frac{7}{4}\pi)$ for each motor's vector. We set 100 as max power, and we divide the magnitude of vector by max value of these, and these values multiplied by the value of the power, which ranges from 0 to 100.

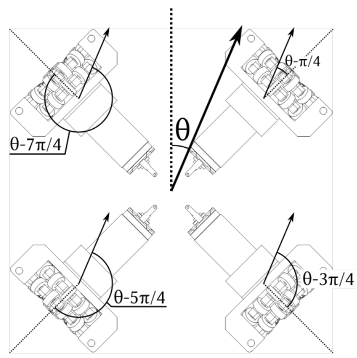

Fig. 4. Angles of each motor

Finally, with the max value as "M" and the power as "p", we create calculation formula of motor's power as below:

$$\frac{\sin(\theta - \frac{n}{4}\pi)}{M} \times p \quad (0 \leqq p \leqq 100, n = 1, 3, 5, 7) \tag{1}$$

Use of arctangent: Next, we decide the value of "θ". Provided that we can get the accurate coordinate with OmniVision System (Please refer to 2.3 OmniVison), we decide to use arctangent for the robot to know the angle against the goal or the ball. We got the angle against the ball in $\arctan(\frac{x}{y})$, and against the goal in $\arctan(\frac{x}{y}) + \pi$.
Now, the robot can go in front of balls accurately. On the other hand, the keeper robot need to maintain a certain distance from the ball. So, we set a horizontal line in order for the robot not to leave the goal. Then, we try to control the robot to move on that line. To identify position of the robot and the ball, we use coordinate system with the goal as origin. The coordinate of the robot is expressed as $(robot_x, robot_y)$, and the coordinate of the ball is expressed as

$(ball_x, ball_y)$. The coordinate of the ball from the robot can be calculated by $(ball_x - robot_x, ball_y - robot_y)$.
When we set horizontal line as $y = 30$, it is desirable that the robot should go to the point $(ball_x - robot_x, 30 - robot_y)$. We conclude that the robot should move on the line with the angle as below:

$$\theta = \arctan\left(\frac{ball_x - robot_x}{30 - robot_y}\right) \tag{2}$$

Best position against the ball: As it stands, the robot can only move on the horizontal line which we decide. We expect the robot to move depending on the y coordinate of the ball within a certain distance. So we use proportional control with y coordinate. Assuming that the certain distance is $30 \leqq Y \leqq 50$, when $ball_y - robot_y \geqq 0$, we expect the robot to go to $Y = 30 + k(ball_y - robot_y)$ (k is a certain constant, $Y \leqq 50$), and when $ball_y - robot_y < 0$, we expect the robot to go to $Y = ball_y - robot_y$.
Considering (2), we conclude that the robot should move on the line with the angle as below:

$$Y = \begin{cases} ball_y - robot_y & (ball_y - robot_y < 0) \\ 30 + k(ball_y - robot_y) & (ball_y - robot_y \geqq 0) \\ 50 & (Y \geqq 50) \end{cases} \tag{3}$$

$$\theta = \arctan\left(\frac{ball_x - robot_x}{Y - robot_y}\right) \tag{4}$$

2.3 OmniVision (Our research in the off-season)

Our robots are loaded with omnidirectional vision sensor and we made properly shaped mirrors, hyperboloid mirrors.

Design of hyperboloid mirrors: We can consider a three-dimensional coordinate system with the projected Y-Z plane shown in Fig.5. In this case, the hyperboloid of two sheets can be expressed by the following equation.

$$\frac{x^2 + y^2}{a^2} - \frac{z^2}{b^2} = -1 \tag{5}$$

Where a and b by are constants that define the shape of the hyperboloid. The hyperboloid in the $z > 0$

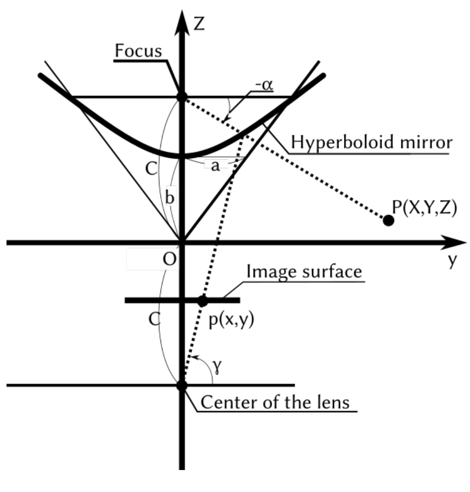

Fig. 5. Hyperboloid mirror

region of the hyperboloid of two sheets
is used as a mirror.

mirror	Eq.5 $(z > 0)$
mirror focus	$c = \sqrt{a^2 + b^2}$
Coordinates of the mirror focus	$(0, 0, +c)$
Center of the camera lens	$(0, 0, -c)$

We design the mirror to have a radius of $26.5 (= \sqrt{x^2 + y^2})$ and a height of $25 (= c)$. By substituting these into Eq.5, it follows.

$$a^4 + 26.5^2 \times a^2 + 25^2 \times 26.5^2 = 0 \tag{6}$$

By using The Quadratic Formula, it follows

$$a \approx 19.97 \tag{7}$$

From Eq.7

$$b \approx 15.04 \tag{8}$$

Coordinate transformation for exact distance: A robot move horizontally with an omnidirectional vision sensor with a hyperboloid mirror, as shown in Fig.6.

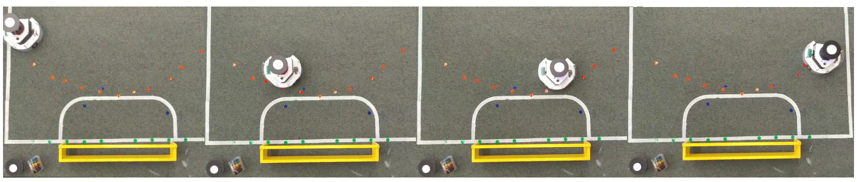

Fig. 6. Figure before coordinate transformation

The coordinate information from the omnidirectional vision sensor with the accompanying hyperboloid mirror is used to perform a coordinate transformation to obtain the exact distance.
The relationship between the coordinate positions obtained from the omnidirectional vision sensor and the actual target object is expressed by the following equation, assuming that the structure of the omnidirectional vision sensor is Fig.7.

$$x = X \times f_x \times \frac{\left(b^2 - c^2\right)}{\left(b^2 + c^2\right) Z - 2bc\sqrt{X^2 + Y^2 + Z^2}} \tag{9}$$

$$y = Y \times f_y \times \frac{\left(b^2 - c^2\right)}{\left(b^2 + c^2\right) Z - 2bc\sqrt{X^2 + Y^2 + Z^2}} \tag{10}$$

By using the above equation, we can convert any coordinate (X, Y, Z) in 3D space to the coordinate (x, y) obtained from the vision sensor. We measure from the goal at a distance of 25 cm in each x-coordinate and y-coordinate, the coordinate of (x, y) is $(34, 37)$ and the coordinate of (f_x, f_y) is $(498.6, 458.2)$.

Camera parameters	
Focal length	50mm
angle of view	62.2°
Number of pixels	3280×2464 pixels

Hyperboloid mirror parameters	
b	14.15
c	25
Z	-170

Fig. 7. Structure and dimensions of the vision sensor

In Fig.7 case, Eq.9 and Eq.10 can be expressed as follows:

$$x = X \times \frac{2.1118 \times 10^5}{1.402 \times 10^5 + 7.08 \times 10^2 \times \sqrt{X^2 + 2.89 \times 10^4}} \tag{11}$$

$$y = Y \times \frac{2.1118 \times 10^5}{1.402 \times 10^5 + 7.08 \times 10^2 \times \sqrt{Y^2 + 2.89 \times 10^4}} \tag{12}$$

Using this result, we performed the lateral movement again, and the robot moved accurately and smoothly as shown in Fig.8 and Fig.9.

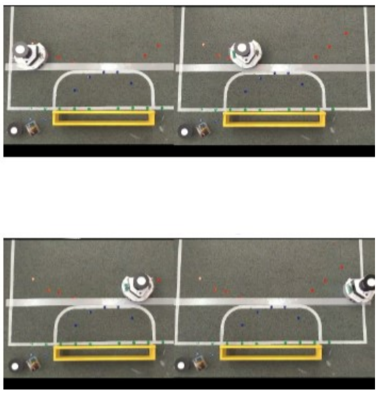

Fig. 8. Figure before coordinate transformation

Table3 Measurement results at the robot's displacement and coordinate positions

Number of times	Displacement	Displacement(cm) -50	-40	-30	-20	-10	0	10	20	30	40	50
1	Distance(cm)	25	25	25	25	25	25	25	25	25	25	25
	x-coordinate	67	53	33	25	11	-5	-24	-37	-54	-67	-78
	y-coordinate	28	33	40	41	42	43	41	41	37	32	27
2	Distance(cm)	25	25	25	25	25	25	25	25	25	25	25
	x-coordinate	67	53	33	25	11	-5	-24	-37	-54	-67	-78
	y-coordinate	28	33	40	41	42	43	41	41	37	32	27
3	Distance(cm)	25	25	25	25	25	25	25	25	25	25	25
	x-coordinate	67	53	33	25	11	-5	-24	-37	-54	-67	-78
	y-coordinate	28	33	40	41	42	43	41	41	37	32	27
4	Distance(cm)	25	25	25	25	25	25	25	25	25	25	25
	x-coordinate	67	53	33	25	11	-5	-24	-37	-54	-67	-78
	y-coordinate	28	33	40	41	42	43	41	41	37	32	27
5	Distance(cm)	25	25	25	25	25	25	25	25	25	25	25
	x-coordinate	67	53	33	25	11	-5	-24	-37	-54	-67	-78
	y-coordinate	28	33	40	41	42	43	41	41	37	32	27
Average value	Distance(cm)	25	25	25	25	25	25	25	25	25	25	25
	x-coordinate	67	53	33	25	11	-5	-24	-37	-54	-67	-78
	y-coordinate	28	33	40	41	42	43	41	41	37	32	27
Calculated value	θ(rad)	1.17	1.01	0.69	0.55	0.26	-0.12	-0.53	-0.73	-0.97	-1.13	-1.24
	θ(deg)	67.35	58.12	39.54	31.39	14.68	-6.64	-30.36	-42.09	-55.61	-64.50	-70.94
	r=SQRT(x^2+y^2)	72.62	62.43	51.86	48.02	43.42	43.29	47.51	55.23	65.46	74.25	82.54
	X=250/cos(θ)	648.35	472.98	324.10	292.81	258.43	251.68	289.68	336.75	442.30	580.07	764.27
	y	67.06	60.13	50.60	47.89	44.53	43.81	47.60	51.61	58.52	64.74	70.24

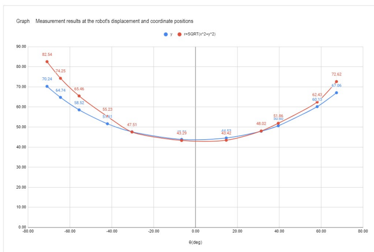

Fig. 9. Table before coordinate transformation

Distortion correction: We create a transformed image in the direction of the floor so that the transformed image plane is the same as the floor plane, and correct the distortion.

$$\tan\theta = \frac{Y}{X} = \frac{y}{x} \tag{13}$$

$$R_p = \frac{-(b^2 - c^2) \times Hr \times r_p}{(b^2 + c^2)f - 2bc\sqrt{r_p^2 + f^2}} \tag{14}$$

$$R_p = \sqrt{X^2 + Y^2} \tag{15}$$

$$r_p = \sqrt{x^2 + y^2} \tag{16}$$

(R_p, θ):polarized representation of P(X,Y)
(r_p, θ):polarized representation of p(x,y)

The Eq.13 to Eq.16 are reorganized

$$X = \frac{R_p}{\sqrt{1 + \tan^2\theta}} \tag{17}$$

$$Y = \tan\theta \times X \tag{18}$$

This makes it possible to accurately measure the distance to an object by generating a coordinate system in the real space from the distorted coordinate system of the omnidirectional vision sensor.

3 Conclusions and Future Work

3.1 Conclusions

In this season, we have realized that "theoretical analysis" is a very important part of our work. Just as recent sports are mathematical (analysis is very important), robotics is also mathematical. Coding and assembling hardware seem to be the main focus of robots. In reality, however, robots are a mass of mathematics, and doing the mathematics (theoretical analysis) means devoting manpower and time to it.
That is the real joy of robotics, and the work that must be done at RCJ. In the sense that we were able to realize this, our year was very meaningful.
In other words, we consider it a success and a victory.

3.2 Future Work

The remaining work for the future are identified as follows:

Elimination of optical line sensor: In section 2, we described how to convert to the floor direction. By performing the transformation, it becomes possible to obtain XY coordinates in real space coordinates. The equation of a straight line is calculated from the acquired image using the straight line detection library of OpenCV. The absolute value of the equation can be used to determine whether the robot is touche the line or not, and the X and Y equations can be obtained respectively to detect the excess.
The most important advantage is that the robot can decelerate when it approaches the line.

Recognition of a Partner Robot Using Panorama Expansion: From the reference paper[3], it is possible to output the same image as the one to be recognized visually by correcting the image by panorama expansion. By using the corrected image, we think that it is possible to recognize the other robot using the object detection function of OpenCV.
By detecting the opponent robot, it is possible to prevent "shooting the ball without being able to see it", which is a tactic used by "Macao" in 2019.

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