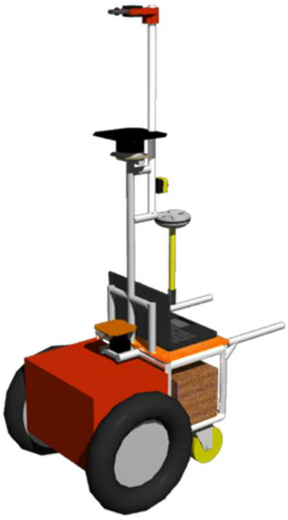
HOSEI UNIVERSITY



Orange2018

Design Report

Ryota Nakamure (Team Captain)	ryota.nakamura.2m@stu.hosei.ac.jp
Tomohiro Shimizu	tomohiro.shimizu.4i@stu.hosei.ac.jp
Hiroka Shigi	hiroka.shigi.4a@stu.hosei.ac.jp
Shuya Aoyagi	shuya.aoyagi.4k@stu.hosei.ac.jp
Tatsuya Kawano	tatsuya.kawano.9f@stu.hosei.ac.jp

May 15, 2018

Faculty Advisor Statement

I hereby certify that the engineering design on Orange2018 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　　　　　　　　　　　　　　　　　　　　Date

Prof. Kazuyuki Kobayashi　　　　　　　　　　May 15, 2018

Professor Kazuyuki Kobayashi

Assistant Professor Tomoyuki Ohkubo

Faculty of Science and Engineering, Hosei University

3-7-2 Kajinocho Koganei, Tokyo 184-8584, Japan

E-mail; ikko@hosei.ac.jp

ORANGE2018

Hosei University
Ryota Nakamura, Tomohiro Shimizu, Hiroka Shigi, Shuya Aoyagi and Tatsuya Kawano

Tomoyuki Ohkubo and Kazuyuki Kobayashi

ABSTRACT

This paper describes the development of Orange2018 for participation in IGVC2018. Orange2018 is built on the basis of Orange2017, which challenged IGVC last year. The authors' team result was 2nd place overall, 2nd in the Auto-Nav Challenge, and 3rd in the IOP Challenge. Based on failure experiences in the IGVC 2017, we redesigned both chassis configuration and navigation software, to improve running stability and navigation accuracy.

1. INTRODUCTION

The Hosei University Autonomous Robotics Laboratory (ARL) team has redesigned and greatly improved the vehicle Orange 2018 from last year to complete the 26th Annual Intelligent Ground Vehicle Competition (IGVC), 2018. Based on failure experiences in the IGVC 2017 and enhance the capability of mobility, the hardware structure of the vehicle was redesigned for running stability and weather resistance.

1.1. Team organization

This year, five members are working on this project. The roles of the individual participants and the hours spent by them on the project are summarized in Table 1.

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

Areas of Concentration						
Team Member	Mechanical	Electrical	Software	IOP	Design Report	Hours
Ryota Nakamura (Team Captain)	○	○	○	○		600
Tomohiro Shimizu	○	○	○			600
Hiroka Shigi	○	○	○		○	600
Shuya Aoyagi	○	○			○	350
Tatsuya Kawano			○		○	20

1.2. Design process

The goal of the Hosei University Autonomous Robotics Laboratory (ARL) team is to build an autonomous vehicle which complete in this competition course as fast as possible. To achieve the goal, we design and build the new vehicle based on both improved hardware and software can be summarized as;

Improve running stability-> Weather proof-> Employment of Corrugated plastic board
-> Employment of deep groove tires to prevent slip
-> Redesigned Payload space
-> Image processing algorithm from python to C++ code.
-> Employment of new lane detection algorithm for stable running

To conclude above problem and solutions, we apply the D-case model, which is developed by JST (Japan Science and Technology Agency). The D-case model of Orange2018 is shown in Figure 1.

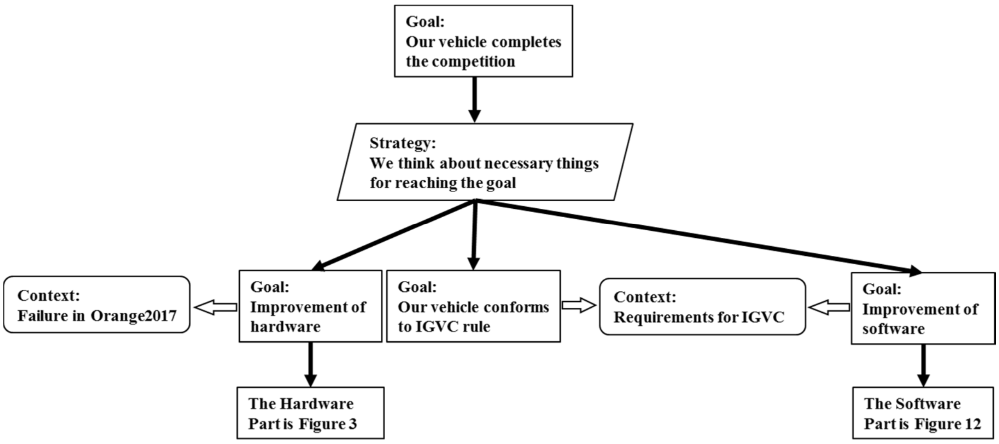


Figure 1. The D-case model of Orange2018

To build the D-case model for Orange2018, we analyzed the failure incidents of Orange2017 and set the final goal (top goal) as defined “Our vehicle completes the IGVC course as fast as possible”. To achieve the top goal, our vehicle must satisfy three requirements shown in Figure 1. They are “Our vehicle conforms to IGVC rules,” “Improvement of hardware,” and “Improvement of software.” These are based on the requirements of IGVC and our analysis of the failure of Orange2017. The requirements of IGVC is shown in Table 2. For satisfying these requirements, we think about points related to hardware, namely, easy maintenance and stability, and about points related to software, namely, and the software technology to be adopted. Making strategies like these and repeatedly creating sub goals would help us achieve the main goal easily. We finally did the following to achieve the goals: use corrugated plastic board, fabrication of the new module, reassignment of space arrangement considering the center of gravity, improvement of vehicle dimension ratio for running stability, employing larger radius tires and rewrite programming code from python to C++ code and employing a new algorithm for lane detection. The D-case model is conceptualized based on reliability, and its own tree structure shows the reliability of the system.

Table 2. Requirements for IGVC

IGVC rules	Airline requirements for carried baggage/International team (outside of the United States)
Vehicle design satisfies IGVC rules. (Length: 3–7 ft., width: 2–4 ft., Height: ~6 ft.) Securing payload space (Payload size: 18 × 8 × 8 in, Payload weight: 20 lb.)	Vehicle design is suitable for suitcase. (The total of suitcase length, width, and height must not exceed 62 inches)
･Safety Light ･Mechanical E-stop (It must be located at a height of 2–4 ft. from ground) ･Wireless E-stop (It must react even from 100 ft. ahead)	
･Accurate speed control from 1–5 mph ･Obstacle detection and avoidance	

2. INNOVATION

2.1. Innovative concepts from other vehicles designed into our vehicle

Hardware: Since MDF (Medium Density Fiberboard) which we used for the exterior of the vehicle is not suitable for adverse weather condition, we newly use corrugated plastic board, which also enables lighter weight comparing to last year's vehicle.

Software: In order to improve image processing speed, we newly use a new lane detection algorithm. In addition, we have also written image-processing program from python to C++ code, which enables 20% faster processing. As a result, we can achieve stable navigation.

2.2. Innovative technology applied to our vehicle

The innovations of Orange2018 are summarized in Table 3. There are four innovations in hardware and three innovations in software. Innovative technologies of hardware are corresponding to stable running, weather-proof body, and easy maintenance ability for emergency situation. According to software profiling, image-processing code is optimized by using C++ code instead of python code.

Table 3. The innovations of Orange2018

Hardware (Mechanical and Electrical)	Software
1. Changed the exterior from MDF (Medium Density Fiberboard) to corrugated plastic board. 2. Arranged location of batteries and DC/DC converters so that the center of gravity is not offset. 3. Employment of deep groove tire. 4. Easier to maintain custom vehicle control module.	**1. Improve image-processing speed from python to C++. 2. Detected lanes are converted as obstacles in the SLAM map. 3. Diminished delay time.**

3. MECHANICAL DESIGN

3.1. Overview

The vehicle body of Orange 2018 is shown in Figure 2.

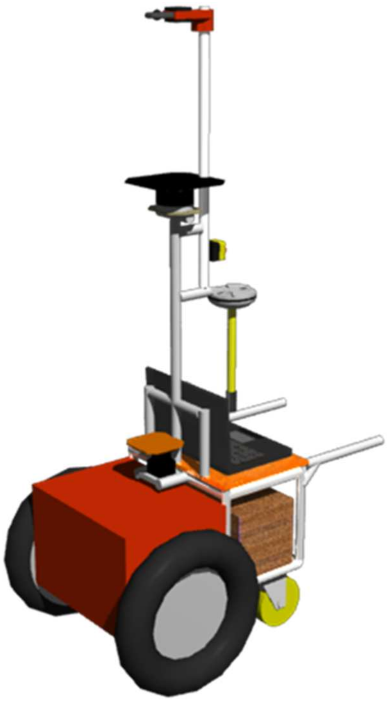


Figure 2. The vehicle body of Orange 2018

The mechanical design is based on the D-case which is the production process of Orange 2018 shown in Figure 3. Main problem in our mechanical hardware is running stability which can be decomposed following reasons; (1) The center of gravity of the last years vehicle was biased on the left. (2) Because of a narrow tread in the tire, frequently the vehicle is slipped during the navigation. (3) To achieve stable running, the vehicle must navigate regardless of weather condition even if rainy day.

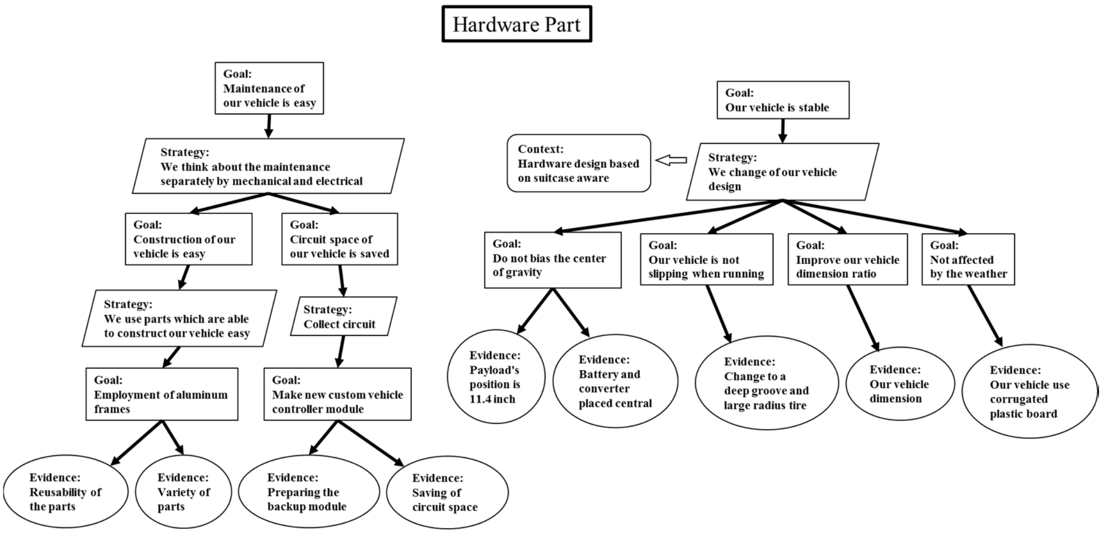


Figure 3. The D-case model of Orange2018 (Hardware part)

Maintenance abilty and portablity, we design vehicle chassis can be separate front and rear parts which is determined by the suitcase dimentions. For vehicle running stability without slip, we newly emloy deep groove tire. The combinaion of new dimensioned chassis and new tire enable maintenance abilty and portability while keeping running stability.

3.2. Decision about frame structure, housing, structure design

Drive chassis, frame structure: The drive chassis and frame structure of Orange 2018 are shown in Figure 4. Based on our experience in Orange2017, dimension of the drive chassis is redesigned which satisfied the durability, extendibility, and maintenance ability requirements, was selected for Orange 2018.

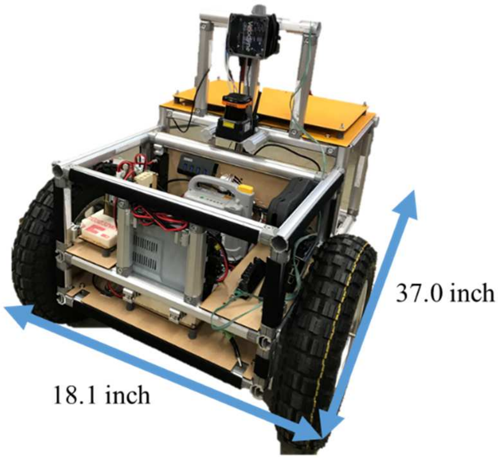


Figure 4. The drive chassis and frame structure of Orange 2018

The front components include a battery, a DC / DC converter, a custom vehicle controller module (including motor drivers, both E-stop and wireless E-stop), and two directly connected to the drive wheels' motor and tires.

The battery location in the vehicle is very important as a viewpoint of maintenance ability and center of gravity since weight of the battery is relatively heavy comparing to other devices. As shown in Figure 5, we locate the battery between center of two wheels for maintenance ability as well as the overall the CG for stable running.

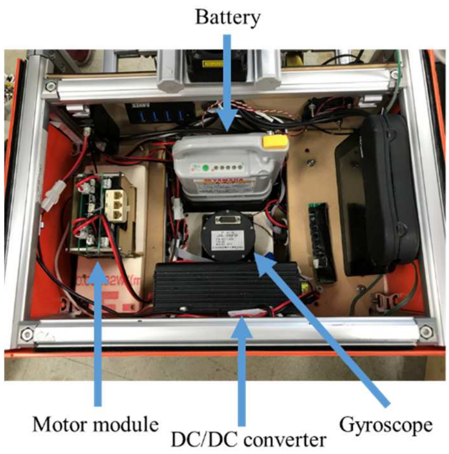


Figure 5. Location of each device

Figure 6 (A) shows radius of Orange 2017 and Orange 2018 tires. Figure 6 (B) shows groove of each tire. Since Orange2017 use narrow tread tire, the vehicle is frequently slipped during the navigation. To prevent slip, we newly use a deep groove and large radius tire.

Figure 6. Comparison of Orange 2017 and Orange 2018 tires

As shown in Figure 7, the rear component contains a laptop personal computer, GPS and a payload storage space. A laptop computer space is assigned in the upper part for program debugging. The payload storage space is assigned in the lower part, which lowers the center of gravity for running stability.

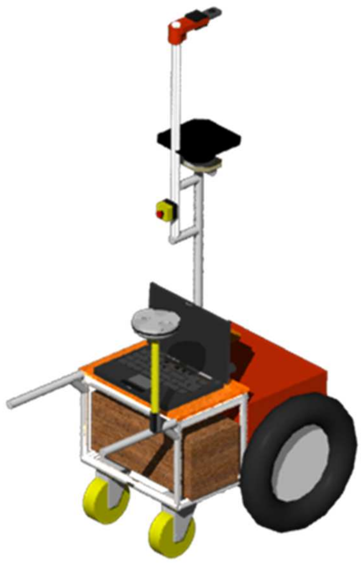


Figure 7. Rear part of Orange 2018

3.3. Weather proofing

As shown in Figure 8, Orange 2018 employs corrugated plastic board as the exterior. The use of corrugated plastic board is as weather proofing and lightweight comparing to MDF board. As same as MDF, thermal shielding to protect against direct sunlight is achieved. Table 4 shows the exterior comparison between MDF and corrugated plastic board. Total weight of the exterior can be reduced about 50%.

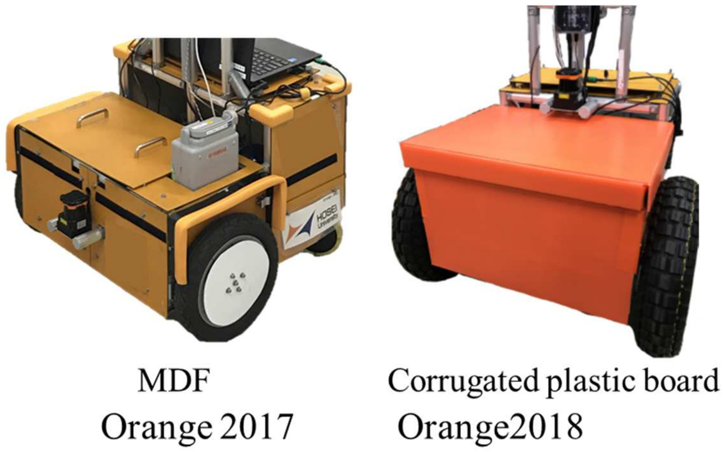


Figure 8. Comparison of Orange 2017 and Orange 2018 exteriors

Table 4. Comparison between MDF and corrugated plastic board

	Area(cm²)	Thickness(cm)	Weight(g)
MDF	900.0	0.25	140.0
Corrugated Plastic Board	900.0	0.25	36.0

Decrease about 75%

4. ELECTRONIC AND POWER DESIGN

4.1. Overview

The electrical design based on the D-case model. According to D-case model and the IGVC rules (Vehicle E-stops must be hardware-based and not controlled through software.). As shown Figure 9, we made the custom vehicle controller modules which includes functions of the motor driver, LED light controller, wired E-stop and wireless E-stop for the safty reason without PC software control. To prevent damage due to vibration caused by running on rough terrain, all modules and sensors are protected by insulating them from the vehicle chassis. In the event of electronic module failure during the competition, to shorten recovery failure time, we will simply replace failed modules without troubleshooting the vehicle. After replacing the failed modules, we will analyze the reason for failure on a desk instead of in the vehicle. It is based on D-case to save the circuit space of these vehicles and to consider hardware separately with simple maintenance and stability.

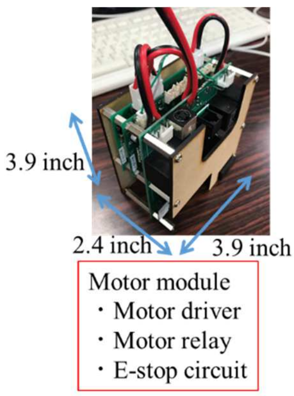


Figure 9. Custom vehicle controller module

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

Figure 10 shows the flow of electronic power and the signal flow configuration in Orange 2018.

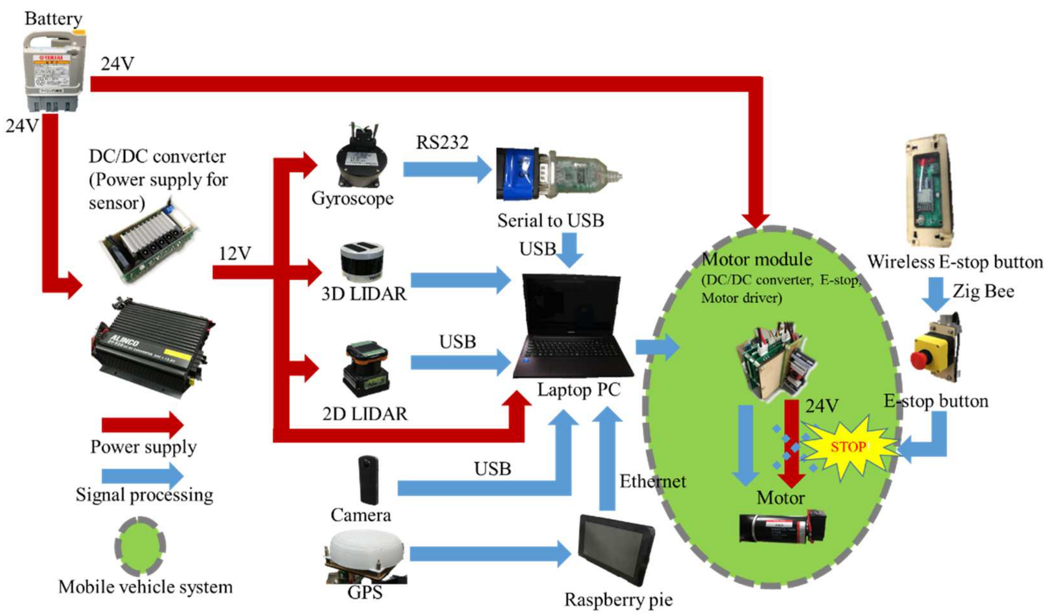


Figure 10. The flow of electronic power and the signal flow configuration in Orange2018

24V is supplied using a nickel-metal hydride battery to the custom vehicle controller module and DC / DC converter. Two motors, LED light controller, wired E-stop and wireless E-stop are connected to custom vehicle controller module (Figure 9) which is important for control. The 2D-LIDAR, the 3D-LIDAR, the omnidirectional camera, the gyroscope and two cooling fans are powered by lowering from 24 V to 12 V by the DC / DC converter. The 2D-LIDAR, the omnidirectional camera and the gyroscope are connected to the PC by USB. The 3D-LIDAR is connected to the PC by an Ethernet cable.

4.3. Electronics suite description including CPU and sensors system integration/feedback concepts

Table 5 shows power requirement of the electrical sensing devices in Orange 2018.

Table 5. Power requirement of the electrical sensing devices that employing in Orange 2018

Component	Product name	Power Consumption	Operating Voltage	Source
3D-LIDAR	Velodyne LIDAR VLP- 16	12W	12VDC	Power supply from DC/DC converter
2D-LIDAR	HOKUYO UTM-30LX	8W	12 VDC	Power supply from DC/DC converter

Gyroscope	Japan Aviation Electronics Industry JG-35FD	1W	12 VDC	Power supply from DC/DC converter
GPS	Ublox NEO-M8P	---	12VDC	PC
Omnidirectional camera	RICOH THETA S	---	USB Power	PC
Laptop personal Computer	FRONTIER NX series	30W	19 VDC	Power supply from DC/DC converter

3D-LIDAR: This sensor collects data not only 3D shape of obstacles but also 360 degrees surrounding obstacles from 0.7 to 328 ft. ahead with an accuracy of ±0.1 ft. It is used for map generation and self-localization.

2D-LIDAR: This sensor covers a range of 180 degrees in the horizontal direction, and it can measure from 0.3 to 98.4 ft. ahead with an accuracy of ±0.1 ft. It is used for obstacle detection.

Gyroscope: Measurement range of this is ±200degree/s. It is used for self-localization.

GPS: This GPS has RTK correction capability, when RTK correction signals are available. It is used for self-localization.

Omnidirectional camera: Employment of dual lens covers upper side and lower side of images. Lower side lens is used as lane detection and upper side lens is used as ambient light intensity to determine lane detection threshold.

4.4. Safety devices and their integration into your system

Our vehicle has two safety devices. One is E-stop button. Another is LED light. These are shown in Figure 11.E-stop button is installed in a location that anyone can operate easily. When the E-stop button is pressed, the custom vehicle controller module immediately shuts off power supply to the motors, without PC operation. The LED light is also in an easily understandable position just like the E-stop. We can judge the E-stop button is pressed by looking at the color of the LED light. When the LED light is lighting up in red, it represents the vehicle is in the warning state of the autonomous navigation mode, which is controlled by PC. When the LED light is lighting up in blue, it represents the vehicle is in the safety-stopped state that means not controlled by PC.

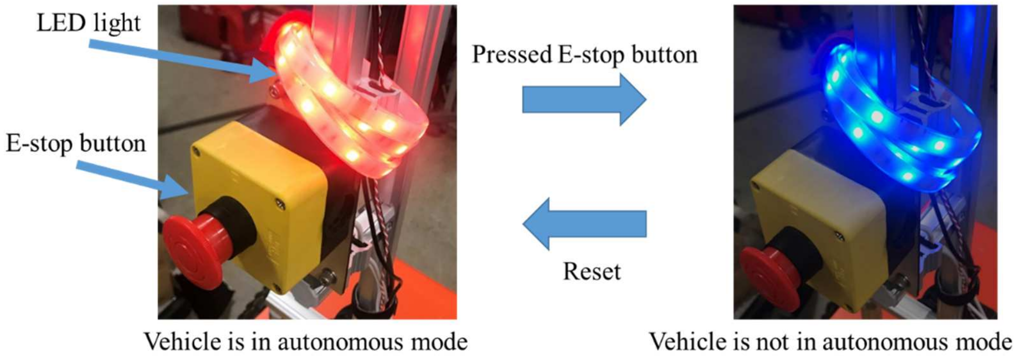


Figure 11. E-stop button and LED light

5. SOFTWARE STRATEGY AND MAPPING TECHNIQUES

5.1. Overview

Figure 12 shows D-case block diagram for software design.

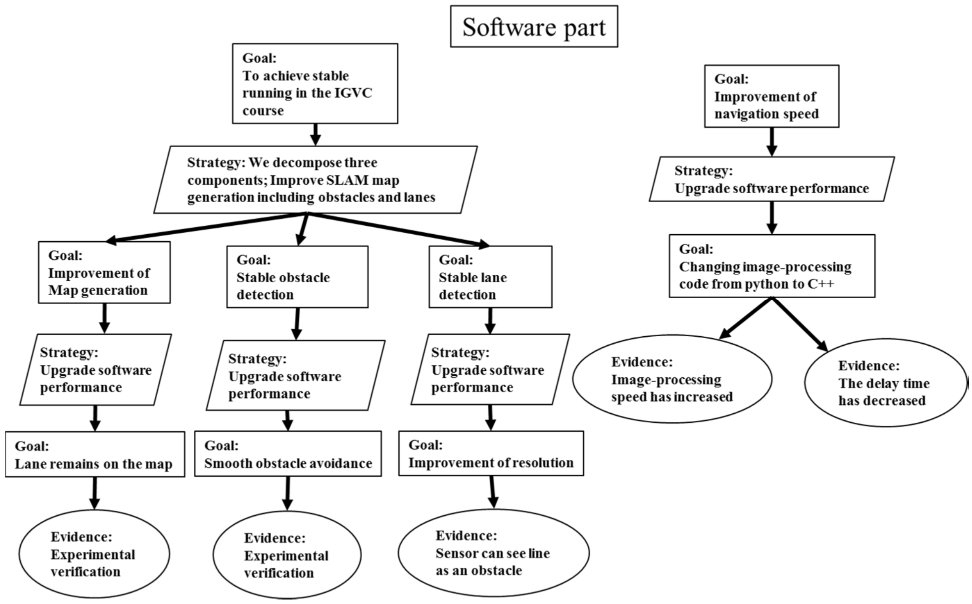


Figure 12. The D-case model of Orange2018 (Software part)

According to analysis of failure in Orange 2017, image processing speed was one of bottle necks for stable navigation. The python based implementation for rapid prototyping, image processing speed was a frequently occurring time delay which cause navigation failure. To improve stability of vehicle navigation, we have totally written image processing algorithm from python to C++ language, which can achieve 20% faster processing speed comparing to the python language implementation.

In order to integrate sensors information and to control the vehicle, we employ ROS (Robot Operating System). Since ROS can be easily applied to many pre-existing open source packages and sensor drivers such as camera and LIDAR. The move_base package is used for our vehicle control.

5.2. Obstacle detection and avoidance

Figure 13 shows the block diagram for both global and local SLAM map generation procedure.

In order to generate both global SLAM map and local map, we employ two types of LIDARS.

(1) 2D-LIDAR is used as for obstacle detection and avoidance and local map generation.

(2) Since 3D-LIDAR can observe almost 360 degrees of surrounding obstacles, the purpose of 3D-LIDAR is for global SLAM map generation.

Since lane cannot be detected by LIDARS, we employ omnidirectional camera for both global and local map generation.

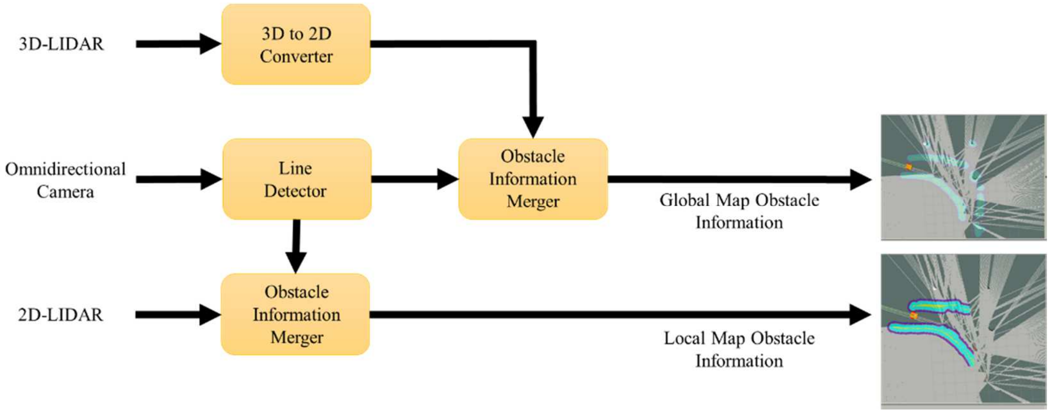


Figure 13. How to generate both local map and global SLAM map.

As shown in Figure 14, (a) captured omnidirectional image is converted to the grand plane image, and (b) to convert the gray scale image, (c) to convert the binary image by applying template matching, (d) transform r-theta coordinate image which is same coordinate of the 2D-LIDAR. (e) Merge detected lanes from r-theta image and 2D-LIDAR obstacles.

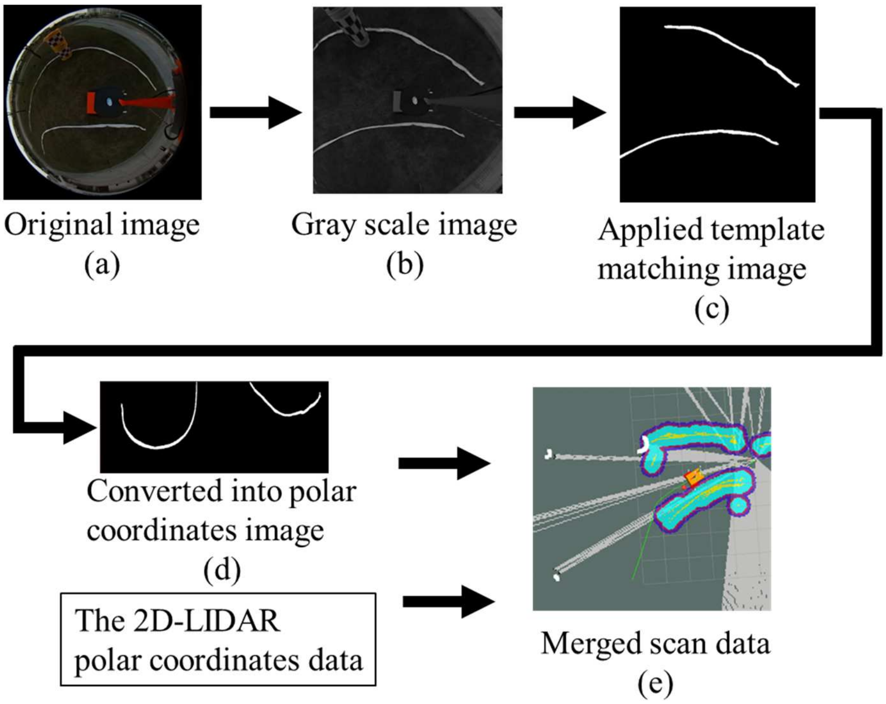


Figure 14. Lane detection flow

For avoidance, environmental obstacles are detected by both the 3D-LIDAR and the 2D-LIDAR. The use of both LIDARs improves accuracy and sensing speed. The avoidance module combines the obstacles detected by the two LIDARs with the lanes detected by the omnidirectional camera, analyzes the environmental situation, and generates the shortest and safest path for the mobile vehicle.

5.3. Software strategy and path planning

Self-Localization: The mobile vehicle retrieves its self-position from GPS and 3D-LIDAR. If the GPS signal is not available, self-localization is performed by particle filtering based on the data obtained by the 3D-LIDAR. Self-localization is performed by corresponding local map surrounding the mobile vehicle to the global map.

Path Planning: To ensure robust and stable path planning for the mobile vehicle, we employed a potential path-planning method. In the first step, a local map is created using the 2D-LIDAR data and the lanes detected by the omnidirectional camera. In the second step, the path of the mobile vehicle is generated using a " A* " search algorithm. The first and second step are iterated to obtain a safe and robust path from the current position to the next waypoint.

5.4. Map generation

As shown in Figure 15(a), to generate maps based on surrounding obstacles location, we used the 3D data obtained by the 3D-LIDAR in Figure 15(b). Since we use scanning type LIDAR, when some objects are existed to the same direction, the object having the closest distance to the vehicle is recognized as an obstacle. Only the white clusters of dots in Figure 15(c) are reflected on the 2D map as obstacles location. The pale grey area in the generated map in Figure 15(d) is the running possible area, and the dark grey area represents the unidentified area. Even if the navigation fails, the map is saved and is used for the next run. The vehicle uses only the map generated in the previous run. Lanes are also registered in the maps as an obstacle.

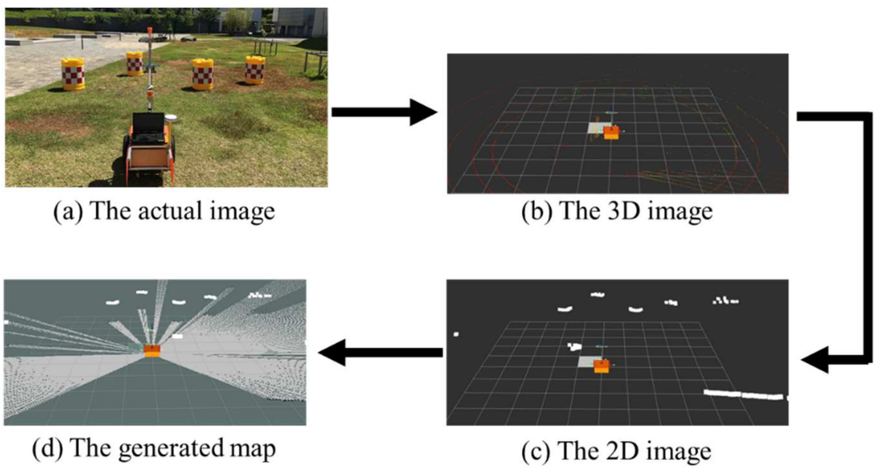


Figure15. Generate map

5.5. Goal selection and path generation

Path generation is divided into two functions, namely, cost map generation and path planning. The cost map is generated based on the collision risk value, which is determined by detected relative locations of obstacles. The path planner calculates the shortest path to the goal by considering based on the generated cost map. In addition, to navigate safely, we introduce two different types of the cost maps, namely, global cost map and local cost map. The global cost map uses global map information to collision risk value, and local cost maps use local maps navigation.

Path planning is of two types as well, global path planning and local path planning. Both types calculate the shortest path to the goal, but the only difference is that the local path planner refers to local maps and the global path planner refers to the global map. In Figure 16, the yellow-colored-area represents the locations of the objects, and the pale-blue-colored area represents where the vehicle crashes into objects. The blue area shows the locations that the vehicle should avoid if possible, even if it will not crash into an object at those locations. The area indicated by red shows the border between the area of crashing into an object and 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 red line that sticks out from the front of the vehicle is the path generated by the local path planner.

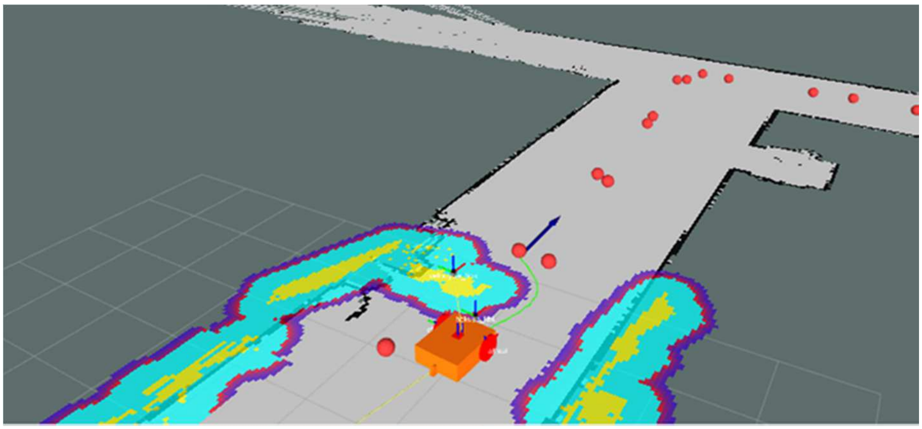


Figure 16. Path planning

5.6. Additional creative concepts

According to Auto-Nav rules, we introduced two types of navigation modes. One is for lane following navigation mode, the other is waypoint navigation mode. In the lane following area, image processing is required for the navigation; therefore, the vehicle speed is relatively slow down for the stable and robust image processing. In the waypoint navigation area, image processing is not necessary for the navigation; the vehicle speed is relatively faster than the lane following area.

6. FAILURE MODES, FAILURE POINTS AND RESOLUTIONS

- Failure: Since all locations of electric devices are arranged to the front part of our vehicle, heat problems can be occurred navigation on sunny days.

  Resolution: To prevent heat problem, we attached dual fan in the front part of our vehicle.

- Failure: Because of the vibration during navigation, instantaneous interruption may occur between the laptop PC and sensors that cause failure of navigation.

  Resolution: When the instantaneous interruption is detected, reconnection routine is executed between the laptop PC and sensors to prevent failure of navigation.

- Failure: Threshold of the lane detection is affected by ambient sunlight intensity that may require dynamic thresholding.

Resolution: Since we employ dual lens omnidirectional camera, the lower part of the lens is used as lane detection based on dynamic thresholding, which is determined by the upper part of sunlight intensity.

- Failure: Image processing for lane detection is required processing time that may cause unstable lane following navigation.

  Resolution: We introduce two modes for the navigation.
  Slow navigation mode: lane following navigation with image processing.
  Fast navigation mode: waypoint navigation without image processing.

7. SIMULATIONS EMPLOYED

We use combination of ROS and Gazebo that is open-source platform. As shown Figure 17, we created to the virtual world similar to the real environment. This allows us the test in the PC how our vehicle is running. It is an advantage that we can test without actually running the vehicle. For example, path planning, obstacle detection and avoidance, and debugging.

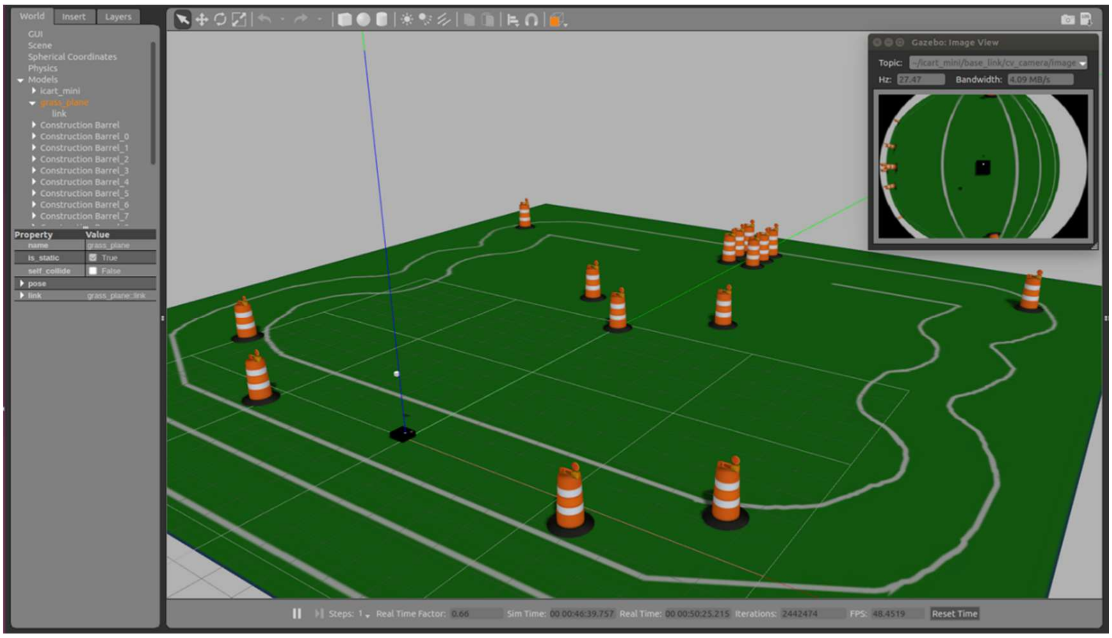


Figure 17. Gazebo simulation

8. INITIAL PERFORMANCE ASSESSMENTS

Table 6 shows performance of Orange 2018

Table 6. Performance of Orange 2018

Measurement	Performance prediction	Performance result
Speed	5.1km/h (3.2mph)	4.9km/h (3mph)
Ramp climbing ability	17% incline	15% incline
Reaction time	0.22s	0.21s
Battery life	2.5h	2h
Obstacle detection distance	0-10m(0-33ft.)	0-10m(0-33ft.)

Waypoint navigation	± 0.08m(±0.27ft.)	± 0.1m(±0.33ft.)

9. CONCLUSION

Orange2018 is an autonomous mobile vehicle designed by The Hosei University Autonomous Robotics Laboratory (ARL) team. Orange2018 was designed to be able to complete the IGVC course accurately and quickly. We had done a lot of tests in order to improve Orange2017's deficiency. As a result of the test, stable running and faster navigation have improved over last year. In addition, we employ corrugated plastic board to our vehicle exterior to enhance weather proofing.

We feel confident that Orange2018 will be obtained the best results.

10. REFERENCES

[1] IGVC Official Competition Rules (2018), "IGVC 2018 Homepage," http://www.igvc.org/rules.htm (accessed February 7, 2018).

[2] Open Source Robotics Foundation (2018), "ROS Wiki," http://wiki.ros.org/ (accessed April 10, 2018).

[3] ROS integration overview (2018), "GAZEBO Homepage" http://gazebosim.org/ (accessed April 18, 2018).