

HOSEI UNIVERSITY



Orange2019

Design Report

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Faculty Advisor Statement

I hereby certify that the engineering design on Orange2019 was done by the current student team, and it is significant and equivalent to what might be awarded credit in a senior design course.

Signed

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Date

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1.Introduction

The Hosei University Autonomous Robotics Laboratory (ARL) team has redesigned the Orange 2018 and has presented the new vehicle Orange 2019. By reviewing the successes and failures in Intelligent Ground Vehicle Competition (IGVC) 2018 and by discussing about them with the team members, we found that we should focus on making the vehicle more stable in both hardware and software. Major points to make hardware stable and those to make the software stable can be summarized as follows;

Hardware

- (H1) To realize the stable running, the chassis and the arrangement of the various components are set to make the vehicle's center of gravity lower.
- (H2) To prevent slipping of wheels when navigating slopes, stud-less tires instead of normal tires are newly employed.
- (H3) To make the image recognition stable, we employ a new hardware to accelerate software calculation (Jetson TX2).

Software:

- (S1) To make frame capturing stable, we speed up the image processing by tuning the software.
- (S2) To make vehicle control stable, higher frequency control loop is achieved by tuning the software.
- (S3) To make the image recognition stable, the YOLO v3-tiny based deep learning algorithm is employed as an image recognition engine.

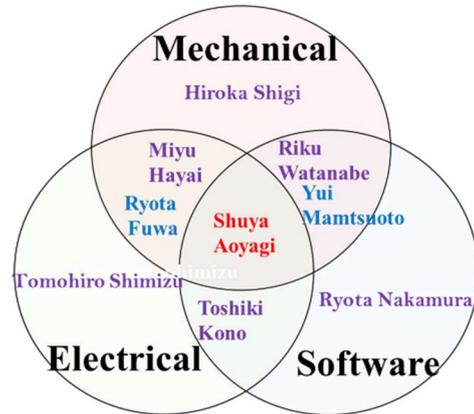
Orange2019 is now a complete autonomous vehicle, ready to take on every aspect of this year's competition.

2. Team Organization

This year, the team ARL has worked on the project, by team members of four graduate students and five undergraduate students. The team ARL was organized by three sub-teams to focus on the specific areas of the design. Table. 1 shows a team organizational chart, including Mechanical, Electrical, and Software sub-teams. To make communication smooth in team members, the role of each sub-team is intentionally overlapped and allocated appropriately to each member, according to their design skills.

Table 1. Roles of individuals and hours spent by them on project

Team Member	Areas of Concentration			Hours
	Mechanical	Electrical	Software	
Shuya Aoyagi (Team Leader)	○	○	○	700
Toshiki Kono		○	○	600
Miyu Hayai	○	○		600
Ryota Fuwa	○	○		600
Yui Matsumoto	○		○	600
Riku Watanabe	○		○	600
Ryota Nakamura			○	20
Tomohiro Shimizu		○		20
Hiroka Shigi	○			20



3. Design process

The goal of ARL team is to let Orange 2019 run completely as fast as possible while keeping stability of the vehicle on the competition course. Figure 1 illustrates our process which aims at agile development.

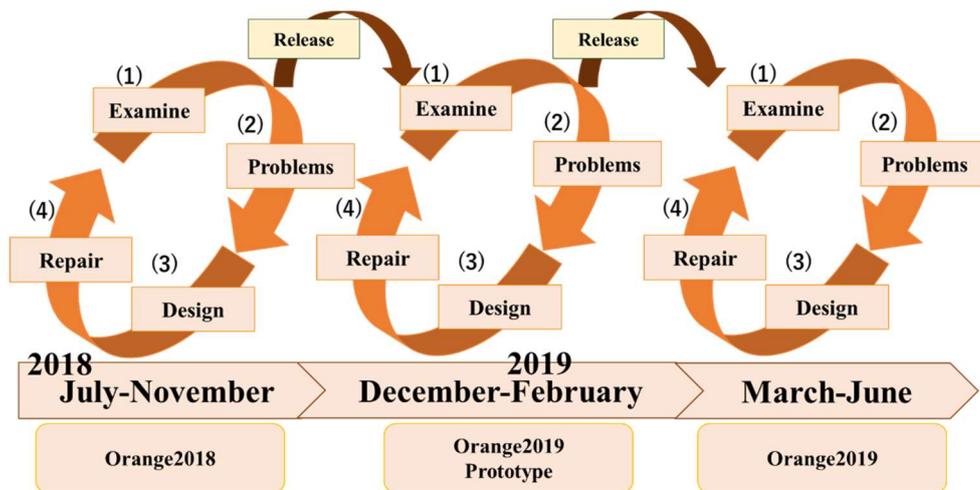


Figure 1. Our development process

The design was begun by analyzing the resulting performance of the vehicle of the previous IGVC 2018 and identifying and investigating the problems that we had experienced. Application of the 4-step process approaches shown in Figure 1 to the Orange 2018 clarifies the basis of design problems. Following to the approaches and team discussions, we conclude that “stabilization” is one of the key concepts to be considered for redesigning a new vehicle.

To make it possible to bring the vehicle as normal baggage by air-plane from Japan to the USA, we design the basic skeleton frame of the vehicle that can be easily dismantled to three parts. Figure 2 shows (a) upper part, (b) lower front part and (c) lower rear part of skeleton frame which can

be loaded in three suitcases.

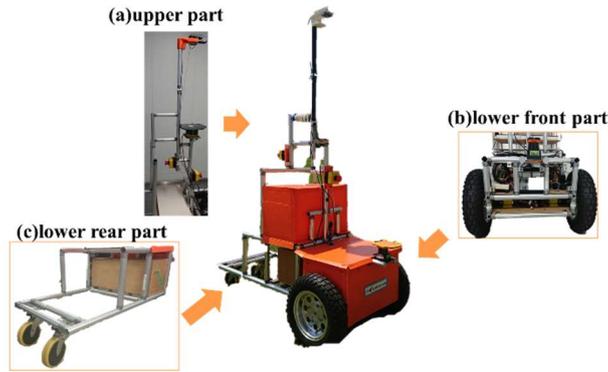


Figure 2. Body composition

4. Innovative concepts

Here, we summarize innovative designs including both hardware and software to stabilize the vehicle, which is our main design goal. Table 2 shows the problems and the innovative improvements for our design.

Table 2. Hardware and Software improvement

Problem	Improvement
Hardware	
(1) Frame stiffness problem	Solved by adding extra support frame for upper part sensors to suppress direct vibration during navigation on the rough terrain.
(2) Rear wheels slip problem	Solved by employing larger radius studless tire and redesigned aspect ratio of vehicle size especially front and rear axle are longer than before.
Software	
(3) Image grabbing time problem	Solved by refactoring the image grabbing source codes to optimize for speed.

4.1 Hardware

Table 2 shows major two hardware problems that we faced during IGVC 2018 competition.

(1) For the frame stiffness problem in Table 2, we redesign the support frame to support the upper part sensors by adding the secondly pillar to suppress direct vibration (Figure 3) by which we can stabilize the sensing function of the vehicle. As a result, the overall vehicle rigidity is improved.

(2) For the rear wheel slip problem in Table 2, we elongate the vehicle frame from front and rear axle (Figure 4) by which we can stabilize the rolling motion and prevent rear wheels slip during

navigation

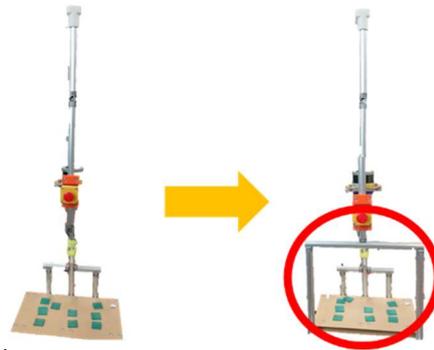


Figure 3. Upper frame design



Figure 4. Lower frame design

4.2 Software

To improve software stability, we refactor overall software for navigation. Major refactoring and improvement are the optimization of source code for image frame capturing process and DC-motor monitoring and controlling process. We newly employ YOLO v3-tiny which is based on the deep learning assisted by the software acceleration hardware Jetson TX2.

5. Mechanical design

5.1 Overall

The vehicle body of Orange 2019 is shown in Figure 5.



Figure 5. The Orange 2019 vehicle body

We employ corrugated plastic board for vehicle exterior as was employed in Orange 2018.

The merits to use the corrugated plastic board are durability, impact resistance, lightweight and water resistive and easy to maintain and replaceable without special tools such as a laser cutter. Figure 6 shows exterior of Orange2019.



Figure 6. Exterior of Orange 2019

To make the viewing area of vehicle Orange 2018 wider, we set the 3D-LIDAR and omnidirectional camera on the top of the longest pole as shown in Figure 7(a). As we set them on the high position, image and distance acquisition becomes more accurate and stable. As shown in Figure 7(b), the support frames are employed upper part in Orange 2019.

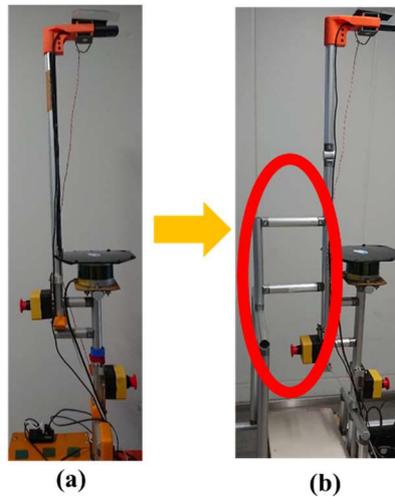


Figure 7. Upper frame (a)before, (b)after

How the vehicle frame from front and rear are shown in Figure 8.



Figure 8. Distance from front and rear axle (a)before, (b)after

5.2 Front component

Figure 9 shows front electric components implemented.

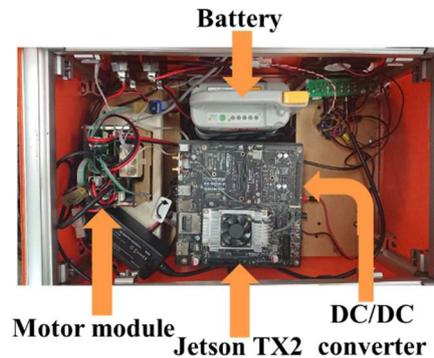


Figure 9. Electric components

Following electric components are contained in the front area in Figure 9:

- Battery
- DC/DC converter
- Controller module including motor driver, E-stop and wireless E-stop
- Two motors connected directly to the tire
- Jetson TX2

Since the battery is one of heaviest components of the vehicle, we arrange to set the battery to the lower position of the center of front wheel axle to make center of gravity of vehicle lower. The DC/DC converter and battery are deployed center to keep balance. The wire harness for sensors are tied by using binding band and clips to make it easy to understand how the electrical circuits are connected in the junction box. As a result, maintenance procedure becomes simple.

5.3 Selection of tire type

In Orange 2018, we employed normal tires for the front wheel, and thus when the vehicle ran on steep slopes, the vehicle frequently slipped that yielded dead reckoning errors. To solve the slip problem, we employ large stud-less tires as the front tires in Orange 2019. Table 3 shows the difference of front tires used in Orange2018 and Orange2019.

Table 3. The difference between Orange 2018 and Orange 2019

	Tire type	Tread	Diameter
 Orange2018	Normal tire		12.6inch
 Orange2019	Studless tire		15.6inch

+3.0inch

6. Electronic and power design

Following to the IGVC regulations (the vehicle's emergency stop must be hardware based and not software controlled), we develop a vehicle controller unit including a motor driver, a LED light controller and a wired E-stop and a wireless E-stop that can stop the vehicle without software as shown in Figure 10(a). To prevent vibration problem that is caused by running on rough terrain, we use styrofoam guide board to support vehicle controller unit which is shown in Figure 10(b).

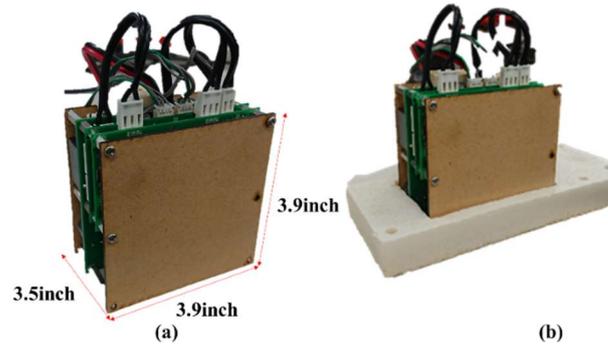


Figure 10. (a) Vehicle controller unit, (b) Vehicle controller unit and styrofoam

6.1 Power distribution system (capacity, max. run time, recharge rate, additional innovative concepts)

Figure 11 shows power and signal follow in the Orange2019. Red lines represent power flow and blue lines represent signal flow.

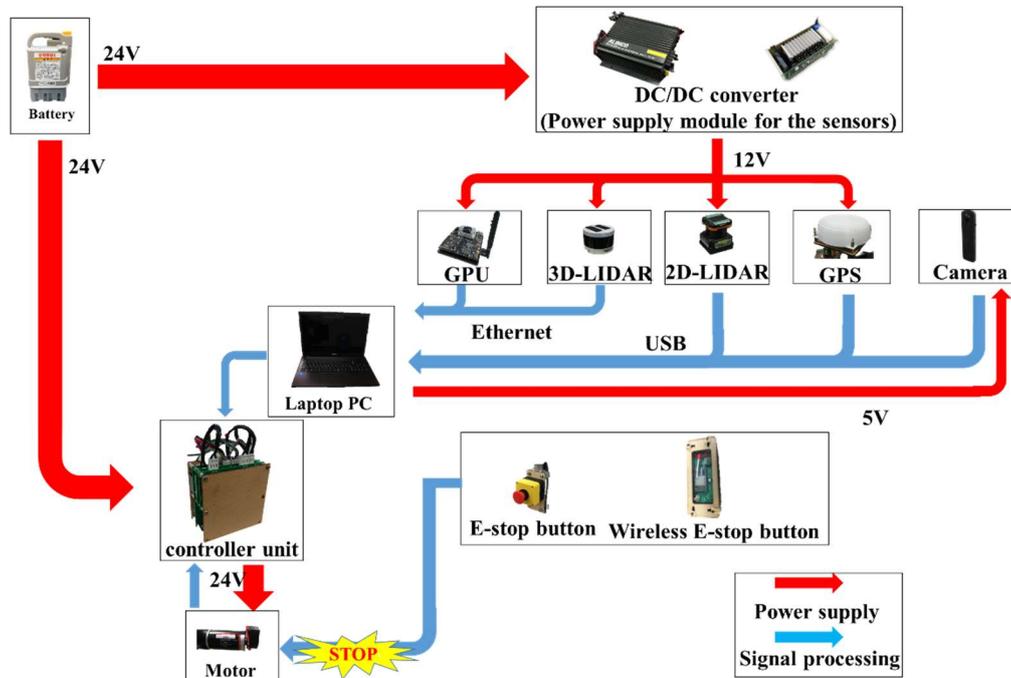


Figure 11. Power and signal follow of the Orange2019

The 24V nickel metal hydride battery supplies the power to the motor module and the DC/DC converter from 24V to 12V supplies the power to onboard modules such as GPU board, GPS, the 3D-LIDAR, the 2D-LIDAR, vehicle control unit and laptop PC.

The 2D-LIDAR, the omnidirectional camera, GPS and motor control unit are connected to the laptop PC via USB. The 3D-LIDAR and GPU board are connected to the laptop PC via an Ethernet cable. Table 4 shows the electrical components mounted on Orange 2019.

Table 4. The Orange 2019 electrical devices

Component	Product name	Power Consumption	Operating Voltage	Source	Team cost (Retail cost)
3D-LIDAR	Velodyne LIDAR VLP-16	12W	12VDC	Power supply from DC/DC converter	\$11,685 (\$0)
2D-LIDAR	HOKUYO UTM-30LX	8W	12 VDC	Power supply from DC/DC converter	\$4,000 (\$0)
GPS	Hemisphere Crescent A100	---	12VDC	PC	\$2,414 (\$0)
Omnidirectional camera	RICOH THETA S	---	USB Power	PC	\$330 (\$0)
Laptop personal Computer	FRONTIER NX series	30W	19 VDC	Power supply from DC/DC converter	\$840 (\$0)
GPU	Jetson TX2	7.5W	19VDC	Power supply from DC/DC converter	\$399 (\$399)

- 3D-LIDAR: This sensor collects data not only 3D shape of obstacles but also 360 degrees surrounding obstacles from 0.7 to 328 ft distance ahead with an accuracy of ± 0.1 ft. It is used for map generation and recognition of self-position localization of the vehicle.
- 2D-LIDAR: This sensor covers the environments in the range of 180 degrees in the horizontal direction, and it can measure from 0.3 to 98.4 ft distance ahead with an accuracy of ± 0.1 ft. It is used for obstacle detection.
- GPS: This GPS has RTK correction function, when RTK correction signals are available. It is used for recognition of self-position of the vehicle.
- Omnidirectional camera: This camera with the dual lens views and covers the upper side and lower side. Lower side lens is used to detect the lane and upper side lens is used to detect the ambient light intensity by which lane detection threshold is determined.
- GPU board: This GPU board is used for image recognition by employing YOLO v3-tiny based deep learning algorithm.

6.2 Safety devices and system integration

We install emergency stop buttons (Figure 12(a)) at the front and rear positions of the vehicle the positions easy-to-press. Zigbee based the wireless emergency stop unit is shown in Figure 12(b).

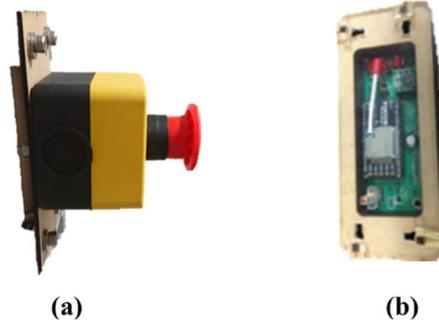


Figure 12. (a)E-stop, (b)wireless E-stop

As shown in Figure 13, during autonomous navigation running, when the LED light is emitted to red, it shows “careful mode”. When the emergency stop button is pressed, the LED light switches from red to blue, it shows “safe mode”. In the “careful mode”, the motor is completely stopped and the motor controller is disconnected from the laptop PC.

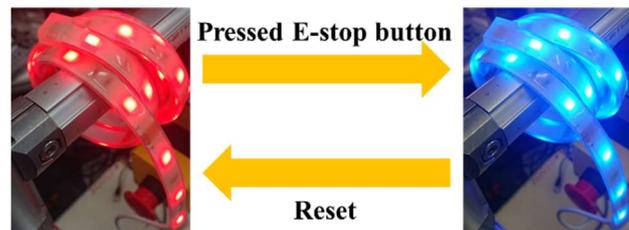


Figure 13. Mechanism of E-stop and Led light

7. Software overview

A deep learning YOLO v3-tiny algorithm is used to increase the reliability and stability in the image recognition processing. To realize the real-time image processing, we newly employ a GPU hardware acceleration board to speed up the image processing. The combination of YOLO v3-tiny and GPU hardware acceleration board achieves more stable and higher recognition rate in comparison with the conventional image recognition processing.

7.1 Obstacle detection and avoidance

In order to generate both the global SLAM map and the local map, we summarize and combine the used components and applications shown in Table 5.

Table 5. Component and use applications

Component	Use applications
2D-LIDAR	Used for obstacle detection and avoidance and local map generation.
3D-LIDAR	Used to generate a global SLAM map and self-position localization
Omnidirectional camera	Used for map generation and local map generation

The omnidirectional camera is employed to detect the painted lane in the IGVC course. Figure 14 shows how to combine and integrate the painted lane and generated a global map and acquired a local map by both the 2D-LIDAR and the 3D-LIDAR.

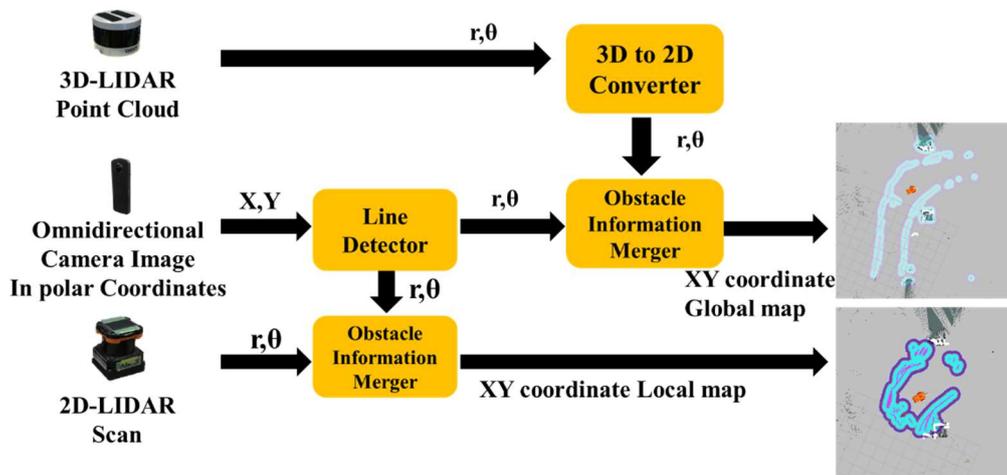


Figure 14. How to generate both local map and global SLAM map

The omnidirectional camera employed has two fisheye lens that covers 360 degree surrounding view. To capture painted lane using one side of fisheye lens, the omnidirectional camera is arranged as shown in Figure 15. As a result, the other side of fisheye lens can observe sky ambient light intensity including the sun light position and supposed shadow direction.

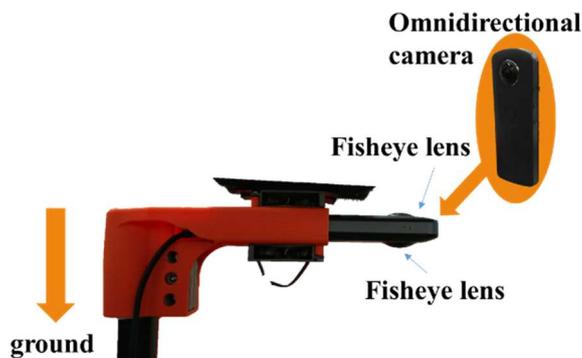


Figure 15. Omnidirectional camera Installation

Figure 16 shows the recognition procedure of the painted lane which is captured by the ground side of fisheye omnidirectional camera.

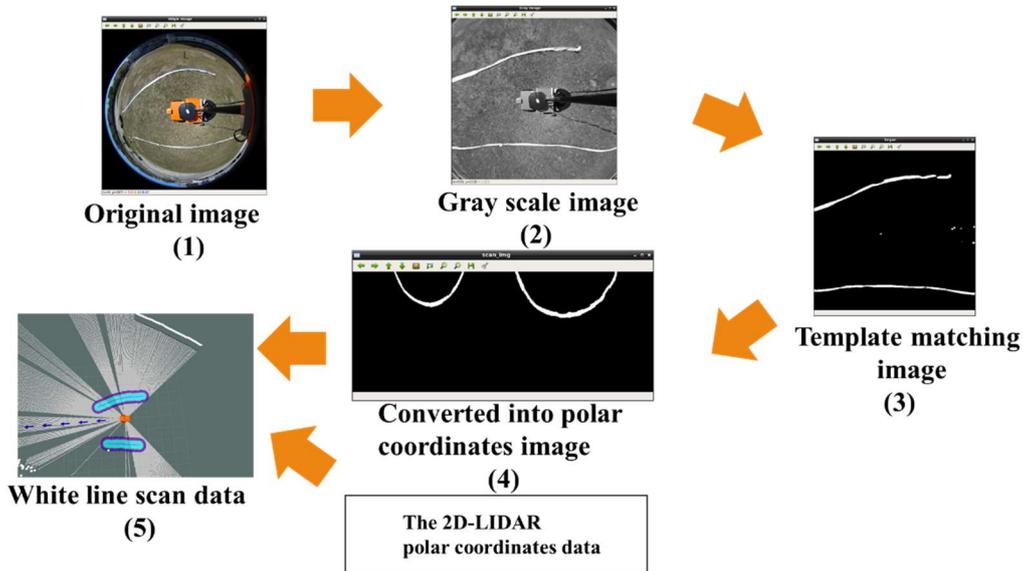


Figure 16. Painted lane recognition procedure

Followings are the recognition procedure:

- (1) Ground side omnidirectional camera with fisheye captures the actual ground plane image.
- (2) The captured ground plane image is converted to gray scale image by applying dynamic threshold method which adapts to ambient light condition detected by sky side omnidirectional camera with fisheye.
- (3) The template matching is applied to the gray scale image) by using a preregistered painted lane shape, to generate binary image.
- (4) To merge the 2D-LIDAR obstacle data and painted lane data, the binary image is converted to r-theta coordinate with the same format of the 2D-LIDAR data.
- (5) Since both painted lanes and obstacles can be regarded as general obstacles, the converted r-theta coordinate data and the 2D-LIDAR obstacle data are merged as the general obstacle data used for navigation.

7.2 Software strategy and path planning

For path planning and navigation in Auto-Nav challenge, the Orange2019 has two different strategies that are switched depending on painted lane zone and waypoint navigation zone. In the painted lane zone, an omnidirectional camera and the 2D-LIDAR are used for the navigation. The omnidirectional camera is mainly used to detect painted lane as obstacles and the 2D-LIDAR is used to detect obstacles to achieve safe navigation so that the vehicle can be within the lanes. When the vehicle reaches to the waypoint navigation zone, the GPS and the 3D-LIDAR are used to identify the

self-position and the 2D-LIDAR is used to detect obstacle and to avoid, for safe navigation. As the results, seamless navigation can be achieved in Auto-Nav challenge course.

7.3 Map generation

SLAM Maps are mainly generated by using the 3D-LIDAR data. Figure 17 shows a typical example of the generated map.

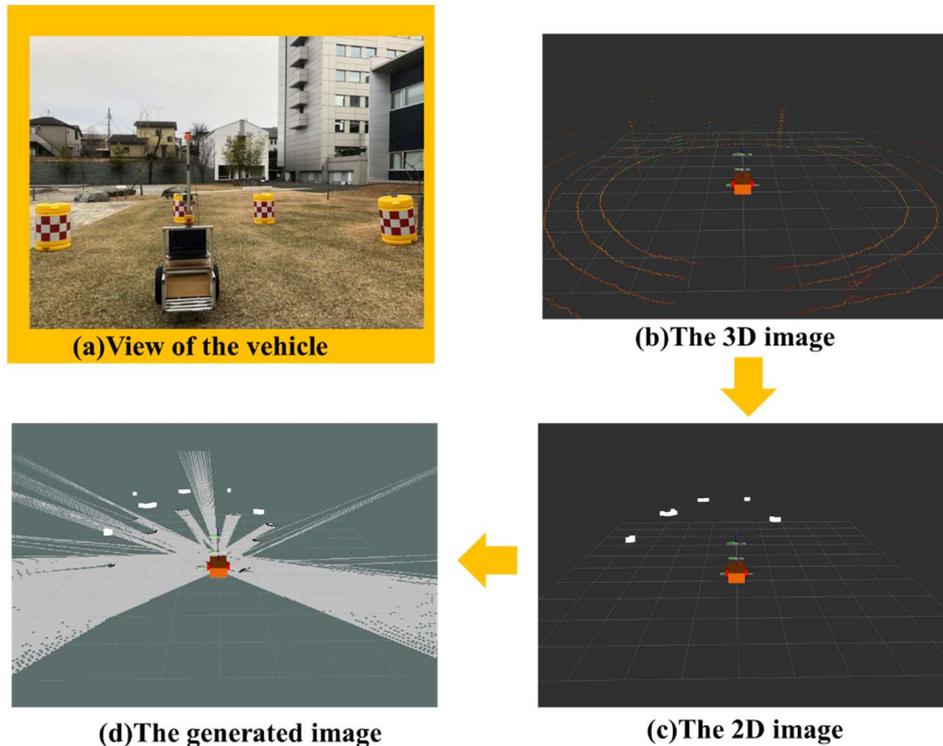


Figure 17. Typical example of generated map

Figure 17(a) shows surrounding view around the vehicle. Figure 17(b) is corresponded to 3D view that is generated by the 3D-LIDAR. Since measurable distance by the 3D-LIDAR is longer than the 2D-LIDAR, we simply convert the 3D-LIDAR data to 2D image as shown in Figure 17(c) for generating accurate self-position map. The pale grey area in the generated map in Figure 17(d) is the area where the vehicle should run, and the dark grey area represents the unidentified area. Even if the navigation fails, the map saved can be used to plan the next run. The vehicle uses only the map generated in the previous run.

7.4 Goal path selection and path generation

In the waypoint navigation mode, path-generation module can be decomposed into two different functions. One is the cost map generation and the other is the path planning. The cost map which represents the collision risk map for the navigation, is generated based on the obstacle location

information. The path planner calculates the shortest path to the goal by referring the cost map that minimize the risk of collision. In Figure 18, the magenta-colored-area represents the areas of the objects, and the pale-blue-colored area represents areas where the vehicle might collide to objects. The blue area shows the areas that the vehicle should avoid if possible, even if it will not collide to an object at those areas. The area indicated by red shows the border between the area of colliding to objects and is the area to be avoided if possible. The green line that sticks out from the front of the vehicle is the path generated by the global path planner. The blue arrows represent the minimum distance path generated.

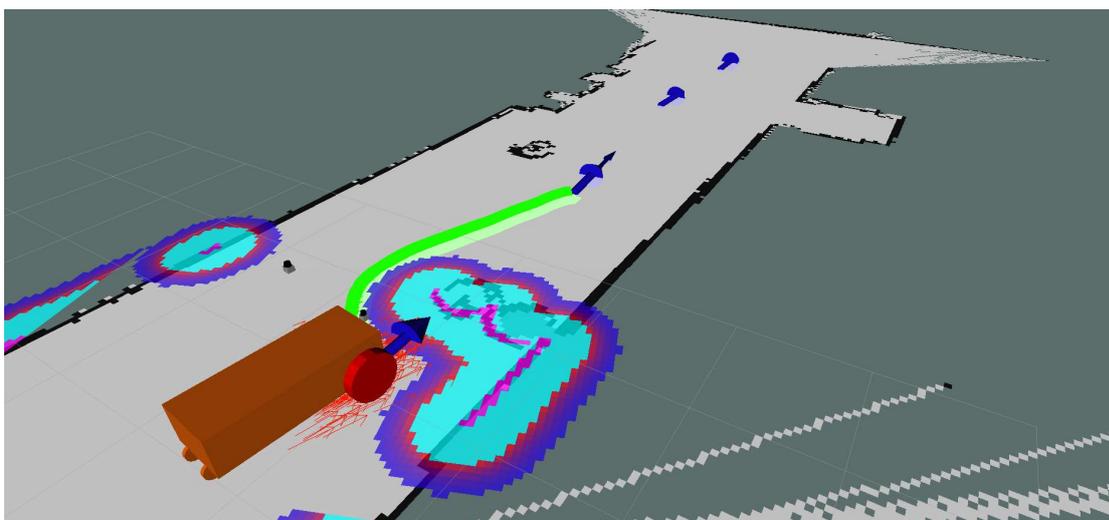


Figure 18. Path planning

7.5 Additional creative concepts

Combination of newly introduced hardware-based acceleration board (Jetson TX2) and deep learning software Yolo v3-tiny yields the accurate image recognition. Even if the vehicle encounters to a complex environment, the vehicle can accurately recognize surrounding situation without reducing vehicle speed.

8. Vehicle failure points (electronic, electrical, mechanical, structural, etc.) and resolutions

In Table 6, we summarize vehicle failure points and resolutions.

Table 6. Vehicle failure points and resolutions

Problem	Solution
When the frames of vehicle are damaged. (Structural, Mechanical)	Since we employ reconfigurable frame, even if the frames are suffered, we can easy change and/or replace new frame by using stocked spare frames.
When the one of sensors is damaged. (Electronic, Software)	Since the vehicle sensors are basically redundant configuration. For example, we can observe obstacles both camera as well as LIDAR. We can change sensor configuration in the ROS lunch file to keep stable navigation without avoiding obstacles.
When motor control modules are damaged. (Electronic)	Since we have spare modules for backup, we can simply replace the module without debugging.

9. Simulations in virtual environment and theoretical concepts in simulations

Since we employ ROS (Robot Operating System), simulations and actual runs of vehicles are seamlessly and directly comparable. Since ROS can be easily applied to many pre-existing open source packages and sensor drivers for such as camera and LIDAR. The combination of ROS-bridge and MATLAB enables rapid visual debugging without compiling debugging software. Figure 19 course of IGVC2019 which has been shown in IGVC rules. The advantage of using Gazebo is that the vehicle can navigate almost similar environment without navigating real competition course.



Figure 19. Simulation

10. Initial Performance Assessments

Table7 shows Performance prediction and Performance result.

Table 7. Performance of Orange 2019

Measurement	Performance prediction	Performance result
Speed	5.1km/h(3.2mph)	5.0km/h(3.1mph)
Ramp climbing ability	17%incline	15.5%incline
Reaction time	0.22s	0.20s
Battery life	2.5h	2.0h
Obstacle detection distance	0-10m(0-33ft)	0-10m(0-33ft)
Waypoint navigation	$\pm 0.08m(\pm 0.27ft)$	$\pm 0.09m(\pm 0.30ft)$

11. Conclusions

Our goal is to build a stable and fast-running vehicle. To build such the vehicle, we have made following improvements;

[Hardware]

By making the upper frame rigid

- stable sensing is yielded

By elongation the frame from front to rear wheels of vehicle

- anti-roll stability is yielded.

[Software]

By refactoring software,

- faster image frame capturing rate is yielded, which makes the image capturing stable.
- faster motor monitoring and controlling process is yielded, which makes the vehicle control stable.

By the combination of Yolo v3-tiny based deep learning software and by employing software acceleration board (Jetson TX2)

- robust and stable image recognition is yielded.

We believe confident that Orange2019 will be obtained the best results.

References

1 IGVC Official Competition Rules (2019), "IGVC 2019 Homepage," <http://www.igvc.org/rules.htm> (accessed January 25, 2019).

2 Open Source Robotics Foundation (2019), "ROS Wiki," <http://wiki.ros.org/> (accessed April 10, 2019).