Orange2014

Design Report

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Faculty Advisor Statement

I hereby certify that the engineering design on Orange2014 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 9, 2014*

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ORANGE2014

Hosei University

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ABSTRACT

This paper describes the development of Orange2014 for participation in IGVC2014. Orange2014 is basically built on the basis of Orange2013, which participated in last year's IGVC. The authors' team achieved second place in the overall judgment, fourth in the Auto-Nav Challenge, and first in JAUS Challenge. Based on the experiences gained from the failures encountered in the last year's competition, we have reviewed the shortcomings of Orange 2013 and redesigned Orange2014 with overall improvement in performance.

INTRODUCTION

The Autonomous Robotics Laboratory research team of Hosei University has redesigned and amended both the hardware and software of Orange2014 based on the team discussions to implement the new concept of "dependability" for IGVC 2014. Dependability is a measure of a system's availability, reliability, and maintainability. This also encompasses the mechanisms designed to increase and maintain the dependability of a system. Based on the experiences gained from the failures and shortcomings of IGVC 2013, it is believed that such concepts are very important for designing the autonomous mobile robot.

A summary of the failures and shortcomings of Orange2013 from the viewpoint of dependability is presented in Figure 1. This paper provides a detailed explanation of the problems that need to be circumvented in this regard.
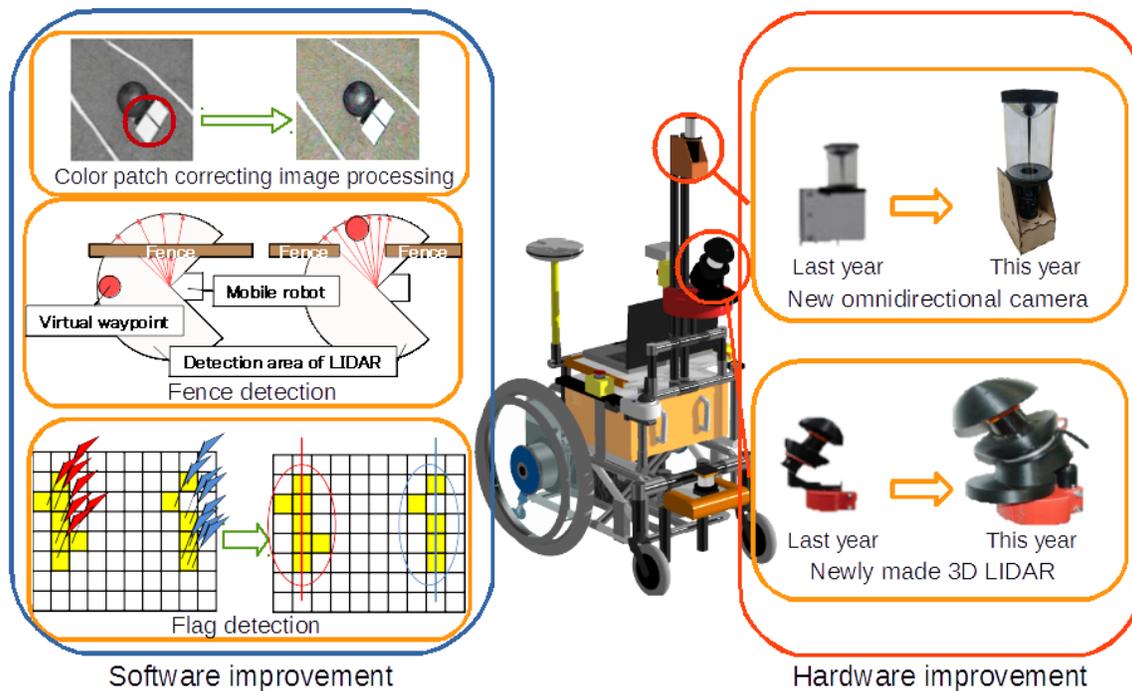
Figure 1. Schematic depicting the shortcomings of Orange2013 and the suggested improvements in Orange2014 in terms of both software and hardware

Table 1. Problems associated with Orange2013 and the corresponding solutions for circumventing the shortcomings, as proposed in Orange2014

Problem	Solution
Low resolution of the Omnidirectional camera.	To improve the resolution par grid of the straight lane pixels in omnidirectional image, the camera is rotated 45° with respect to the yaw axis.
Line detection failed because of the color tone change in the Omnidirectional camera image.	The brightness of the image is corrected, signifying the observation of the color patch.
3D LIDAR failed to detect the fence owing to the extreme thinness of the fence.	The fence is detected using the Omnidirectional camera.
3D LIDAR was sensitive to rain.	A waterproof 3D LIDAR is reconstructed.
The glass of the Omnidirectional camera was fogged.	An anti-fog coat is sprayed on the lens of the Omnidirectional camera.

TEAM ORGANIZATION

Figure 2 shows the list of team members from various groups, including mechanical, electrical and software experts, involved during the early stages of our team organization. Based on the amendment in the IGVC2014 IOP rules, the software and electrical subgroups have been reorganized into three sub-groups, as software, electrical, and IOP.

The team leader is responsible for managing and leading the three subgroups toward the completion of their respective components through frequent team meetings and discussions. Overall, the time spent for building Orange2014 is approximately 1200 man hours.
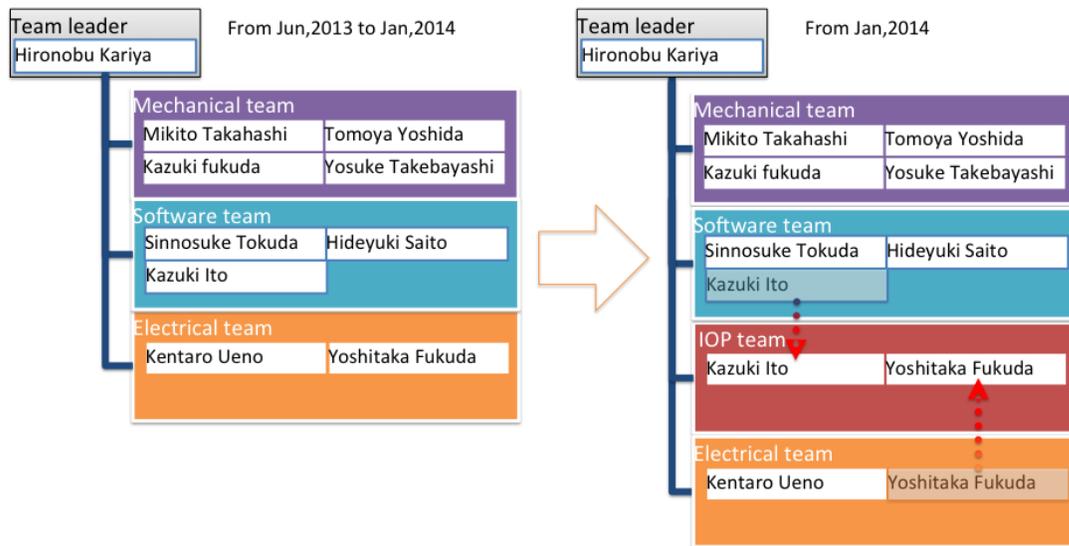
Figure 2. Team organization

DESIGN PROCESS

Last year, the failure mode, effects and criticality analysis (FMECA) table was used for improving performance and preventing the considerable risks associated with the mobile robot. Upon reviewing the difficulties and failures encountered in the last year's competition, we realize that the considerable risk does not truly reflect the actual competition environment. For example, the failures caused due to weather changes are rather unpredictable, which lead to fogging of the Omnidirectional camera lens and/or tuning of the image-processing software due to changes in sunlight.

The D-case (Dependability-case) model invented by the JST (Japan Science and Technology Agency) has the potential for encompassing the real-time risks. Figure 3 illustrates a typical example of the D-case model.
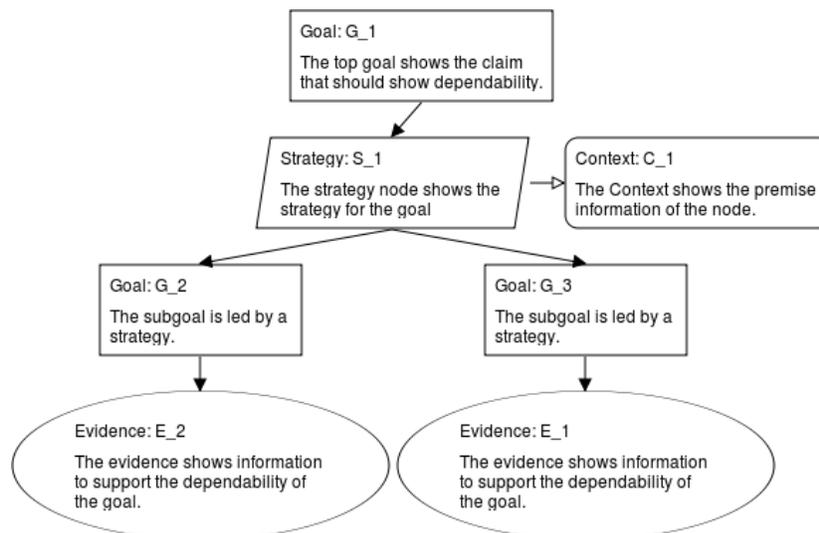

Figure 3. D-case model

The D-case model is conceptualized on the basis of "Dependability" from the reliability engineering perspective. The unique tree structure used in the D-case model depicts the dependability of the system. This model facilitates the realization of the goal the in premise, as shown in Figure 3, by repeatedly creating subgoals based on its strategy, until the final goal is achieved. After reaching the goal in the D-case model, we find the evidences for each subgoal to support our goal. Figure 4 depicts the D-case model of Orange2014 upon applying the new concepts. The lower part of the Figure 4 illustrates the efficacy of the D-case model, wherein the example shows the solutions for acquiring detailed environment data and for improving the maintainability of the mobile robot system.
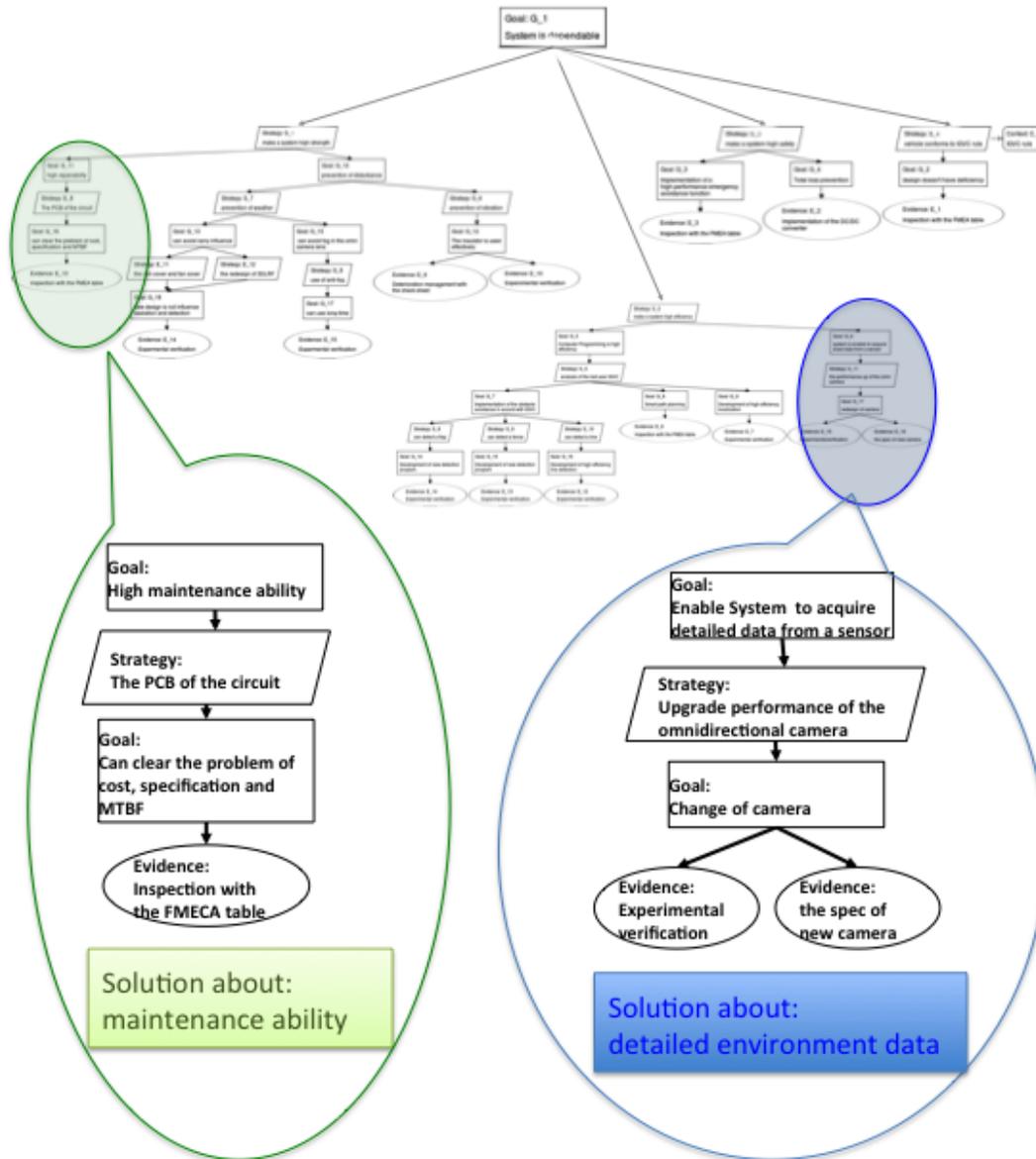

Figure 4. D-case model for Orange2014

MECHANICAL DISIGN

Based on the detailed team discussions and results of the D-case model analysis, our mobile robot concept is defined as the mobile robot portability.

In pursuit of a compact design for the mobile robot in Orange2013, we encountered difficulties in assembling, especially the electrical circuit box, according to the results of the D-case model analysis. To improve the feasibility of assembling accessibility in the electrical circuit box, we redesigned Orange2013 to a newer form in Orange2014. Figure 5 shows the new CAD design of Orange2014.

Orange2014 consists of an actuator part, detachable circuit box part, and pole part for attaching the sensors, such as 3D LIDAR. Moreover, to circumvent rain-related issues, we have designed a raincoat and a fan cover attached to the circuit box.
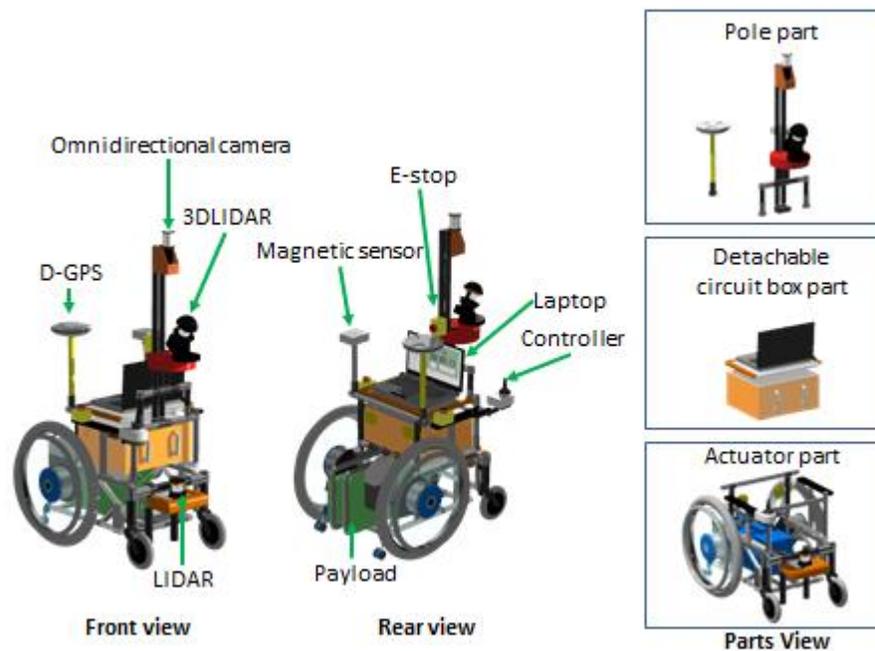

Figure 5. New design of Orange2014

Chassis and Circuit Box

The chassis used for the Orange2014 is the YAMAHA electric chair (JW-Active) and some short poles. The circuit box is positioned on the top of the chassis, whereas the bottom of the chassis offers enough space for payload. The circuit box is made of aluminum and has a width of 41 cm (1.35 feet), depth of 39 cm (1.28 feet), and height of 21 cm (0.69 feet). As a change from the last year's design, the circuit box is demountable. This allows the mobile robot to be taken from the home country, without the need for dismantling the circuit box each time. Besides, the mobile robot can be easily carried everywhere and the circuit box can be built rather quickly. Figure 6 shows the CAD design of the chassis and circuit box of Orange2014.
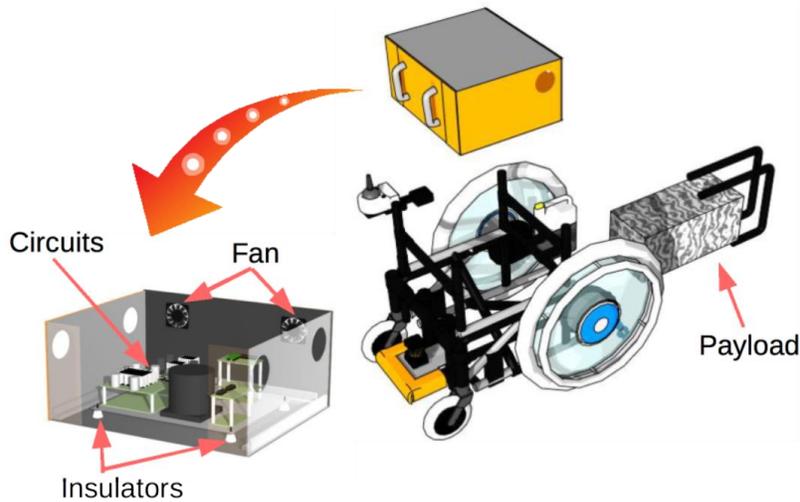
Figure 6. CAD design of the circuit box and chassis of Orange2014

3D Light Detection and Ranging

On the basis of the D-case model analysis, Orange2014 has been completely redesigned with 3D LIDAR module to incorporate a rainproof design and to improve smooth rotational mechanism for reducing unwanted motion. Figure 7 shows the comparison of 3D LIDAR used in Orange2013 and Orange2014.
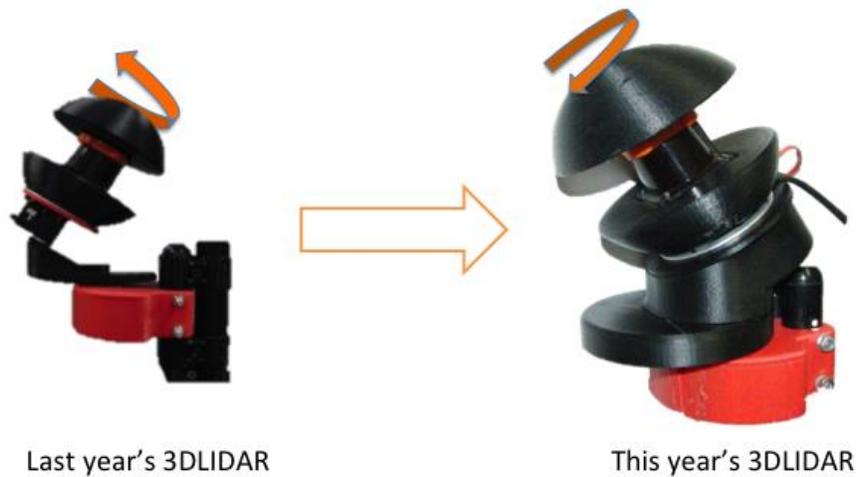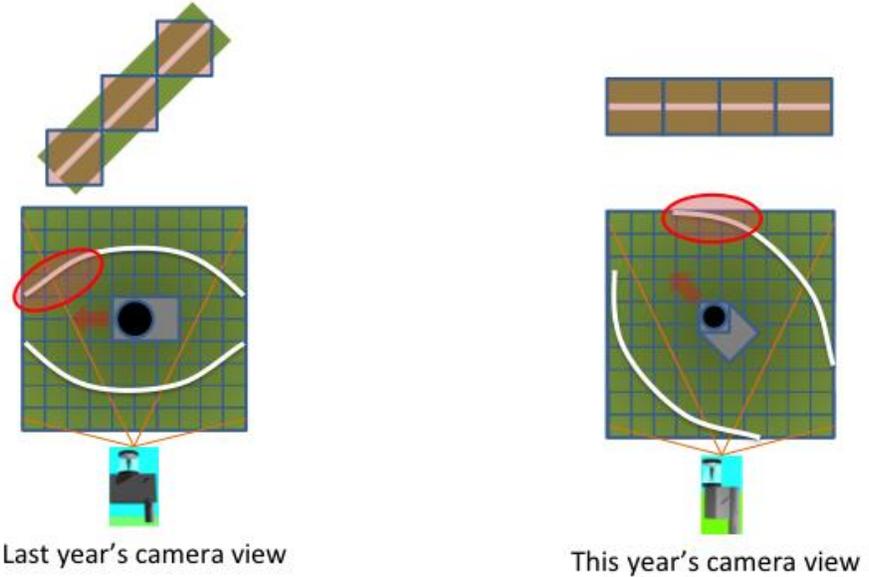

Last year's 3DLIDAR   This year's 3DLIDAR

Figure 7. Comparison of 3D LIDAR used in Orange2013 and Orange2014

Omnidirectional Camera

As shown in Figure 9(a), most pixels of the straight-line component in omnidirectional image are diagonally distributed. To improve the resolution par grid for straight-line pixels in the omnidirectional image, the camera is rotated by 45° with respect to the yaw axis. This enhances the projected straight-line pixels by approximately more than 140%, as shown in Figure 9(b).

Figure 8. The New omnidirectional camera

Last year's camera view

This year's camera view

(a) **Conventional camera view**   (b) **45° rotated camera view**

Figure 9. Omnidirectional camera view

ELECTRICAL DESIGN

Electrical Design

In the last year's design, we experienced several pressing issues with the electric circuit. To circumvent these limitations, we performed D-case model analysis. Based on the results, we replaced the hand wired circuit board with a custom-designed printed-circuit board (PCB) to prevent the unstable behavior. Figure 10 shows the newly designed AD/DA circuit for JAUS protocol converter used in Orange2014.

Figure 10. AD/DA circuit used PCB

Figure 11 shows the overall electrical design of Orange2014. The pink shaded blocks in the figure represent the newly developed/employed circuit devices in Orange2014. In the new model, the power supply for the motor and other peripheral devices is provided by 24A 6.7V Ah5h nickel hydride battery. The power supply from the battery is supplied to the motor, the laptop via the DC/DC converter, 3D LIDAR module, and different sensors (LIDAR, camera, gyro, GPS, speedometer) through the power distribution board. The environmental information obtained from the several sensors is transmitted to the laptop through an RS232–USB interface. Furthermore, to reduce the computational load of the laptop, we used a signal converter based on microcontroller (Arduino Uno) to process the signals obtained from several sensors and to transmit the signals to the wheel motor. Using the signal converter, the laptop or E-stop sends the signal to the wheel motor from the controller of the mobile robot. All wirings for these electronic bases were manually constructed.
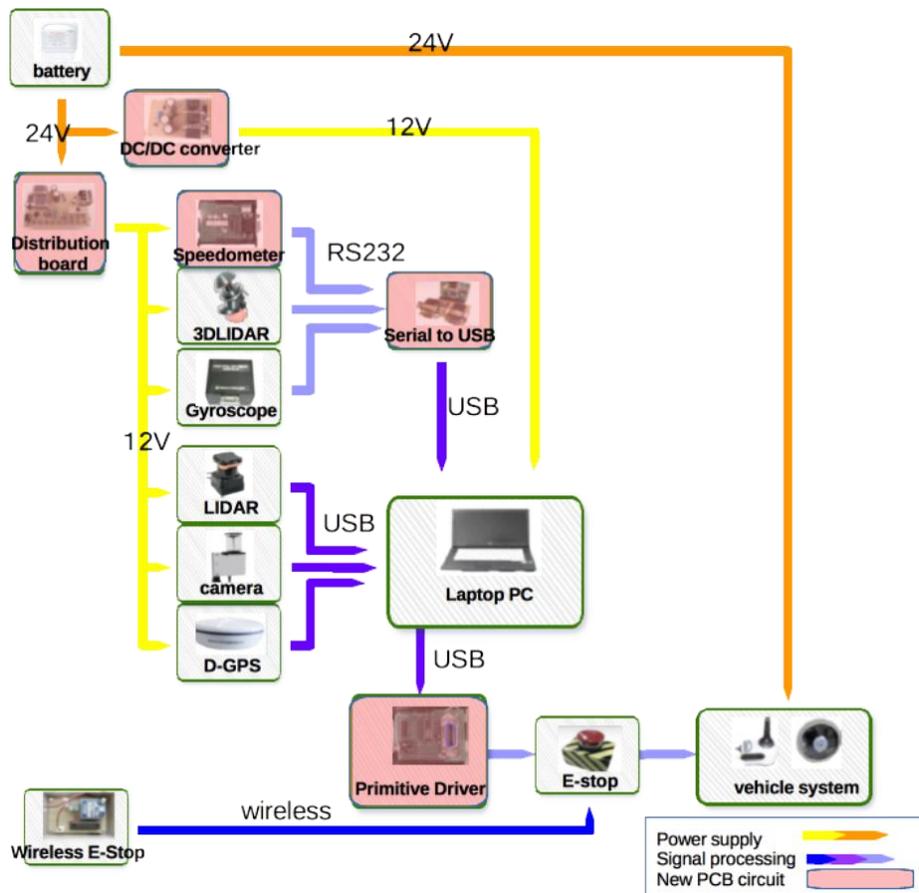
Figure 11. Electrical design of Orange2014

Sensors and Processing Unit

The Orange2014 is equipped with six sensors for acquiring the environmental information. Table 2 summarizes the specifications and targets of each sensor in Orange2014. The main controller for Orange2014 is the laptop (FUJITU LIFEBOOK A561/C) with an Intel Core i5 processor and memory of 16 GB, running on Windows 7 OS.

Table 2. Sensors unit

Sensor	Product name	Target	Specification
LIDAR	HOKUYO UTM-30LX URG-04LX-UG01	・Obstacle detection ・Mapping	Angular range is 240/270 deg. Angular resolution is 0.25/0.352°.
Speedometer	Raspberry Pi Model B	・Self-localization	This module calculates the speed from the pulse signal of the rotary encoder.
3D LIDAR	HOKUYO UTM-30LX	・Obstacle detection ・Mapping	

Omnidirectional camera	Vstone VS-C42N-TK	・Obstacle detection ・Line detection ・Mapping	
D-GPS	Hemisphere A100	・Self-localization	Accuracy is 0.6 m(2 feet), and the output rate is 20 Hz.
Gyroscope	Japan Aviation Electronics Industry JG-35FD	・Self-localization	Angular speed is 200°. and the response frequency is 20 Hz/s.

IOP CHALLENGE

IOP Interface Tasks

In view of the significant rule changes established in the IOP challenge for this year, we decided to assign two persons for the IOP team from the software and electrical teams. Table 3 summarizes the additional JAUS query messages that were included to comply with the new IOP challenge rules. For the sake of simplicity, we have not shown the JAUS query messages that were implemented last year.

Table 3. New supported query in Orange2014

Capabilities Discovery	Platform Management Task
Query Services	Discovery
Core Services Task	Register Services
Event	Query Configuration
Query Event	Query Sub-system List
Create Event	Query Services
Update Event	Liveliness
Cancel Event	Query Heartbeat Pulse
Event	Navigation and Reporting Task
Access Control	Local Waypoint Driver
Release Control	Set Travel Speed
Query Authority	Set Local Waypoint
Query Timeout	Local Waypoint List Driver
Set Authority	Query Travel Speed
Management	
Reset	
Set Emergency	
Clear Emergency	
Liveliness	
Query Heartbeat Pulse	

JAUS Protocol Converter

The JAUS protocol converter module used in Orange2013 was developed by an Arduino-based embedded microcontroller. In Orange2014, we have used a Raspberry Pi microcontroller system with Linux to enhance the intelligent controlling ability, fast message response, as well as the multitasking capability of the system. Besides, the use of raspberry pi enables faster message processing, which is approximately 43 (=700MHz/16MHz) times faster

when compared with the Arduino-based embedded microcontroller used in Orange2013. Figure 12 shows the new JAUS protocol converter module used in Orange2014.

Figure 12. New JAUS protocol converter

SOFTWARE INTEGRATION

This section describes the software integration of Orange2014, as illustrated in Figure 13. For the simplicity of integration, the software systems were developed using MATLAB. Besides, we also increased the memory from 8 GB to 16 GB and changed from HDD to SSD, to reduce the time required for data acquisition, and to enhance the system's ability to handle a large amount of data. This allows the mobile robot to be programmed much more intelligently than the last year's model.
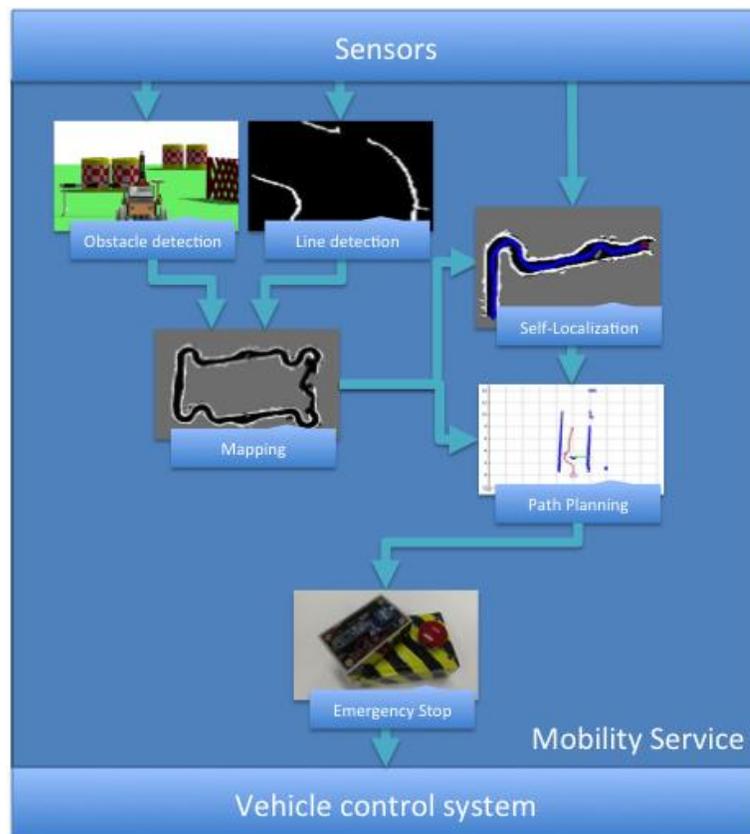

Figure 13. Software integration

OBSTACLE RECOGNITION

Line Detection

During IGVC2013, the rapid changes in the weather conditions induced variations in the color tone of the images generated by the omnidirectional camera. Such tone changes and fixed threshold of the binarized image often lead to line detection failure. Figure 14 shows the typical example of line detection failure in IGVC2013 image. The abovementioned shortcoming can be circumvented by adjusting the line detection brightness level.
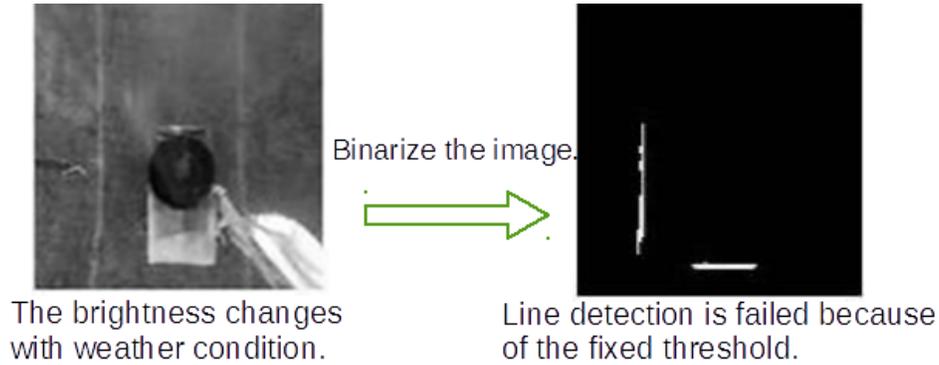

Binarize the image.

The brightness changes with weather condition.

Line detection is failed because of the fixed threshold.

Figure 14. Failure of line detection

To adapt the rapid change in color tone, we introduced the new technique of color patch correcting image processing. Figure 15 shows the actual implementation of color patch in Orange2014. The comparison of the observed color patch and the environmental color illustrates that the color of the target object can be clearly identified regardless of the changes in the weather condition. Figure 16 shows the procedure of line detection using the color patch correction image method for omnidirectional image. Figure 16(a) shows the representative image captured by the omnidirectional camera, and Figure 16(b) shows the reconstructed ground image. After reconstruction, the RGB color image is converted to a gray scale image, using only the B component, as shown in Figure 16(c). We use template matching to binarize the gray scale image. Figure 16(d) shows the binary image. The isolated noise in the binary image is removed using Quad tree. The filtered image thus obtained is shown in Figure 16(e). The lines on the image are piece-wise, which are interpolated by using the eigenvector. After recognizing the lines, the mobile robot subsequently evaluates the eigenvector of the lines. Figure 16(f) shows the eigenvector image. Using the eigenvector, the lines are interpolated.
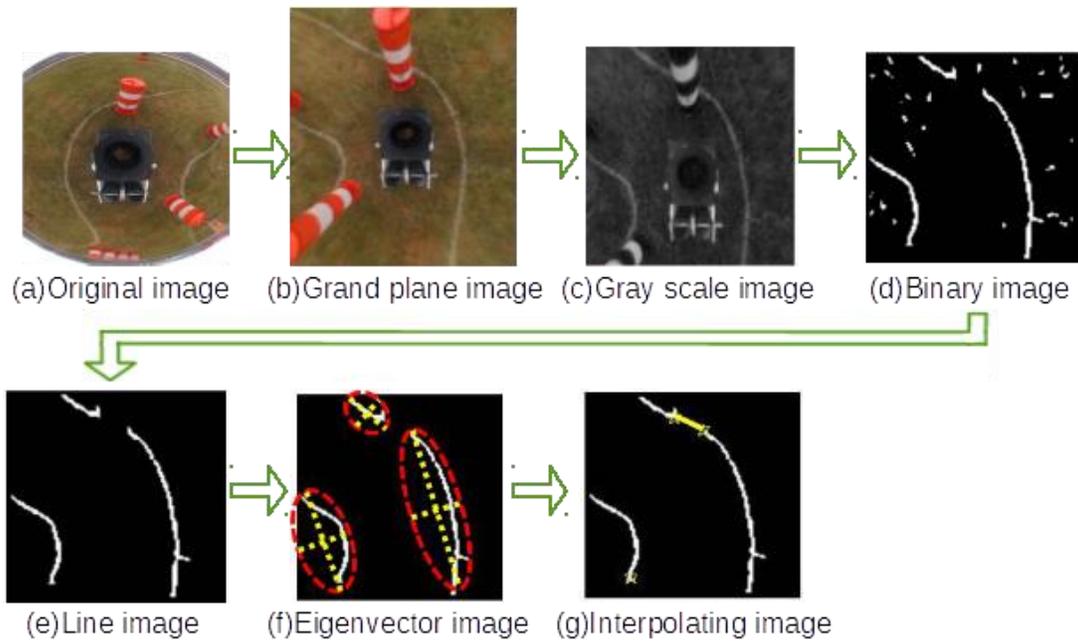

Figure 15. Color patch

Figure 16. Procedure adopted for line detection

Figure 17 shows the arrangement of the omnidirectional camera and several color patches. The color of the patches is determined from the counterparts in the actual lines. Subsequently, by comparing the color of the environmental image and the referenced patch color, the brightness of the original image is automatically corrected by applying the proposed color compensation algorithm.
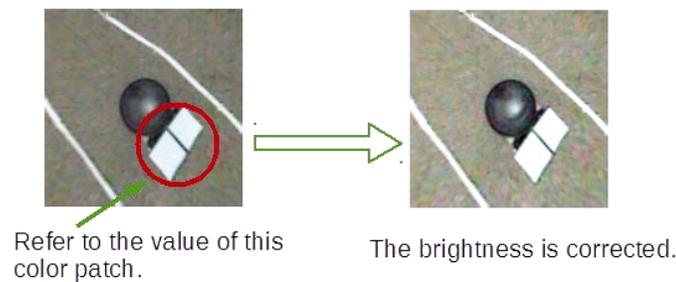

Figure 17. Referred color patch

Fence Detection

Accurate and stable fence detection is one of the key challenges in Auto-Nav function. Especially, the opening position of the fence, which is divided into two areas, is randomly relocated along the fence at the start of each run. Before the mobile robot runs through the opening position of the fence, the mobile robot has to path all the waypoints within the fence area. Figure 1 illustrates the situation after the detection of all waypoints within the fence area. To avoid collisions with other obstacles, such as the cones and barrels, the mobile robot runs near the

fence to find the opening position of the fence by using LIDAR. Once the opening position of the fence is identified, the mobile robot turns and moves through the opening position.

As illustrated in Figure 18, when the LIDAR detects the fence, the mobile robot sets the virtual waypoint to the forward position for searching. When the LIDAR detects the opening position, the virtual waypoint is changed, as shown in Figure 19, to move through the opening position.
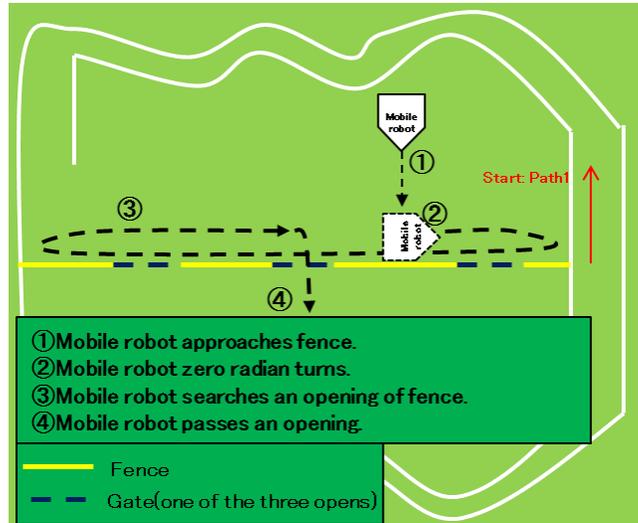

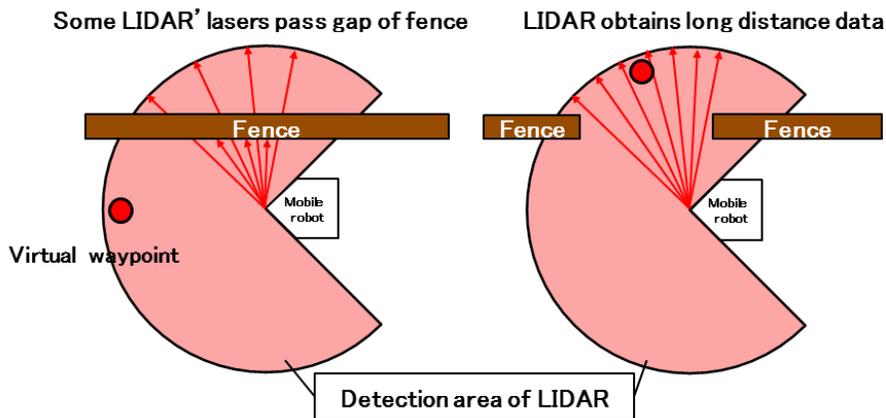**Figure 18. Strategy for identifying the opening position of the fence**

Figure 19. Method for changing the virtual waypoint to find the opening position of the fence

Flag Detection

To find a safe pathway in the flagged area, we have developed a new flag detection algorithm by using LIDAR. The LIDAR often fails to detect the flag wire owing to its low resolution when compared to the flag wire diameter. To overcome this limitation, we have employed a SLAM-based occupancy grid map detection algorithm. Furthermore, to facilitate safe navigation, we define a minimum grid size of about 10×10 cm (0.32×0.32 feet) for detecting the flag wire area. Figure 21 shows the typical example of flag wire detection based on the proposed

SLAM-based occupancy grid map. Because of the gird size and accuracy of LIDAR, a maximum range profile of 2 m (6.6 feet) is used for building the grid map of the flagged area. As shown in left picture of Figure 20, virtual lanes are generated based on the grid map of the flagged area, to facilitate safe navigation.
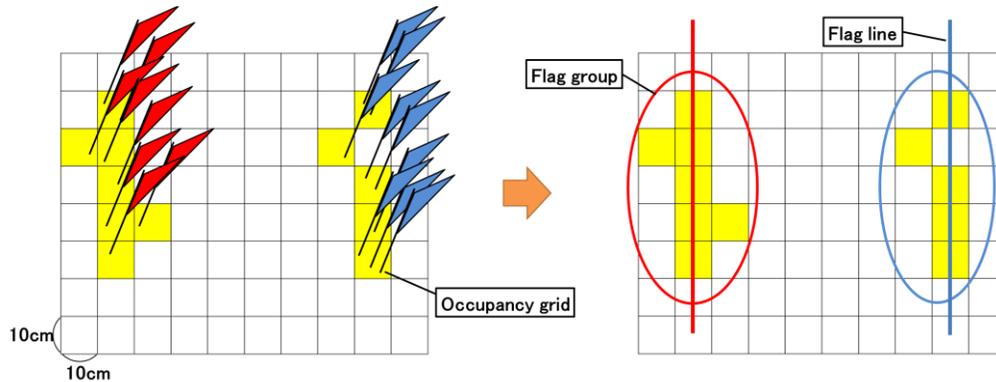

Figure 20. Obstacle grid map

PATH PLANNING

Self-localization and Mapping

As mentioned earlier, the variations in weather conditions greatly influenced the mobile robot image processing system in IGVC2013. A deeper insight on the last year's data indicated that the accuracy of self-localization with GPS was greatly influenced by weather conditions. To improve the accuracy of self-localization regardless of the weather condition, we used LIDAR and omnidirectional camera based SLAM algorithm, when the GPS signal becomes unreliable.

Figure 21 shows the self-localized global map generated for the mobile robot. To compensate the accuracy of the global map, the local maps observed from both the LIDAR and the omnidirectional camera are combined by applying the template matching technique.
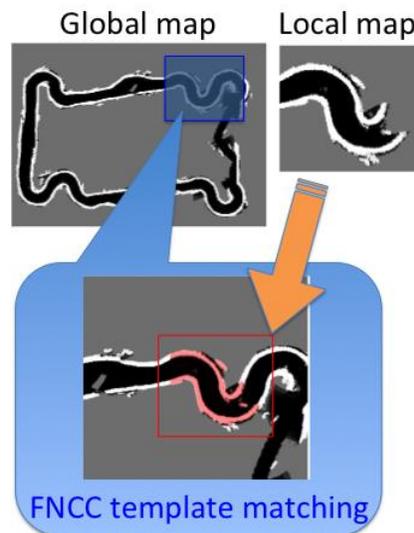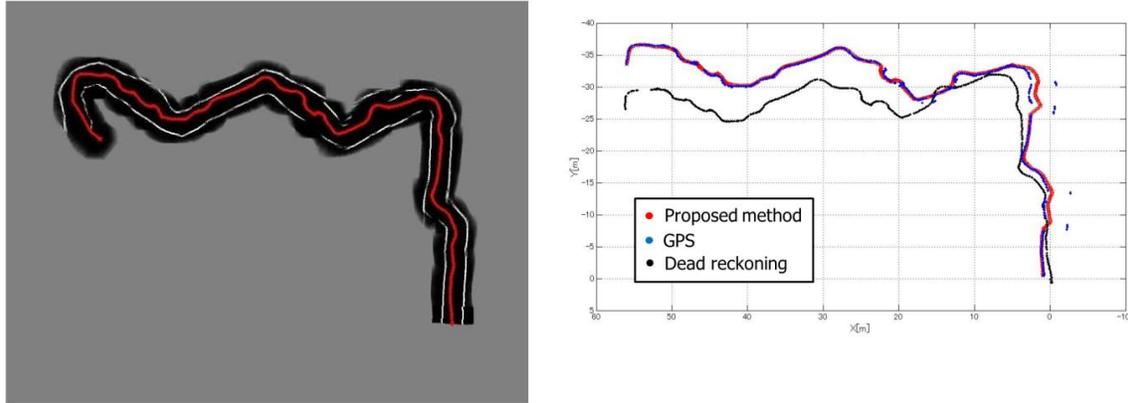

Figure 21. FNCC template matching

In Orange2014, we have used FNCC (Fast Normalized Cross Correlation) to achieve real-time self-localization and global map correction based on the observed local map. Figure 22(a) shows the global map that is corrected by using the template match technique. Figure 22 (b) shows the comparison of the self-localization results.

(a) Locus of self-localization   (b) Comparison of the self-localization results

Figure 22. Self-localization result

Path Planning

We achieved stabilized path generation by combining A* algorithm in the potential method for the path planning. This year, we plan to refine this plan. Based on the design process and IGVC2013, we frequently observed left and right path switching problem which result the colliding with the obstacle in front of mobile robot. Figure 23 shows the planning scheme after fixing the errors. To avoid path switching problem, we newly introduce virtual obstacle, the mobile robot enables the generation of more stable and smooth path planning.
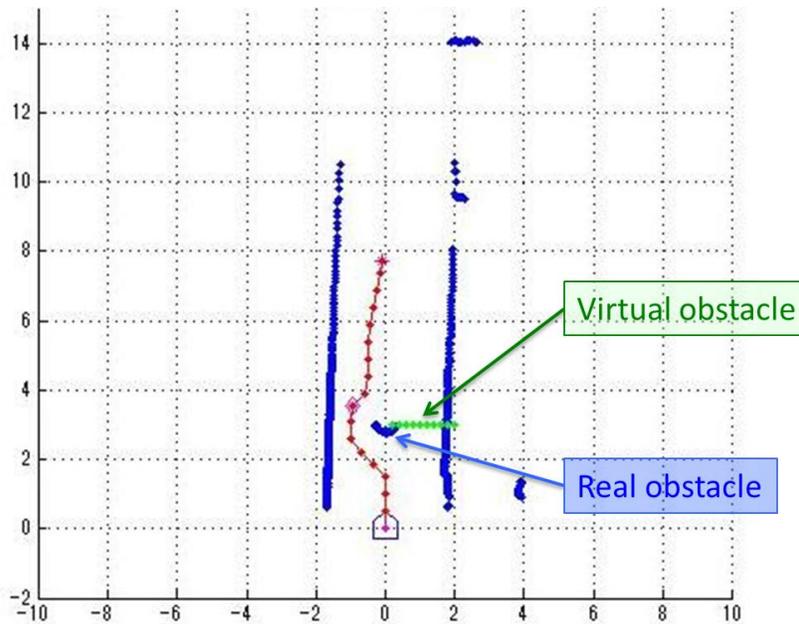

Figure 23. Path planning realized by combining A* and Potential method

PERFORMANCE

This section discusses the performance of Orange2014. Its specifications are based on YAMAHA electric wheelchair (JW-Active). The hardware of the mobile robot has been devised considering the safety factors of not only the circuits but also ensuring the surrounding safety.

Specifications of the Mobile Robot

Table 4. Performance of the mobile robot

Measurement	Performance prediction	Performance result
Speed	5.7 km/h (3.5 mph)	5.6 km/h (3.4 mph)
Ramp climbing ability	10° incline	10.2° incline
Reaction time	0.20 s	0.25 s
Battery life	3 h	2 hours 20 minutes
Obstacle detection distance	0–10 m (0-33 feet)	0–10 m (0-33 feet)
Waypoint navigation	$\pm$ 0.10 m($\pm$ 0.33feet)	$\pm$ 0.14 m($\pm$ 0.46 feet)

Safety

Orange2014 is equipped with two different types of emergency stop systems, namely, the E-stop and wireless E-stop, to prevent any unpredictable accidents. The color of the manual E-stop button is red, while the E-stop box is colored in black and yellow stripes for easy identification. The wireless E-stop is designed on the Arduino-based embedded microcontroller module with XBee transmitter/receiver. According to the specifications of the XBee device, the maximum wireless communication range is approximately 33 m (108 feet), allowing the mobile robot to be stopped remotely in case of an emergency.

To identify the requirement of manual or autonomous modes, a helically wrapped LED ribbon strip is employed as a safety light on the central pole of the mobile robot. The LED ribbon displays a stable (turned on) or flashing light when the mobile robot is in the autonomous or manual mode, respectively.

Cost

Table 5. Estimated developmental cost of Orange2014

Components	Retail cost	Team cost	Description
YAMAHA JW-Active	$5,600	$0	Electric wheelchair
HOKUYO UTM-30LX	$4,000	$0	LIDAR
VS-C42N-TK	$2,613	$2,613	Omnidirectional camera
CSSD-S6tT256NHG5Q	$175	$175	SSD
I-O DATA GV-USB2	$50	$0	USB video capture cable
Japan Aviation Electronics Industry JG-35FD	$5,800	$0	Fiber optic gyroscope
Hemisphere A100	$2,414	$0	DGPS
FUJITSULIFEBOOK A561/C	$1,000	$0	Laptop personal computer
Mechanical parts	$483	$483	Various mechanical components
Electronic parts	$268	$268	Various electrical components
Total	$22,403	$3,539	

CONCLUSION

In this paper, we present the design and implementation of Orange2014 using the D-case model, which was used to address the hardware and software problems identified in the last year's mobile robot (Orange2013).

Moreover, to comply with the new rule changes established in IGVC2014, we developed a robust and reliable robotic system utilizing a new 3D LIDAR module, omnidirectional camera, and improved obstacle detection algorithm. These capabilities are expected to improve the safety, dependability, and durability of the mobile robot. Redesigned with these new functionalities, we look forward to a favorable placement of Orange2014 in this year's IGVC.

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