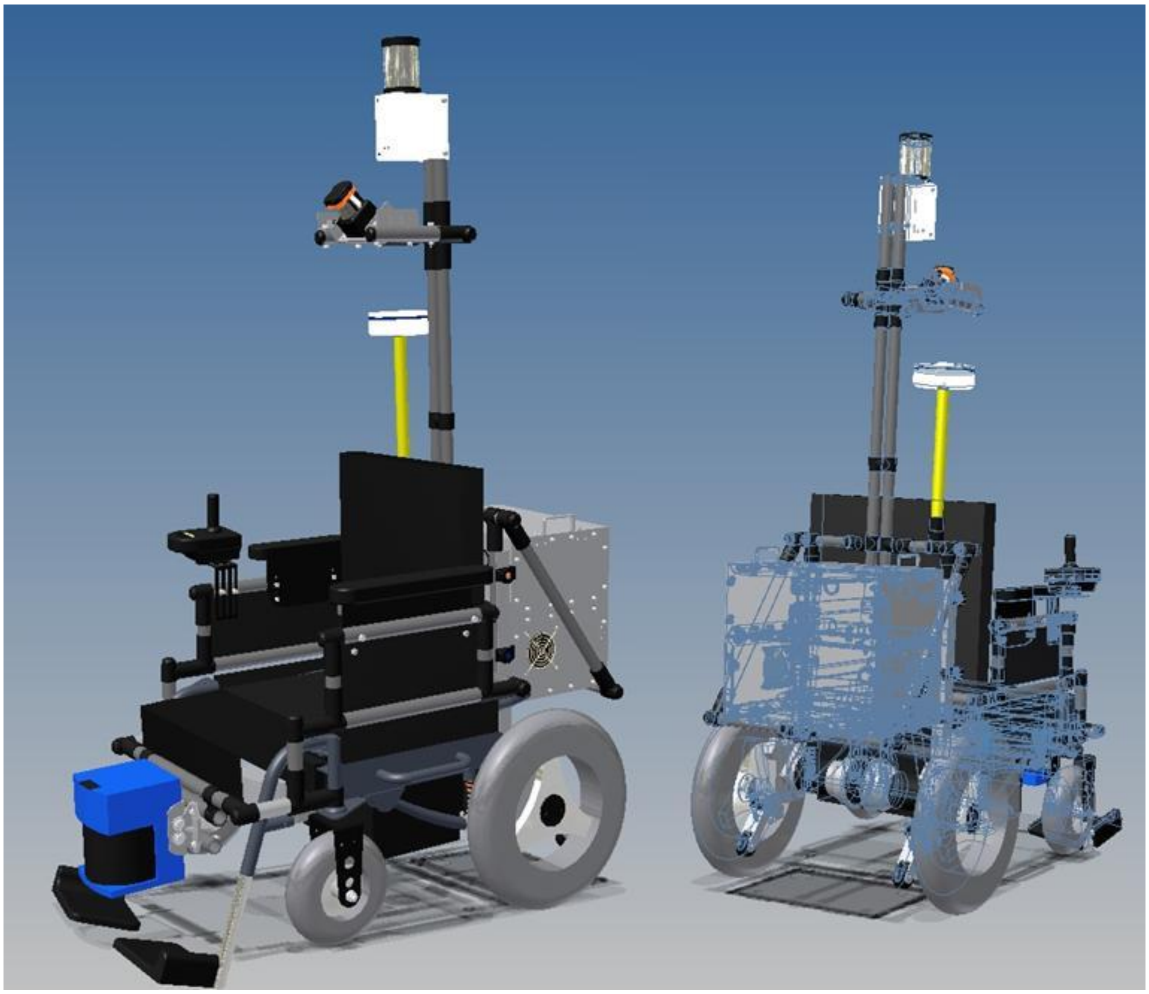
Orange2010

Hosei University



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Faculty Advisor Statement

I hereby certify that the engineering design on Orange2010 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 10, 2010

Prof. Kazuyuki Kobayashi May 10, 2010

1. Introduction

The Hosei University Autonomous Robotics Lab team (ARL2010) designed and developed Orange2010 for entry into the Intelligent Ground Vehicle Competition (IGVC) 2010. The vehicle name was inspired by Hosei University's official school color as displayed in its flag. Orange2010 was built based on a new electric wheelchair chassis and electrical housing box from scratch. The concept of Orange2010 is a next-generation personal intelligent electric vehicle for seniors built based on an electric wheelchair chassis. Orange2010 not only serves as a transportation vehicle but also supports various features for driving assistance.

Figure 1 Hosei University Flag

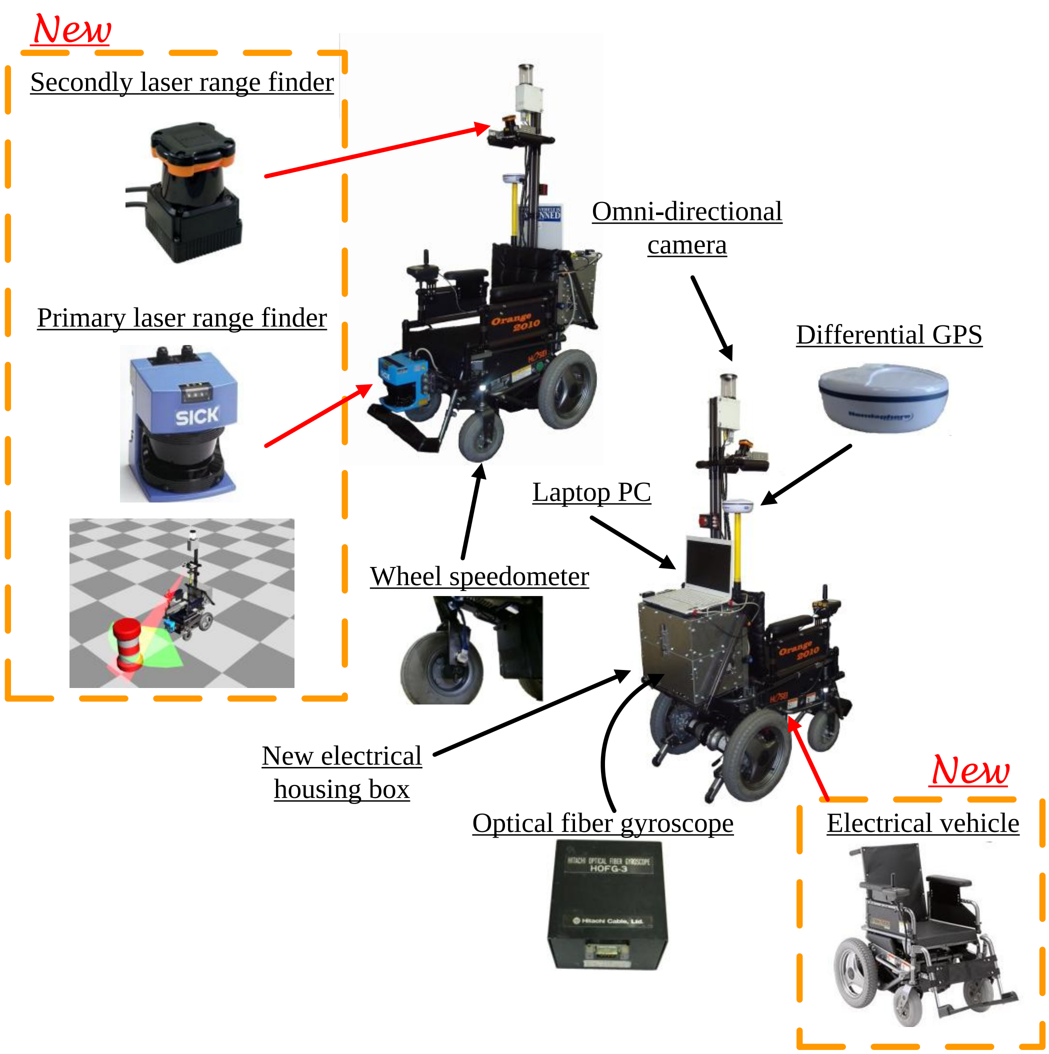
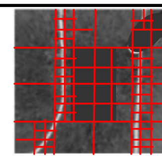
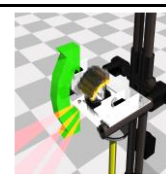


Figure 2 Orange2010

2. Effective Innovation

Through team discussion, we evaluated Orange2010 to determine its weak points. Table 1 shows three aspects of the vehicle that required improvement.

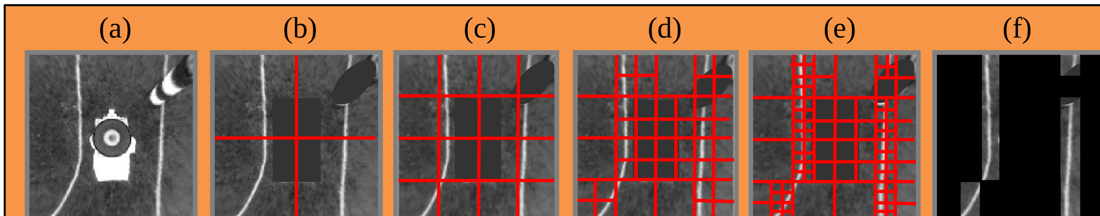
Table 1 Vehicle aspects requiring improvement

Problem	Solution
Lack of intelligence To navigate the vehicle through the complex obstacle area, a more intelligent algorithm must be developed.	We introduced a new path planning algorithm that uses Omni-directional images by applying Heuristic search method. 
False lane boundaries detection Depending on surrounding light condition, false edge detection is occurred.	To overcome false lane boundaries detection due to surrounding light condition, we newly apply region 
Obstacle detection ability Due to the undulating surface of the course, the laser range finder frequently detected false obstacles and/or missed obstacles during course navigation.	In order to detect obstacles regardless of undulating surface, we newly employing two laser range-finders (LRF). 

2.1 Robust lane boundary detection by using quadtree decomposition

Depending on the ground texture and color, it might be difficult to accurately detect lane boundaries. In order to overcome this problem, we conventionally apply a lane-shape-based detection algorithm by using a template matching filter. This year, to achieve robust and stable lane boundary detection, the combination of a template matching filter and quadtree-based dynamic thresholding method was applied.

The quadtree-based dynamic thresholding method divides an image into small areas and detects the uniformity of features. The detailed steps of the procedure are as follows:



(a) Input image, (b)–(e) Region segmentation, (f) Determination of lane areas

Figure 3 Quadtree decomposition

Step 1 Consider an entire image as one region and scan the uniformity of features based on variations in image grayscale density.

Step 2 If the features of a region are detected as non-uniform, divide the image into four squares. If the features are uniform, stop the scan.

Step 3 These steps are repeated for each square.

2.2 Obstacle detection system using two LRFs

To ensure detection of obstacles regardless of an undulating surface such as that found in the IGVC2008 navigation course, we applied two LRFs capable of detecting the three-dimensional shape of an obstacle. One LRF is set up horizontally at a lower position to detect horizontal obstacles, and the other LRF is set up slightly tilted at a higher position to detect an undulating ground surface. These two different configurations can reconstruct not only the three-dimensional shape of obstacles but also the undulating ground surface.

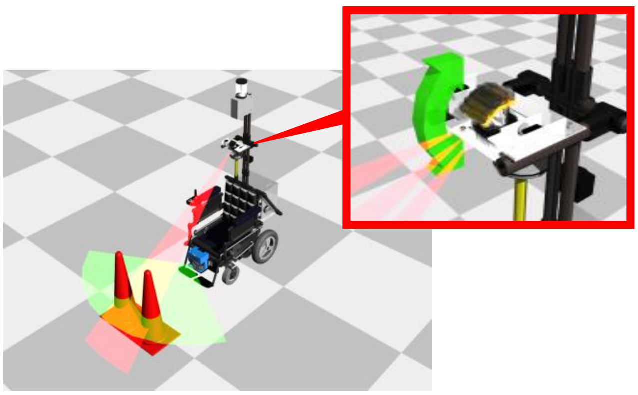


Figure 4 Obstacle detection by two LRFs

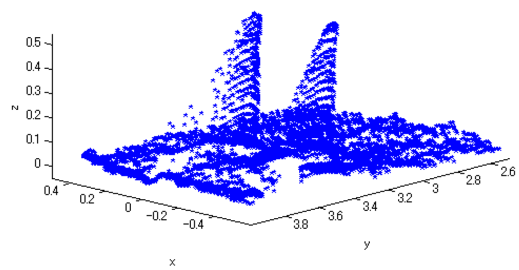


Figure 5 3D environment structure

As shown in Figure 4, the angle of the slightly tilted LRF can be adjusted by controlling the servo motors. Depending on the position of the obstacle, we can control the tilt angle through the PC and identify the shape of three-dimensional obstacles.

3. Team Overview

3.1 Team organization

The ARL2010 team currently has ten members including six undergraduate students and four graduate students. As a result of last year’s flu pandemic, none of the members were able to attend IGVC2009, and thus have no experience in the competition. In order to design our vehicle, we carefully read all IGVC rule documents for the three student competitions (JAUS, Autonomous and Navigation). After a lengthy discussion among team members, we decided to form three functional groups to build the new vehicle. As shown in Figure 6, a Mechanical Team, Software Team, and Electrical Team were designated to oversee the functional groups. The Mechanical Team is responsible for all phases of vehicle fabrication and CAD drawings. The Electrical

Team is responsible for sensor selection, power system and electronics for building the electrical housing box. The Software Team is responsible for all algorithmic design. A total of 3550 hours were spent in the development and testing of the new vehicle.

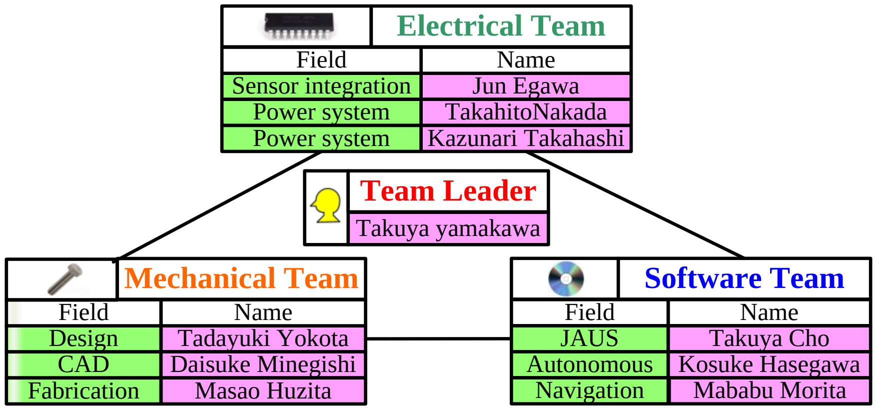


Figure 6 Team organization

3.2 Design process

Weekly team meetings were held to set sub-goals for each functional group and to discuss time schedules. During the meetings, members brainstormed and refined ideas to identify the optimal concept. To visualize the concept, we introduced mind mapping software for discussion. The mind map is a diagram used to represent ideas or tasks linked to and arranged around a central key word. By using the visualized mind map, the overall tasks and detailed tasks could be shared at once between team members. In addition, it was possible to steadily check and carry out each task using the procedure where even a detailed level could be specified and displayed. Figure 7 shows the initial stage of a typical mind map diagram during a team meeting discussion.

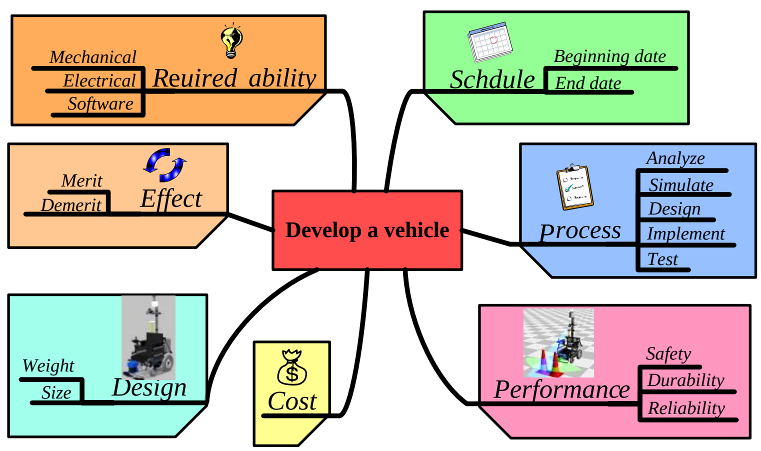


Figure 7 Typical example of mind map

3.3 Software tools

3.3.1 Group Session 2

For Internet-based team communication, we newly introduced “Group Session 2” Java-based collaborative software. Program capabilities include (1) Electronic calendars, (2) Project management systems, (3) Workflow system, (4) Short mail

Figure 8 Group Session 2

system, and (5) Document sharing, to ensure smooth communication between team members.

3.3.2 SVN

In order to manage the developed software version, we newly introduced SVN, a version management source system. Most software is written in MATLAB language and works with Windows software. Tortoise SVN is used as SVN client software.

Figure 9 SVN

4. Electrical Design

4.1 Power system and sensor integration

Two 35 Ah 12-V batteries are installed in Orange2010. These two batteries are connected in series to supply 24 V for controlling the laser range finders and wheel motor. The supplied 24 V is stepped down to 12 V for the sensors (for the laser range finders, DGPS, optical fiber gyro, omni-directional camera), PC, and junction box circuit. Environmental information obtained from the sensors is processed by using a laptop PC. According to the processing results, the PC-connected D/A converter generates the appropriate voltage signal to control the electric wheelchair. In order to stop safely, we added an E-stop box between the D/A converter and motor controller. The sensors are connected through an RS-232-USB converter, with the exception of those for the SICK laser range finder and omni-directional camera. Figure 10 shows how the sensor signal cables and power supply wires are connected and integrated.

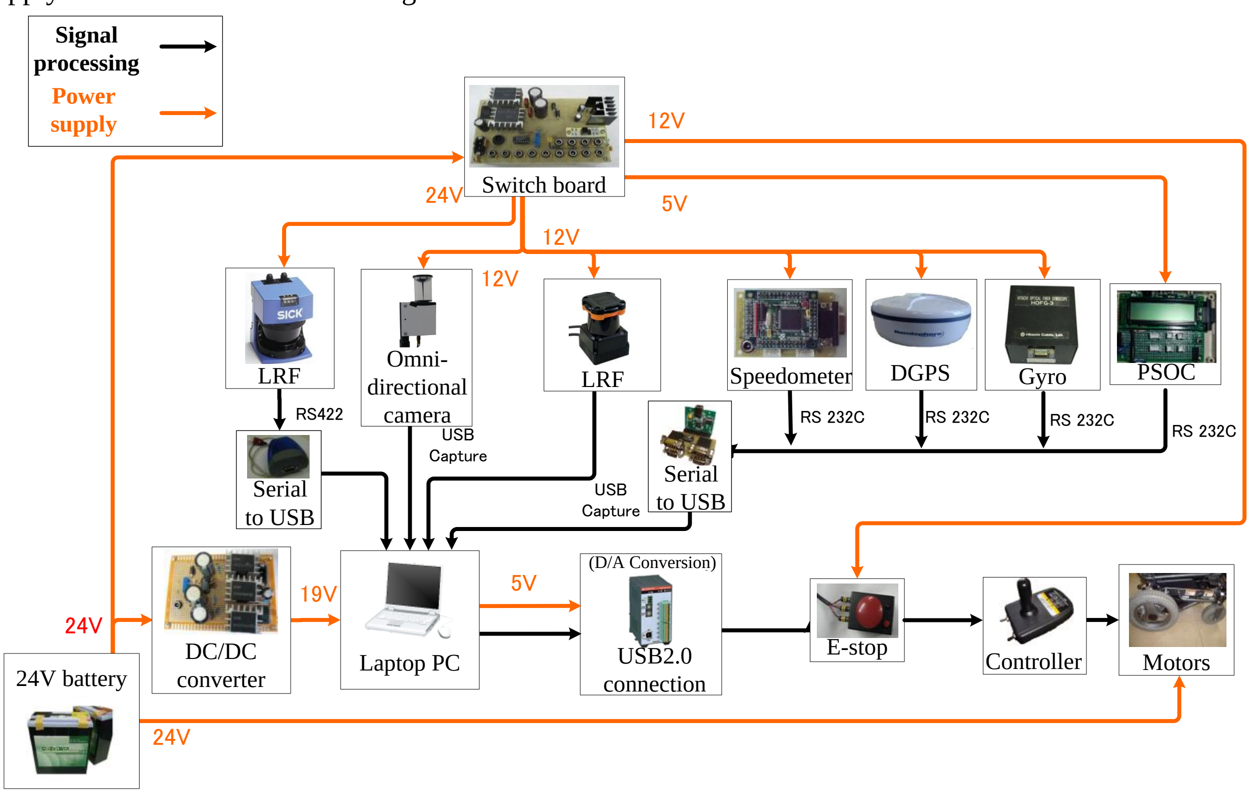


Figure 10 Sensor integration

4.2 Computer

The laptop computer (FMV-BIBLO MG/C77) that we used is a 2.4-GHz Intel Core2 Duo processor with 2 GB of memory, running Microsoft Windows XP Professional. All sensor information comes through USB cables.

4.3 System integration

4.3.1 Obstacle detection using two LRFs

Orange2010's source of obstacle detection is two LRFs (SICK LMS200 and HOKUYO TM-30LX). The SICK LMS200 settings used for Orange2010 allow the device to scan a range of 180° in 0.5° increments, measuring distances up to 20 m away and returning values in millimeters.

The HOKUYO UTM-30LX is set up slightly tilted, takes the difference in the time-series data and detects obstacles in three dimensions. The information is sent to MATLAB for range profile recognition.

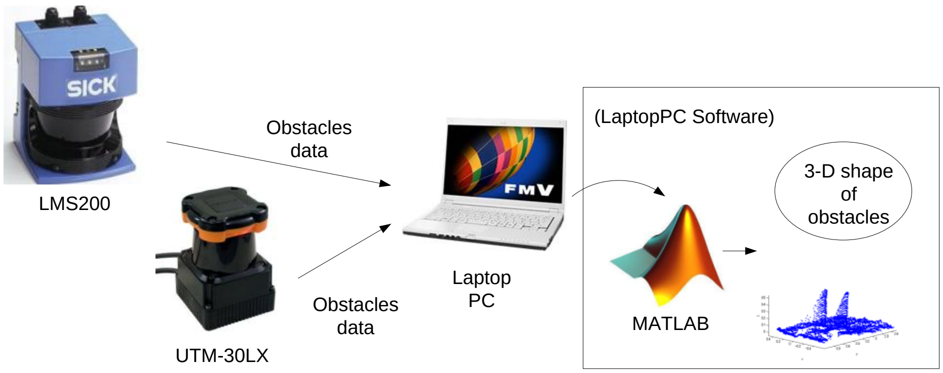


Figure 11 Obstacle detection using two LRFs

4.3.2 Omni-directional camera system

An omni-directional camera (SONY CCD EVI-370 with hyperbolic mirror) is installed on Orange2010. Images from the camera are converted to VCAPG2 by a USB frame grabber (I-O DATA USB-CAP2). The captured images are converted to ground plane images by MATLAB. The detailed algorithm is described in Section 6 "Autonomous Challenge."

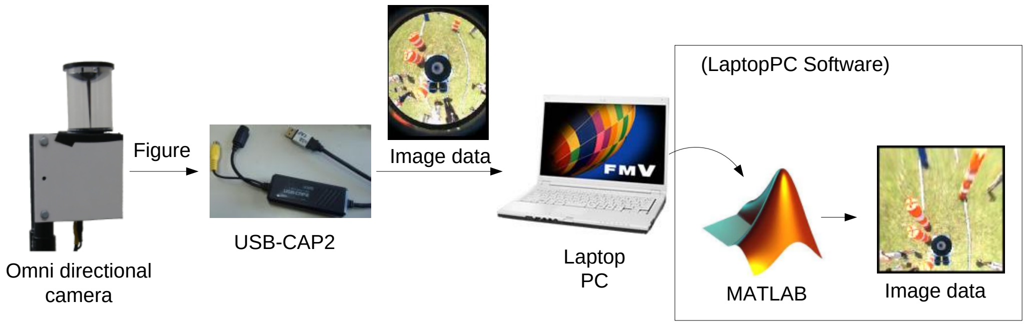


Figure 12 Omni-directional camera system

4.3.3 Estimate to the mobile robot localization

Accurate self-positioning is a key technology in the Navigation Challenge Competition. To ensure accurate estimation of self-positioning, we apply real-time Kalman filtering by fusing dead-reckoning information estimated from the speed-sensor optical fiber gyro (HITACHI HOFG-3) and absolute position data from the DGPS receiver (Hemisphere A100). The optical fiber gyro that we used measures both the angular speed and the rotational angle with almost no offset drift. The receiver is an all-in-one enclosure type with sampling intervals up to 20 Hz. Horizontal accuracy of this GPS is 0.6 m in DGPS mode.

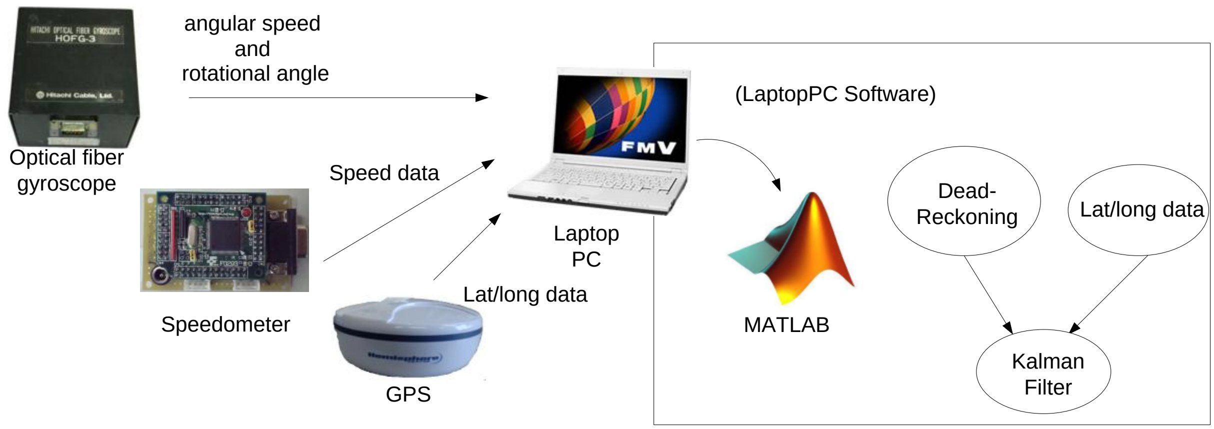


Figure 13 Estimate to the mobile robot localization

5. Mechanical Design

5.1 Structure of the vehicle

We developed our vehicle based on the commercially available electrical wheelchair as the robotic chassis. Prior to starting any construction, the entire robot was modeled using Autodesk Inventor 2008 CAD software. Inventor has digital prototyping capability that enables optimization, improvement, and verification and analysis of the design using a 3D model, which makes it possible to improve the quality and reduce the time and cost.

Since the concept of Orange2010 is an advanced personal electric vehicle, we installed sensors and an electrical housing box while retaining the functionality of the original electric wheelchair. Two LRFs are arranged for detecting front side obstacles. One LRF (SICK LMS200) is set on the front part of obstacles, and the other LRF (HOKUYO UTM-30LX) is set on the top of poles for detecting the front part of the ground surface. The omni-directional camera is set on the top to observe the surrounding view. The electrical housing box is set on the back of the backrest. The sensors and electrical housing box can be easily removed using a wrench and a set of Allen keys.

Figure 14 CAD

5.2 Chassis

To ensure mechanical reliability of the base vehicle in view of its transport by air from Japan, we selected a commercially available electric wheelchair as the robotic chassis. The base chassis is an electrically powered two-wheel wheelchair with powered steering assistance, the MC3000P produced by Suzuki. The maximum limited speed of the wheelchair is 6.0 km/h (3.76 miles/h).

Figure 15 MC3000P (SUZUKI)

5.3 Actuators

Three actuators are used for controlling and driving Orange2010. One actuator is mounted on the front part for steering assistance. The other two actuators are mounted on the rear part for driving the vehicle and controlling the steering. The actuators for driving the vehicle are two 24-V DC motors mounted on the electric wheelchair. Each motor has a maximum rated power of 210 W for 30 min. The power for the motors is supplied by two 35 Ah 12-V batteries.

Figure 16 Actuators

5.4 Electrical housing box

Figure 17 shows the newly developed housing box. The size of the electrical housing box was determined based on baggage-checking dimensions since the unit must be transported by air. In order to balance the weight in the electrical housing box, the lower part accommodates the necessary sensors and cables.

Figure 17 Electrical housing box

6. Software Design

6.1 Autonomous Challenge Competition

In order to successfully pass through the complex obstacle area, we introduced a path planning algorithm that uses a combination of Hough transform, color segmentation based on PCA method, and watershed algorithm. Figure 18 shows the procedure for the proposed path planning algorithm. Color segmentation based on PCA is used for robust lane detection, and the Hough transform is used to detect straight lanes. The watershed algorithm is used for the complex obstacle area to find the optimal path.

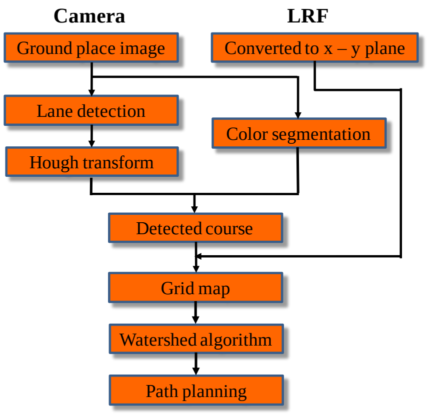


Figure 18 Procedure for path planning

6.1.1 Lane detection

Problems in lane detection are often caused by sunshine and/or shadow effects in an outdoor environment. The shadows of trees or other obstacles can create false lanes and/or false obstacles. Reconstructing the captured images into ground images enhances the lanes so that their identification is not influenced by the shadows in the original image. Figure 19 (a) shows images captured by the omni-directional camera. Figure 19 (b) shows the reconstructed ground image. After reconstruction, the RGB color image is converted to a grayscale image using only the B component. Figure 19 (c) shows the grayscale image. By using a referenced lane template image prepared in advance, normalized template matching is applied to detect the lanes. This technique is robust to noise and sensitive to lanes. The template-matched image is converted to a binary image by comparing thresholds. Figure 19 (d) shows the binary image. The isolated noise in the binary image is removed by the combined algorithms of the labeling and morphological thinning processes; this is called logical filtering. Figure 19 (e) shows the logically filtered image. Finally, the Hough transform technique, which extracts straight lines in images, is applied to detect lane lines. When the image has a sharp curve, the Hough transform algorithm recognizes that there are several lines in the image corresponding to multiple peaks in the M–O Hough domain. Thus, if multiple peaks are detected in the M–O Hough domain, the lane curve is approximated by piecewise linear segments. Implementing such sophisticated lane-detection algorithms, Orange2010 proved reliable at detecting lanes even in cases where the lanes were hidden by obstacles or drawn only by dashed lines. Figure 19 (f) shows a typical example of the region-segmented results. The quadtree decomposition method is applied to distinguish both lane areas and other areas. Figure 19 (g) shows the lane enhancement results. Lane enhancement is achieved based on the labeling result for removing small isolated areas. Figure 19 (h) and (i) show the plots in the Hough domain and the detected lane, respectively. The detected lane lines can be stored as sets of starting points and end points and line-crossing points.

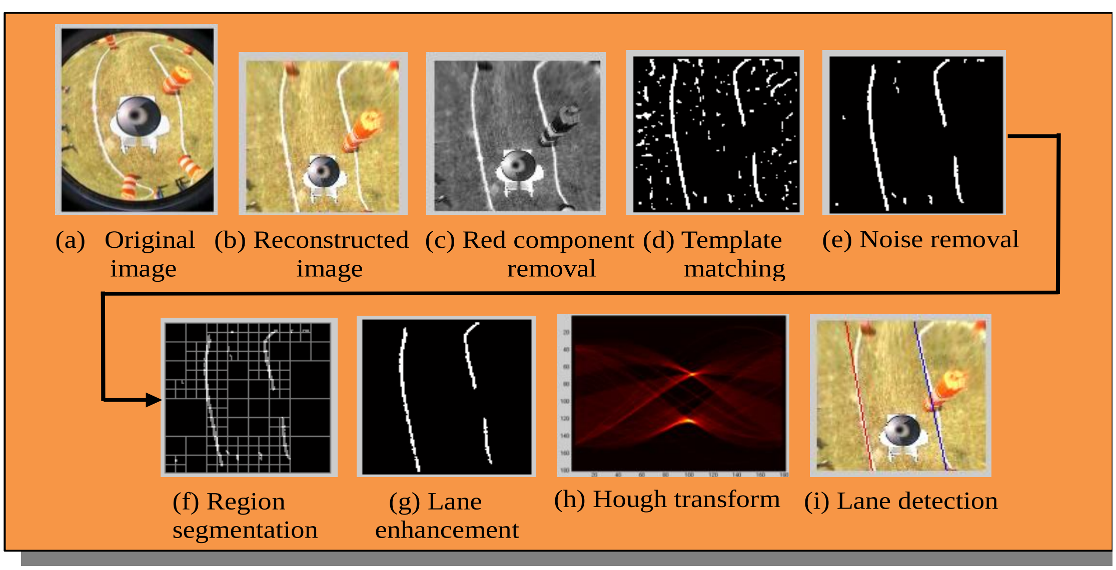


Figure 19 Lane detection

6.1.2 Color segmentation based on PCA (principal component analysis)

The Hough transform is one of the best algorithms for lane edge detection. However, in the complex obstacle area, lane edges are frequently behind obstacles, which results in false lane edge detection. To solve this problem, we focused instead on correlated colors in the grassy ground area that indicate the lane course. To detect the lane course based on grass color, we applied a new color segmentation algorithm based on PCA (principal component analysis). The proposed color segmentation algorithm can robustly detect the lane course regardless of lane edge detection. The proposed method involves the following three steps:

Step 1 Extract the RGB values of the ground color from the vehicle rear part of the image.

Step 2 Convert the binary RGB image of the ground color to a binary image by coordinate transformation using principal component analysis.

Step 3 Remove the isolated noise in the binary image using morphological thinning, to detect the lane course through which it is possible to pass.

Figure 20 shows the path generation flow in the obstacle area. Figure 20 (a) shows an image of the ground plane. Figure 20 (b) shows the ground plane image in RGB space. Figure 20 (c) shows the grass color in RGB space. Figure 20 (d) shows the PCA transform. Figure 20 (e) shows the binary image. Figure 20 (f) shows the noise reduction.

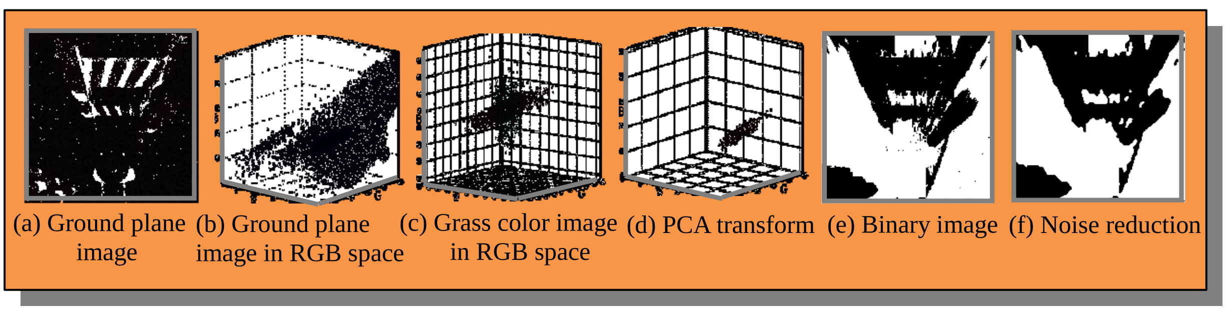


Figure 20 Course detection based on color segmentation by PCA

6.1.3 Path planning

6.1.3.1 Finding the target destination based on watershed algorithm

The target destination in the captured image is determined by the detected obstacle location and lane edges. Once the target destination is determined, the watershed algorithm is applied for path generation. The watershed algorithm is an image processing segmentation algorithm that splits an image into areas based on the topology. Figure 21 shows a typical example of the applied watershed algorithm. Figure 21 (a) shows an image of the lane edge and obstacle detection. Figure 21 (b) shows a binary image integrating the obstacle information based on the detected lane edges and obstacle location. Figure 21 (c) shows a gradient image based on calculating the Euclidean distance to the nearest black pixel on the binary image. Figure 21 (d) shows the threshold processing of the gradient image in response to the width of the vehicle.

Figure 21 (e) shows a watershed image based on the gradient image that used threshold processing. Figure 21 (f) displays the generated target destination indicated by an asterisk. The target destination is set on the watershed farthest from the vehicle.

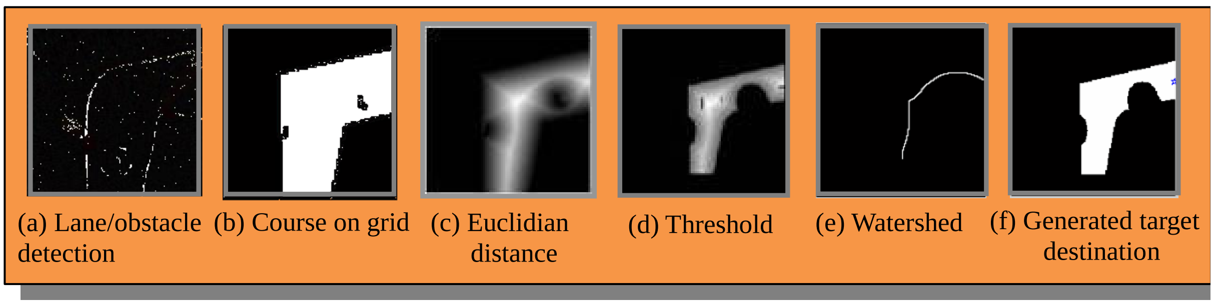


Figure 21 Finding the target destination based on the watershed algorithm

6.1.3.2 A* search algorithm

We applied a newly modified A* search algorithm that can be processed in real time, in order to find a sub-optimal path to the target destination for path planning. The A* search algorithm method is based on estimated costs until reaching the target destination. The estimated costs can be represented by the following equations:

Where is the estimated cost of the route from the start to node n and is the estimated cost of the shortest route from node n until reaching the goal. In order to reduce the processing time, we reduced the number of nodes in the A* search algorithm by processing (a), (b), and (c). Moreover, in order to apply the generated path to the vehicle, (d) is processed. (a) Make the distance to the next node changeable: The distance to the next node is extended, and the distance to the next node is changed in response to the distance to the target destination and obstacles. (b) Close out the search: If the

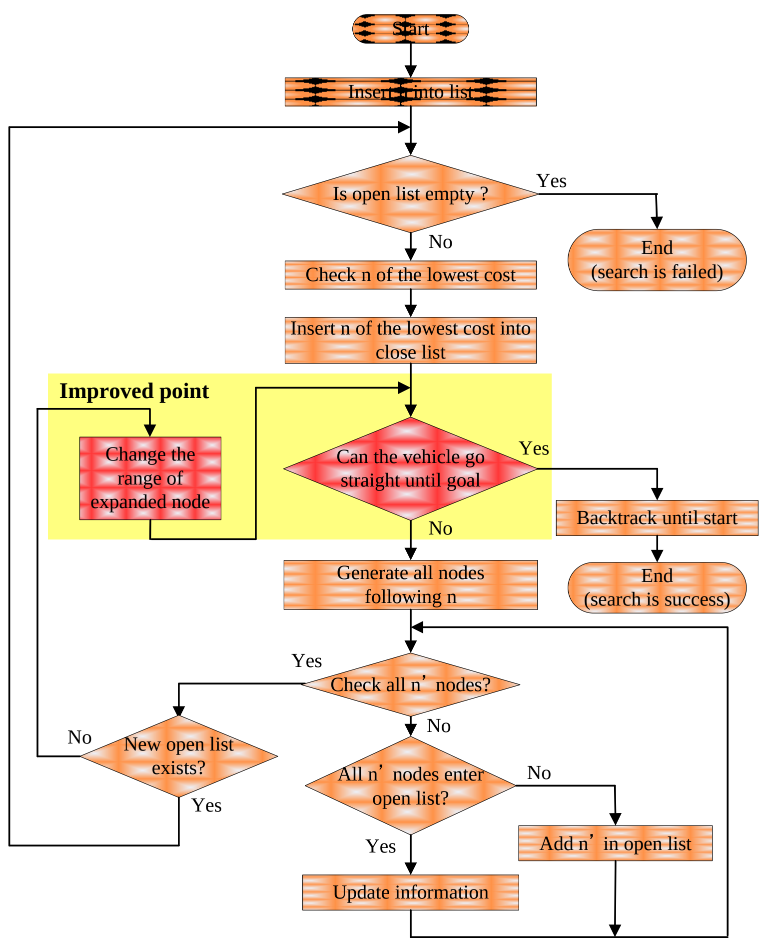


Figure 22 A* search algorithm

vehicle can move straight from the search node to the target destination, the search closes out as a success. (c) Give precedence to the heuristic cost: Speeding up the path search can be done by estimating the heuristic cost as higher than the actual cost. (d) Simplify the generated path: There is a possibility that the path generated by (c) is not the shortest path. In order to simplify the generated path, the proposed algorithm finds a node that can pass straight through and omits the path up to this node. Figure 23 shows an example of simplifying the generated path. In this figure, the red part shows the area where it is not permitted to run. The green circles show the obtained path nodes. The sky-blue line shows the path up to a node that can pass straight through.

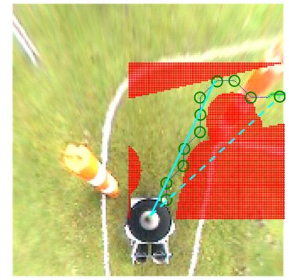


Figure 23 Simplified path

6.2 Navigation Challenge Competition

To improve the obstacle detection ability, we newly employed two LRFs. The primary LRF (SICK LMS200) uses obstacle detection. The secondary LRF (UTM-30LX) is set on the upper part of the vehicle pole and looks downward 2–3 m ahead of the vehicle to detect an undulating ground surface and find a safer path. The downward angle can be controlled by using the PSoC microcontroller.

Figure 24 shows the activity diagram of the navigation system for the Navigation Challenge Competition. Data from the primary LRF, which is arranged horizontally, is transformed from polar coordinates to x-y coordinates, and the clustering method is applied to the data. Data from the secondary LRF is transformed into plane coordinates for acquiring different time-series data compared to the primary LRF. Depending on the status of the different time-series data, we can detect both the three-dimensional shape of obstacles and the angle of the slope in front of the vehicle.

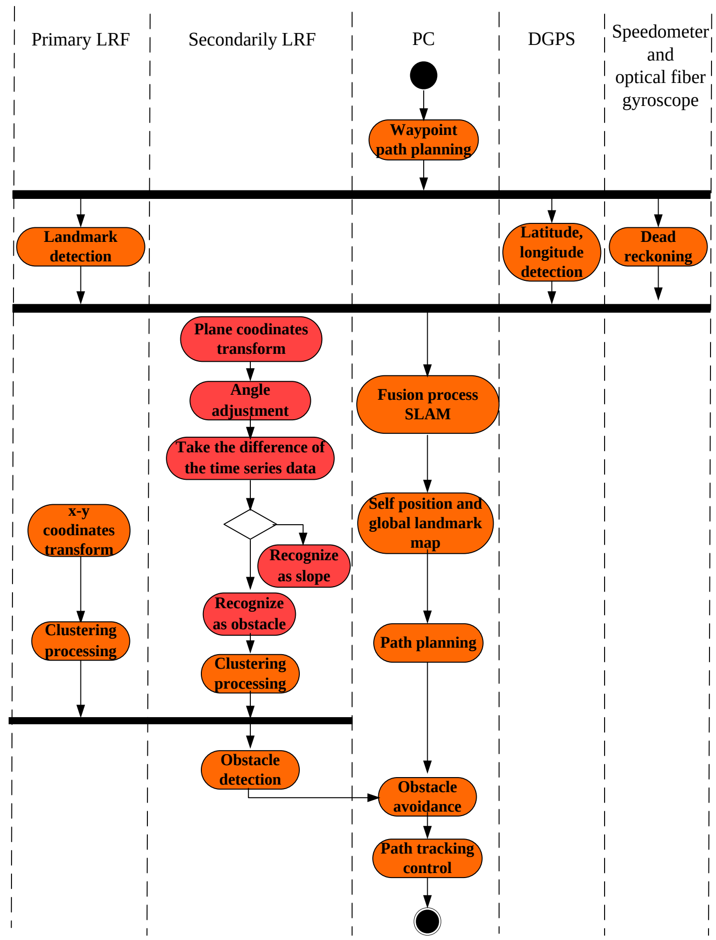


Figure 24 Activity diagram of navigation system for Navigation Challenge Competition

6.3 JAUS Challenge Competition

At IGVC2008, we successfully reached JAUS Level III and satisfied the requirements for the JAUS Challenge. This year, we are taking on the new challenge with enthusiasm. In our new JAUS control system, the JAUS message commands from the Common Operating Picture (COP) via an RF data link are received by a wireless Ethernet converter (BUFFALO WLI-TX1-G54) and are interpreted using a microcontroller board (RENESAS SH3/SH7706) via Ethernet. Interpreted codes are stored in the shared memory of the PC via Ethernet and are executed by PC software for controlling the vehicle. For rapid prototyping, we use both Python and MATLAB languages. In order to communicate between different language programs, we apply the shared memory approach, which can achieve stable and robust asynchronous communication between the microcontroller board and PC.

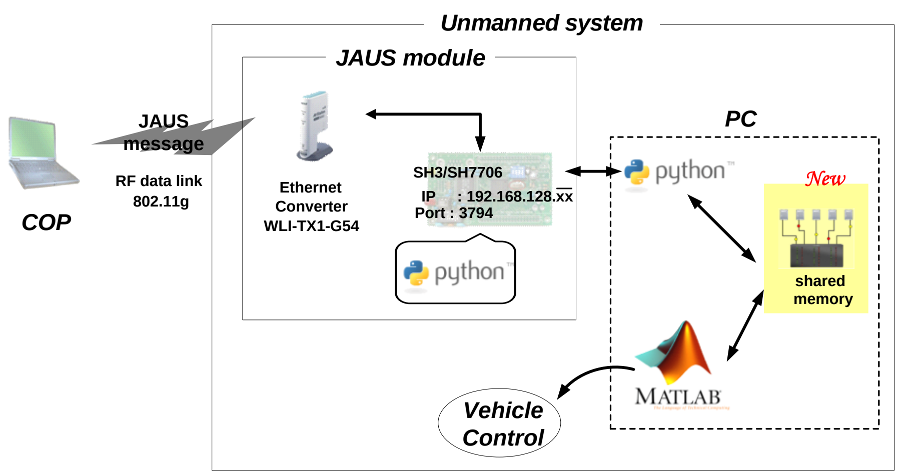


Figure 25 JAUS control system

7. Safety, Reliability, Durability

7.1 Safety

In the electrical design, we developed two different types of emergency stop (E-stop) in accordance with the IGVC rules. One is a wireless E-stop controller and the other is a vehicle-mounted E-stop push button. The remote E-stop signal is transmitted by an automobile wireless engine starter to the E-stop controller. It can transmit signals in a wide range with a maximum distance of about 100 m (330 ft). The mounted E-stop push button is located at the rear of the vehicle and can be easily found and accessed.

7.2 Reliability

The reliability of Orange2010 has been improved by completely redesigning the electrical circuit housing and introducing stiff frames. In the electrical design, the power supply jack is designed to prevent connection to the wrong voltage and thus avoid human errors.

7.3 Durability

To enhance durability, we designed and arranged the electric circuit housing at the center of the electric wheelchair to avoid vibration under driving conditions. The frame supports the electrical circuit housing to prevent vibration caused by running.

8. Analysis of Predicted Performance and Results

Table 2 shows a comparison of predicted parameters and actual experimental results. The majority of predicted parameters are in agreement with the actual experimental results.

Table 2 Comparison of test results and predicted parameters

Performance Measure	Prediction		Results	
	Autonomous	Navigation	Autonomous	Navigation
Maximum speed	3.7 mph (6.0 km/h)		3.6 mph (5.8 km/h)	
Maximum swing speed	137deg/sec		132deg/sec	
Ramp climbing ability	10 degree incline		9.8degree incline	
Reaction times	0.30 seconds	0.20seconds	0.30 to 0.40 seconds	0.20 to 0.26seconds
Battery life	6.0 hours		4.4 hours	
Obstacle detection distance	4.5 meters	10 meters	4.5 meters	10 meters
Waypoint accuracy	—	±0.12 meters	—	±0.14 meters
Remote emergency stop capabili	250 meters[maximum]		100 meters [maximum]	

8.1 Reaction time

Under normal operating conditions, Orange2010's obstacle detection reaction time is 0.3 seconds. At the complex obstacle area in the Autonomous Challenge, the reaction time slowed to 0.3–0.4 seconds by applying the new algorithm. In the Navigation Challenge, by using the two LRFs, the reaction time was 0.20–0.26 seconds. However, since the safety level has been improved by effective innovation, there will be no navigation problems. In the emergency avoidance mode, the reaction time will drop to 0.06 seconds.

8.2 Obstacle detection distance

Two LRFs are used for obstacle detection in both the Autonomous Challenge and Navigation Challenge. Two LRFs make it possible to reconstruct three-dimensional environments by fusing the wheel speed data. Both LRFs can detect not only obstacles at 180° within 10 m but also slopes that may pose a danger to vehicle navigation. The omni-directional camera is used for lane line detection and obstacle detection (4.5 m in front) in the complex obstacle area. Obstacles detected at a distance greater than 3 m are smoothly avoided. If an obstacle is detected within a distance of a meter, the vehicle immediately switches back, corrects the driving direction and finds a safe route.

8.3 Dead ends, traps, and potholes

Dead ends and traps are detected by applying the newly developed environmental recognition algorithm. Once a dead end or trap is detected, the vehicle can drive a safe route. Potholes are detected using the omni-directional images and a suitable, safe route can be determined.

8.4 Accuracy of arrival at navigation waypoints

The positioning accuracy of navigation waypoints was tested and evaluated. The accuracy of Orange2010's arrival at navigation waypoints is limited by the standard deviation of the GPS, which navigates with an error of less than ±0.14 meters.

9. Cost

The costs involved in developing Orange2010 are summarized in Table 3.

Table 3 Estimated development costs for Orange2010

Components	Retail Cost	Team Cost	Description
SUZUKI MC3000P	$4,000	$4,000	Electric wheelchair
SICK LMS200	$8,500	$0	Laser range finder
HOKUYO UTM-30LN	$2,000	$2,000	Laser range finder
Hyperbolic mirror	$4,600	$0	
SONY EVI-370	$360	$0	CCD camera
I-O DATA USB-CAP2	$123	$0	USB video capture cabl
HITACHI HOFG-3	$5,800	$0	Optical fiber gyroscope
Hemisphere A100	$2,414	$2,414	GPS
FUJITSU FMV-BIBLO MG/C77	$1,000	$1,000	Laptop personal computer
SANTECA RS-1500	$160	$0	Automobile wireless engine starter
CONTEC DAI12-4(USB)GY	$600	$0	D/A Converter
BUFFALO WLI3-TX1-AMG54	$104	$104	Wireless ethernet converter
RENESAS SH3 H8	$140	$140	Microcontroller for JAUS Challenge
PRS DE07Ms	$220	$220	SerboMoters for UTM-30LN
IWATSU EC202A050A	$46	$46	Rotary encoders
Mechanical parts	$678	$678	Various Mechanical Components
Electronic parts	$136	$136	Various Electrical Components
Total	$30,881	$10,738	

※reused from Omnix2008

10. Conclusion

This report described the design process, development, and construction of Orange2010. For improved vehicle intelligence, we applied a new environmental recognition algorithm for generating the optimal path for the vehicle. The algorithm consists of three steps: (1) Color segmentation based on PCA; (2) Watershed algorithm; and (3) A* search algorithm that enables robust and stable environmental recognition. We also improved the detection accuracy for obstacles and lane boundaries by employing two LRFs to detect the three-dimensional shape of obstacles and the quadtree-based dynamic thresholding method to achieve robust and stable lane boundary detection. We believe that Orange2010 will perform superbly at IGVC2010.