HOSEI UNIVERSITY

Orange2015

Design Report

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Faculty Advisor Statement

I hereby certify that the engineering design on Orange2015 was done by the current student team and has been significant and equivalent to what might be awarded credit in a senior design course.

Signed Kazuyuki Kobayashi Date May 15, 2015

Prof. Kazuyuki Kobayashi May 15, 2015

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ORANGE2015

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INTRODUCTION

The Autonomous Robotics Laboratory (ARL) research team at Hosei University is proud to present Orange2015 for the 23rd annual Intelligent Ground Vehicle Competition. Our original robot was based on a conventional wheelchair chassis, limiting the modification of both hardware and software. Through team discussion, we resolved the failures of the previous year by adopting a new concept, “Suitcase-aware mobile robot,” to realize a compact size and next-generation mobile robot. To build this robot, various requirements are considered in the design process. Our new design, Orange2015, accommodates the required hardware and software modifications. The most significant change in Orange2015 is the new chassis that replaces the wheelchair chassis. The significant innovations of Orange2015 are summarized in Figure 1.

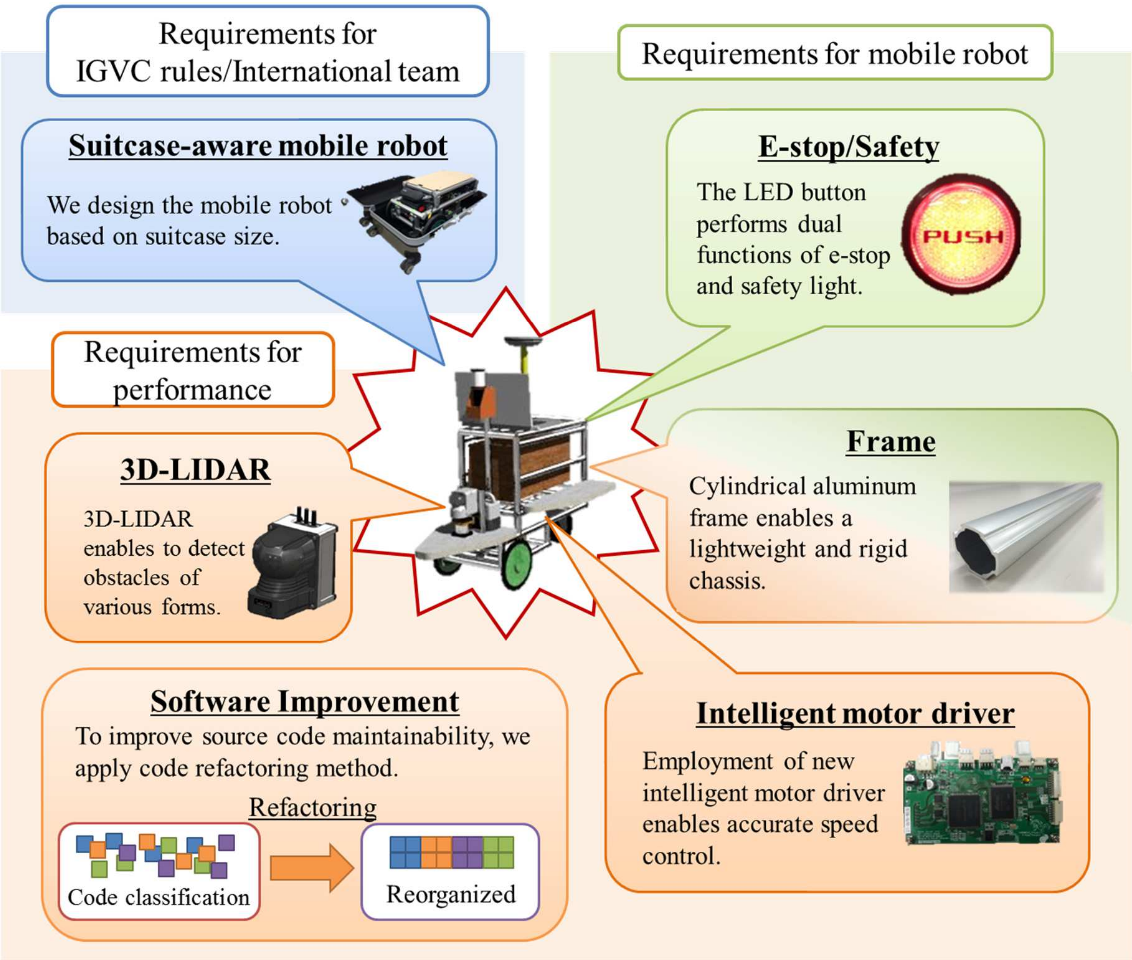


Figure 1. Significant innovations of Orange2015

TEAM ORGANIZATION

Our team comprises two doctor of philosophy students, six Masters' students, and two undergraduates. The team is divided into a team leader and three groups; mechanical, electronic, and software. The roles of each team member are presented in Figure 2. The team leader supervises the three groups and holds discussions with them.

The total development time of Orange2015 was 1200 man hours.

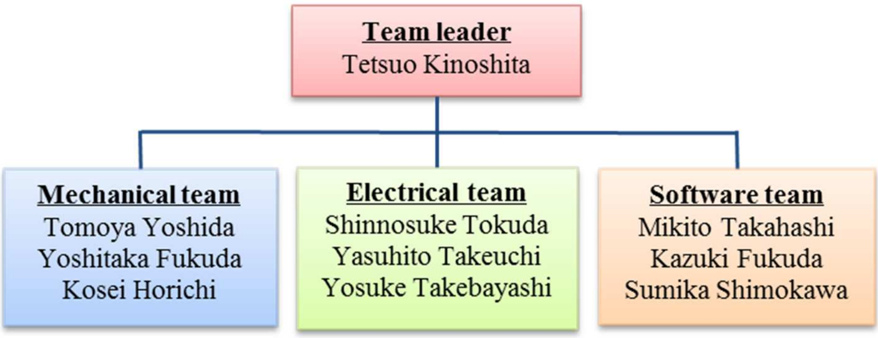


Figure 2. Team organization

DESIGN PROCESS

For international teams (outside of the United States), the size and weight of the mobile robot must be considered in the design process. Our robot must be transported from Japan. Through team discussion, we developed the "Suitcase-aware mobile robot" concept, considering the size of a standard suitcase and improved speed control accuracy (maximum and minimum speeds) of the mobile robot. Adopting this concept, we replaced the conventional electric wheelchair chassis of our mobile robot with a completely new chassis model. As shown in Figure 3, our new mobile robot satisfies several requirements.

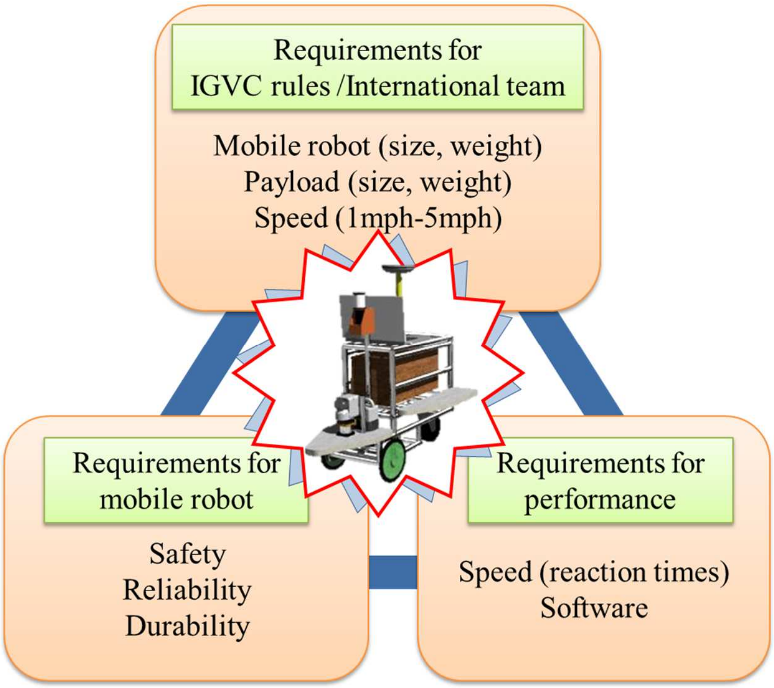


Figure 3. Requirements for IGVC mobile robot

Requirements for IGVC rules/International team

The Orange2015 chassis must fit into a typical air-flown suitcase. Because the depth of the suitcase is limited, the Orange2015 chassis is decomposed into a lower and an upper part, each within the suitcase dimensions. Figure 4 compares the decomposed chassis and suitcase. To transport Orange2015 by air, we need only two suitcases.

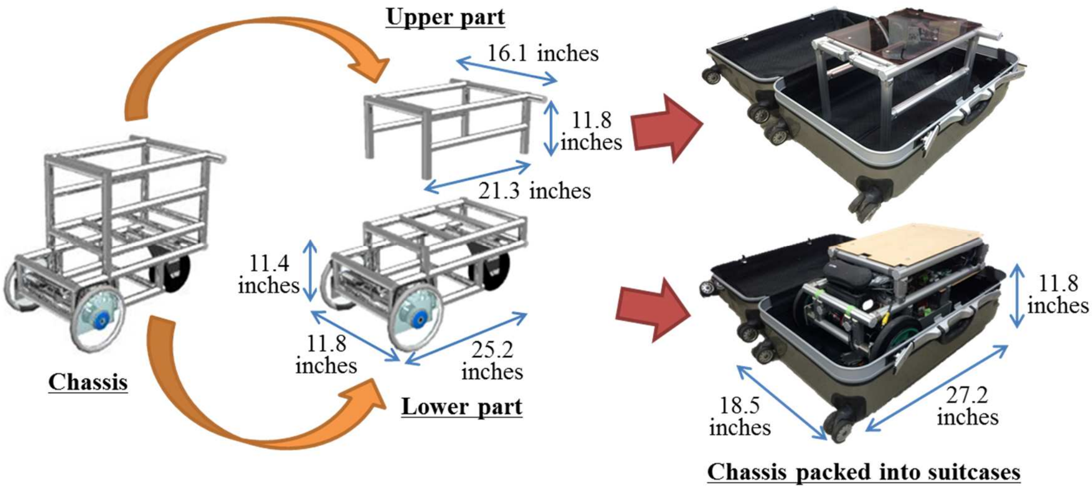


Figure 4. Lower and upper parts of chassis packed into suitcases

To satisfy the IGVC rules and ensure safe operation, the Orange2015 chassis covered with urethane foam as shown in Figure 5. The urethane foam is lightweight and protects the Orange2015 sensors and circuits from obstacle collision impacts. Figure 6 demonstrates that Orange2015 satisfies the IGVC size requirements.

Figure 5. CAD of Orange2015

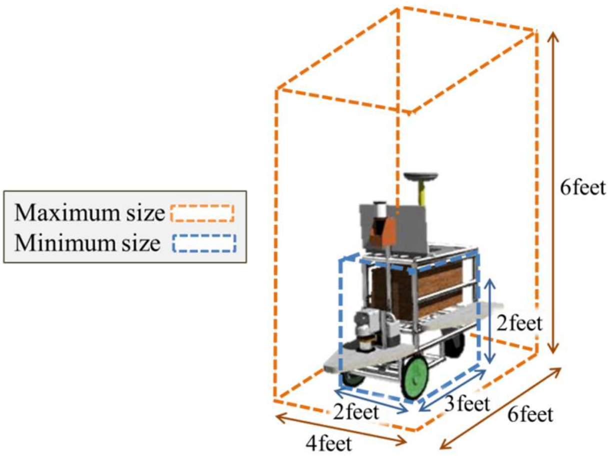


Figure 6. Size comparison between IGVC rules and Orange2015

Table 1. Payload requirements

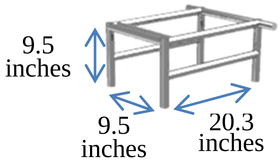
Requirements	Implementation/Solution
Payload space Sufficient power to carry the system Payload size:18 × 8 × 8 inches Payload weight: 20 pounds	Payload space solution: The inside of the upper part (20.3 × 9.5 × 9.5 inches) To meet power requirements: Selection of sufficiently powered motor to carry the weight (including payload weight).  

Table 2. Speed requirements (1–5 mph)

Requirements	Implementation/Solution
Accurate control from 1–5 mph	The chassis constructed from cylindrical aluminum frames enables lightweight configuration. Lightweight configuration requires smaller and lower-torque motors. 
	Employment of new intelligent motor driver enables accurate speed control. 

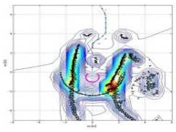
Requirements for performance

Table 3. Speed requirements (reaction times)

Requirements	Implementation/Solution
Improve reaction times	Apply code refactoring and reorganize the modular function-based programming.

Table 4. Software requirements

Requirements	Implementation/Solution
Lane following	Omnidirectional camera-based image processing. 
Obstacle avoidance	Improved new obstacle avoidance algorithm based on new 3D-LIDAR. 

Waypoint Navigation	Improved waypoint navigation algorithm, including 3D-LIDAR. 

Requirements for mobile robot

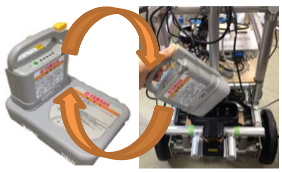
Table 5. Safety requirements

Requirements	Implementation/Solution
Safety Light Mechanical E-stop (2 − 3 feet height from ground)	Employ the three-color LED button that performs dual functions of E-stop and safety light. 
Wireless E-stop (minimum of 100 feet)	Newly developed ZigBee based wireless E-stop controller. 

Table 6. Reliability requirements

Requirements	Implementation/Solution
Reliability considerations	To enhance running stability of Orange2015, the circuit box and payload position are lowered to reduce the barycentric position of Orange2015. 
	Install insulators and suspension to reduce the effect of vibrations on the circuit box, sensor and laptop computer.  Insulator

Table 7. Durability requirements

Requirements	Implementation/Solution
Durability considerations	Cylindrical aluminum frames ensure a rigid chassis. 
	Expired batteries are easily replaced with fully charged batteries, enabling long-time experiments in outdoor environments. 

MECHANICAL DESIGN

Because Orange2014 was based on an electric wheelchair, the hardware specifications limited its maximum speed to 2.7 mph (4.5 km/h). To attain the maximum speed stipulated in the IGVC2015 rules (5 km/h), we constructed Orange2015 anew with new motors installed on a lightweight chassis. The lightweight chassis is constructed from reconfigurable cylindrical aluminum frames. Consequently, the size and weight of Orange2015 are significantly smaller than those of Orange 2014. To stabilize the moving capability of Orange2015, we lowered the barycentric position of the circuit box. As shown in Figure 7, the Orange2015 system weighs over 50% less than Orange2014.

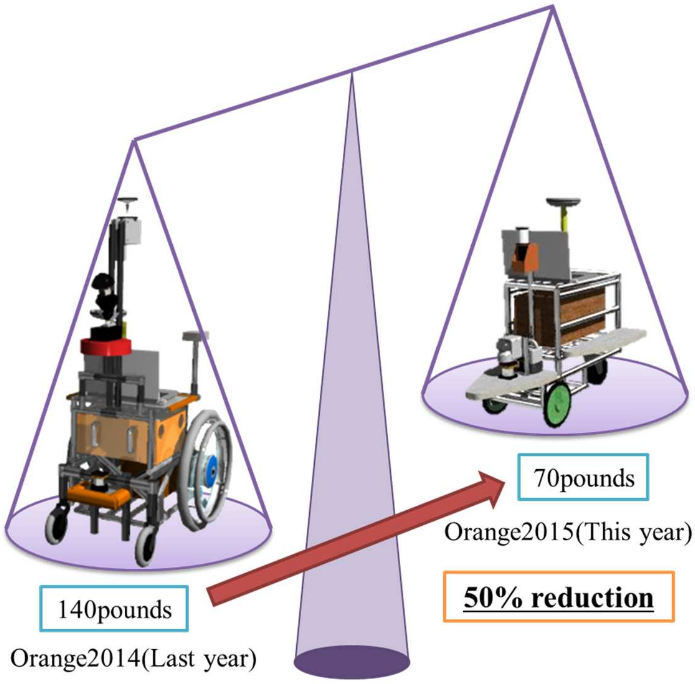


Figure 7. Weight comparison between Orange2014 and Orange2015

Frame

Figure 8 illustrates cylindrical aluminum frames used in the chassis construction. These unique cylindrical frames connect only in four directions, ensuring stuffiness of the joint junctions; moreover, it is lightweight, rigid, and easily assembled and reconfigured. Figure 9 shows the CAD design of the Orange2015 chassis constructed from these frames.

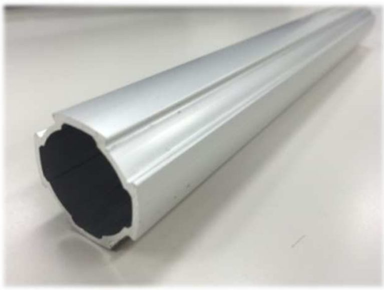


Figure 8. Cylindrical aluminum frame

Figure 9. CAD of Orange2015 chassis

Circuit Box

The new chassis design required a redesign of the circuit box. The insulators and circuit box are installed at low height to reduce the barycentric position of Orange2015. The insulators protect the electric circuit from vibration.

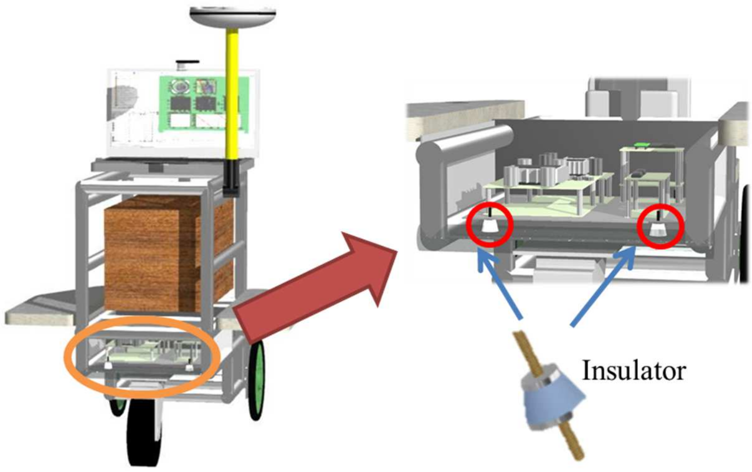


Figure 10. Circuit Box

ELECTRICAL DESIGN

Electrical design

To enable long-duration outdoor experiments, we install rapidly changeable batteries, as shown in Figure 11. As the laptop PC has its own battery, we can replace expired batteries with fully charged ones without system shutdown, ensuring continuous operation during longer outdoor experiments.

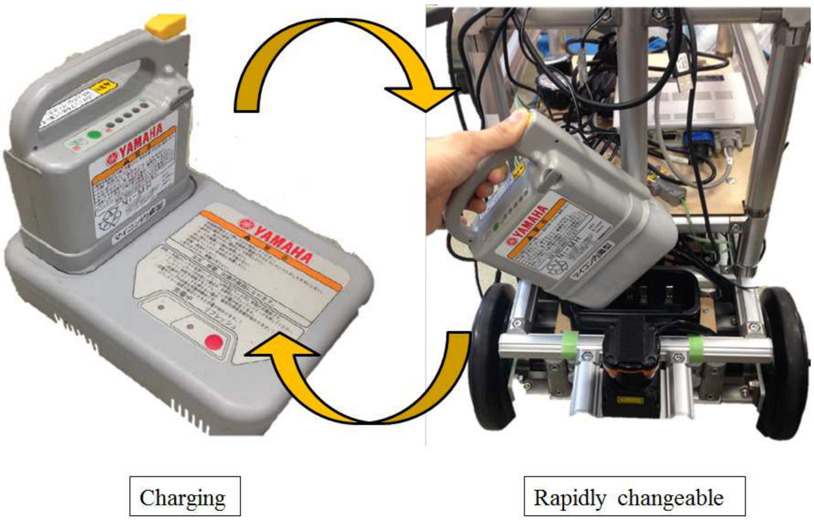


Figure 11. Rapidly changeable batteries

Figure 12 schematizes the electrical power and signal configuration of Orange2015. The motor and peripheral devices are powered by a nickel hydride battery (24 V; 6.7 A·h), which is rapidly replaced as mentioned above.

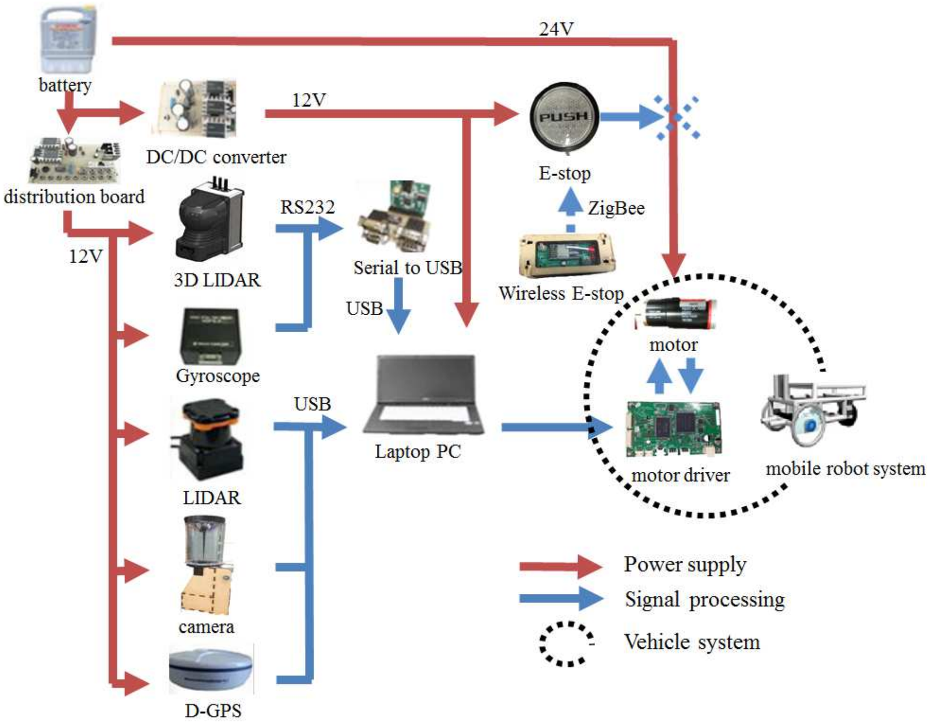


Figure 12. Electrical power and signal configuration of Orange 2015

3D-LIDAR

This year, we replace our handmade 3D-LIDAR with a commercially available low-cost 3D-LIDAR (Hokuyo, YVT-X002), which ensures high reliability. The new 3D-LIDAR weighs 52% less, and occupies 87% less volume, than our original 3D-LIDAR.

Figure 13 shows example of three-dimentional shapes which are captured by using 3D-LIDAR.

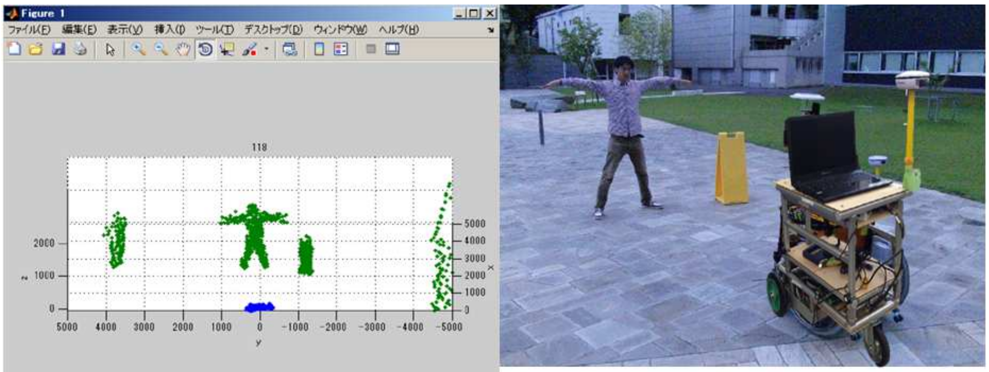


Figure 13. Visual performance

Emergency stop/Safety Light

The three-color LED button performs dual functions of E-stop and safety light. For safety and visibility purposes, the E-stop buttons (Figure 14) are arranged around the mobile robot (at the left, right and back sides).

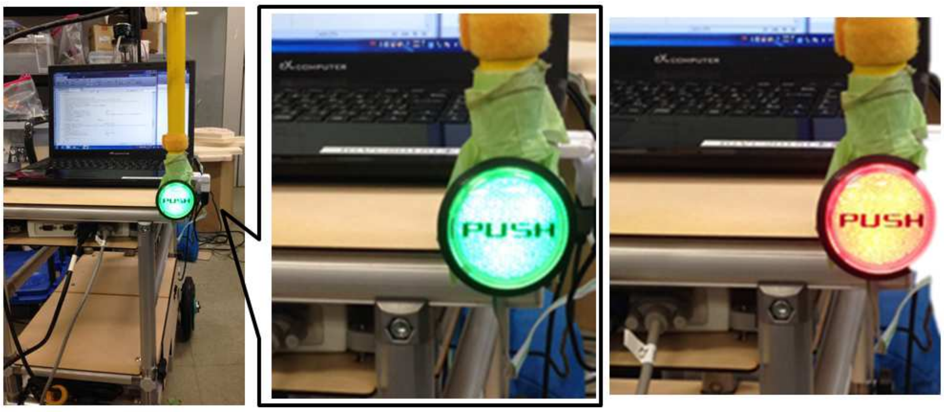


Figure 14. E-stop buttons

When the mobile robot power is turned on, the three-color LEDs perform as mechanical E-stop buttons, and glow solid red. As the mobile robot is run through the computer, the color changes from solid red to flashing red and finally to green. In the green state (indicating autonomous mode), the LEDs operate as safety lights.

SOFTWARE DESIGN

In the software part, the electric wheelchair controller installed in Orange2014 is replaced by a new motor driver (YP-Spur), which accurately controls the speed and trajectory of the mobile robot. The YP-Spur is based on Yamabico Project-Spur (YP-Spur) developed at the University of Tsukuba, Japan. The YP-Spur enhances the speed and trajectory control through feedback and feed forward controls of the mobile robot dynamics.

Although changing from the electric wheelchair controller to a mobile robot motor controller requires significant hardware modifications, we realize a rapid prototype by programming a YP-spur/MATLAB bridge function. Furthermore, we improve the existing MATLAB controller code by a refactoring method. In this manner, we can improve the speed and trajectory control using the Orange2014 MATLAB program and saving considerable development time. Figure 15 shows the four modules of the mobile robot controlling software. The modules are run sequentially, with each process subsuming the decision of the previous module. As shown in Figure 15, the modules are waypoint navigation, line following, path planning, and obstacle avoidance.

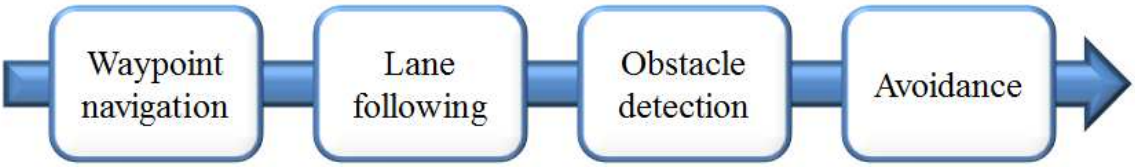


Figure 15. Flow diagram of the four modules programmed in Orange2015

Waypoint navigation

Self-localization. The mobile robot retrieves its self-position from GPS. If the GPS signal becomes unreliable, self-localization is performed by a Simultaneous Localization and Mapping (SLAM) algorithm based on LIDAR and omnidirectional camera data. Self-localization from LIDAR and camera data is performed by a map matching technique, in which the mobile robot searches a global map for points that match its surrounding local map.

Path Planning. To ensure robust and stable path planning for the mobile robot, we employ a potential path planning method. In the first stage, a potential field map is created from LIDAR data and lanes detected from the omnidirectional camera (Figure 16). In the second stage, the mobile robot’s path is generated by an A-star search algorithm. The first and second stages are iterated to obtain a safe and robust path from the current position to the next waypoint.

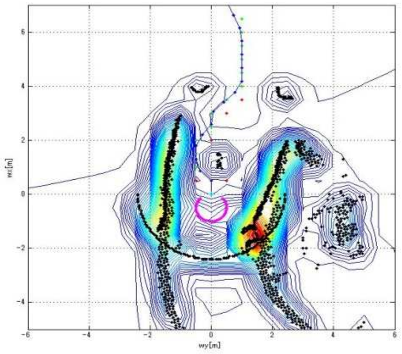


Figure 16. Generated potential field map

Lane Following

Lane following proceeds in two steps as follows: (1) lane detection and (2) lane following.
The lane detection procedure of Orange2015 is presented in Figure 17.
The lane following procedure considers the white lanes as obstacles.

Panels (a) and (b) of Figure 17 are the original image captured by the omnidirectional camera and the reconstructed ground image, respectively. After reconstruction, the RGB color image is converted to a gray scale image, using the B component only (panel (c)). The gray image is then binarized by template matching (panel (d)). The isolated noise in the binary image is removed using Quad tree. The resulting filtered image is shown in panel (e). After recognizing the lines in the image, the mobile robot evaluates the eigenvector of the lines, and uses it to interpolate the disconnections. The eigenvector and interpolated images are presented in panels (f) and (g), respectively.

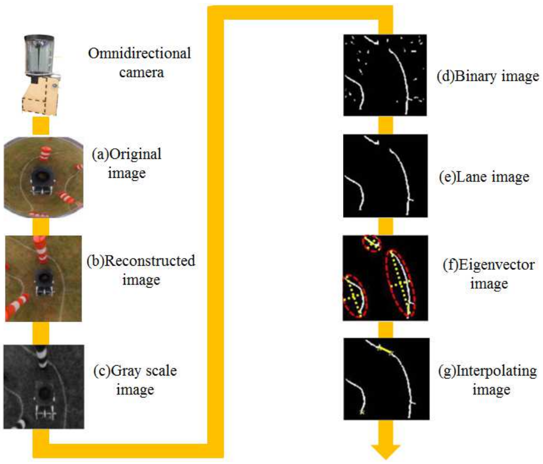


Figure 17. Lane detection procedure

Obstacle detection

Fence detection. Accurate, stable fence detection is a major challenge in Auto-Nav functioning. In particular, the fence opening, which is divided into two areas, is randomly relocated along the fence at the start of each run.

Passage through a fence opening is illustrated in Figure 18.

Figure 18. Passage through the opening of a fence

Flag detection. The flag area presents two problems. First, flags are thin structures that are seldom detected by the mobile robot's LIDAR. Second, the mobile robot needs to turn to the left of the red flags and right of the blue flags. To solve both problems, the flags are recorded in a grid map and the waypoint is generated as the flags are passed. Figure 19 shows the robot running through a flagged area, along with the generated grid map.

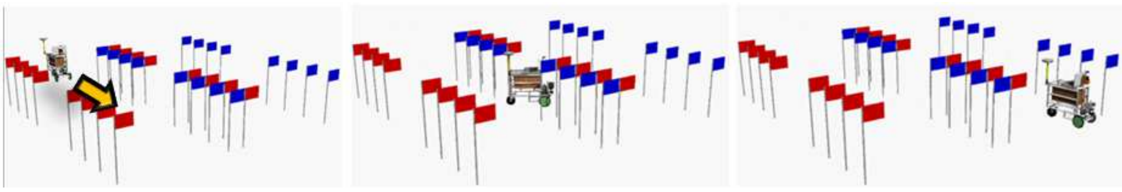


Figure 19. Process of passing through a flagged area

Avoidance

Avoidance is the most important function of the mobile robot controller. To improve the accuracy and sensing speed, surrounding environmental obstacles are detected by two different LIDARs. The avoidance module combines the obstacles detected by LIDAR with the lines detected by the omnidirectional camera, analyzes the environmental situation, and generates the shortest and safest path for the mobile robot.

PERFORMANCE

This section discusses the performance of Orange2015.

Table 8. Performance of Orange2015

Measurement	Performance prediction	Performance result
Speed	5.0 km/h (3.1 mph)	5.0 km/h (3.1 mph)
Ramp climbing ability	9.0° incline	8.9° incline
Reaction time	0.19 s	0.18 s
Battery life	3.5 h	3.0 h
Obstacle detection distance	0–8 m (0–27 feet)	0–8 m (0–27 feet)
Waypoint navigation	±0.10 m (±0.33 feet)	±0.14 m (±0.46 feet)

Cost

Table 9. Estimated developmental cost of Orange2015

Components	Retail cost	Team cost	Description
3D-LIDAR	$8,000	$0	YVT-X002 (3D-URG)
Motor, gear and encoder	$1,000	$1,000	Maxon RE-40-GP42C-HEDL5540
Motor driver	$315	$315	TF-2MD3-R6
LIDAR	$4,000	$0	HOKUYO UTM-30LX
Omnidirectional camera	$2,613	$0	VS-C42N-TK
USB video capture cable	$50	$0	I-O DATA GV-USB2
Fiber optic gyroscope	$5,800	$0	Japan Aviation Electronics Industry JG-35FD
DGPS	$2,414	$0	Hemisphere A100
Laptop personal computer	$790	$790	eX.computer note N1500J-721/E
Mechanical parts	$1,000	$1,000	Various mechanical components
Electronic parts	$500	$500	Various electrical components
Total	$26,482	$3,605	

CONCLUSION

In this study, we presented the design and implementation of Orange2015. Our new concept, "Suitcase-aware mobile robot," satisfies three major requirements:

1. Complies with the IGVC rules and fit into a standard suitcase for air travel
2. Meets the specified performance
3. Meets the mobile robot specifications

To satisfy the above requirements, we designed and built a new chassis mobile robot from the bottom up. Moreover, to comply with the altered rules established in the IGVC2015, we incorporated a new 3D-LIDAR module, omnidirectional camera, and a new refactored image processing algorithm to realize a robust and reliable robotic system. We look forward to a favorable placement of Orange2015 in this year's IGVC.

REFERENCES

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[2] Lei Tang, Songyi Dian, Gangxu Gu, Kuni Zhou, Suihe Wang, and Xinghuan Feng. "A novel potential field method for obstacle avoidance and path planning of mobile robot," IEEE Computer Science and Information Technology (ICCSIT), pp.633-637, 2010.