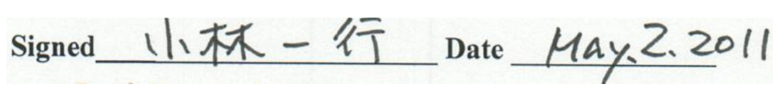
Active2011

Systems and Control Engineering Department
Faculty of Engineering, Hosei University
3-7-2 Kajinocho Koganei, Tokyo 194-8584, Japan
E-mail; ikko@hosei.ac.jp

Faculty Advisor Statement

I hereby certify that the engineering design on Active2011 was done by the current student team and has been significant and equivalent to what might be awarded credit in a senior design course.



Prof. Kazuyuki Kobayashi May 2, 2011

1. Introduction

The Autonomous Robotics Laboratory (ARL) team of Hosei University presents "Active2011" for entry in the 19th IGVC (Intelligent Ground Vehicle Competition). Our previous vehicle, Orange2010, won second place in last year's competition.

Due to a significant change in rules related to moving speed, we decided to design a new robotic vehicle from scratch based on a YAMAHA electric wheelchair. (JW-Active) Our vehicle name was inspired by the name of the original base chassis of this wheelchair. By using the YAMAHA electric wheelchair, we achieved lower weight and higher speed for the new vehicle. As a result, we were able to build a safe, reliable, and robust vehicle that complies with the rules of IGVC 2011. We are confident that Active2011 and ARL will be a serious competitor at this year's competition.

2. Effective innovation

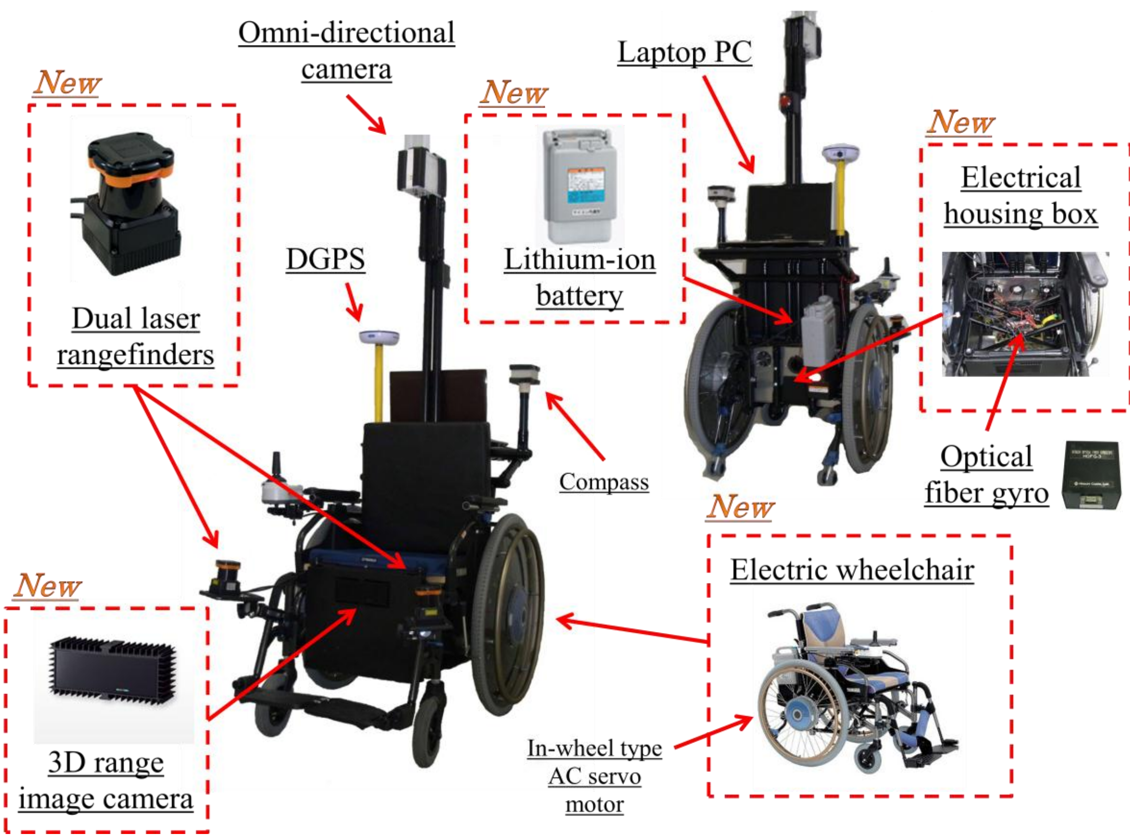
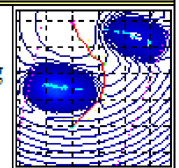
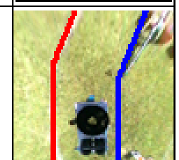


Figure 1 Active2011

In view of the major changes in rules, we held a team discussion about last year's vehicle, and summarized ways to innovatively improve the design.

(1) We evaluated Active2011 to determine if it addressed all the weaknesses of the vehicle that we built last year. The problems to be improved are described in Table 1.

Table 1 Last year's problems and this year's solutions

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 use sensors by applying **potential field method with modified A* search algorithm**	
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 **RANSAC** instead of Hough transform	
Obstacle detection ability Due to the undulating surface of the course and flags, the laser rangefinder frequently detected false obstacles and/or missed obstacles during course nabigation	In order to detect obstacles regardless of undulating surface and flags,we newly employing **3D range image camera**	

(2) In order to comply with the changes in the rules from last year, we attempted to integrate several innovations, as described in Table 2.

Table 2 Innovative solutions to the new rules

Problem	Solution
Allow mapping and course memorization	We introduce **Particle based SLAM algorithm**.
Maximum speed change	Employing new chassis with **in-wheel drive motor** that enables reducing vehicle weight and simple frame configuration. Vehicle weight distribution is rearranged for stabilizing maximum speed running capability.
Safety light requirement	**The ribbon strip type of LEDs** is employed to enhance visibility of light even if sun light situations.
Long distance wireless E-stop	We newly developed **Xbee based wireless controller** which has capability to sending JAUS message.

3. Design process

The design of Active2011 is based on the principle of continuous improvement by making the most of our accumulated IGVC experience. Last year, our Orange2010 vehicle won second place at IGVC 2010.

For this year, however, the moving speed of Orange2010 was too slow. The new IGVC rules include a significant increase in the maximum speed of the vehicle, from 5 mph to 10 mph. In order to adopt this rule at IGVC 2011 as well as improve the design of the vehicle, we introduced the latest design approach: "AAR (After Action Review)" commonly used by the U.S. Army as an adaptive project framework. AAR is a structured review for analyzing what happened, why it happened, and how it can be done better, to be used by the participants and those responsible for the project.

This year, the objective of our team was to build a stable, more reliable, faster vehicle by improving both the hardware and software to achieve a quality level worthy of first prize. Figure 2 summarizes AAR.

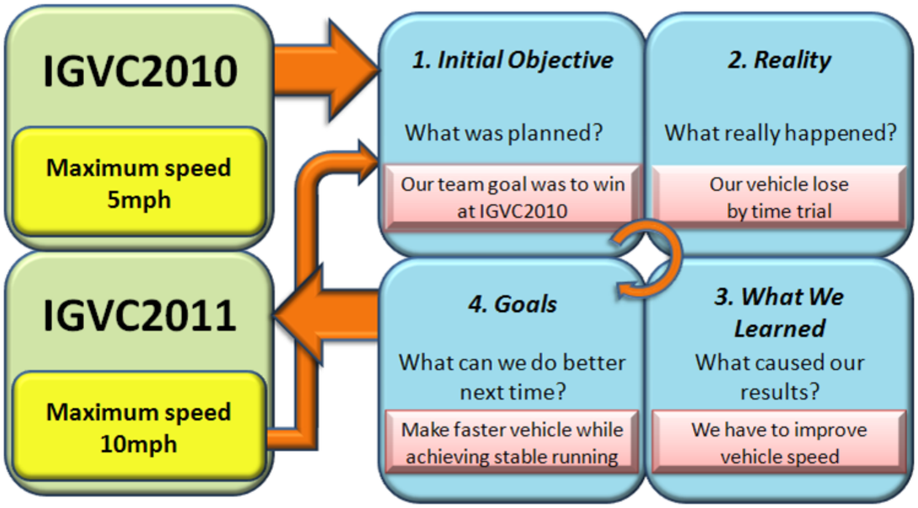


Figure 2 AAR chart

3.1. Team organization

The Active2011 team is composed of ten members: four undergraduate students and six graduate students. After a lengthy discussion among team members, we formed three functional groups focused on efficiently building an innovative vehicle.

As shown in Figure 3, a Mechanical Team, Software Team, and Electrical Team were designated to oversee the functional groups. The Mechanical Team was responsible for all phases of vehicle fabrication and CAD drawings. The Electrical Team handled sensor selection, the power system and the electronics for building the electrical housing box. The Software Team was in charge of designing all the algorithms. To oversee these groups, we designated a student team leader specializing in project management. In total, 3550 hours were spent in the development and testing of the new vehicle.

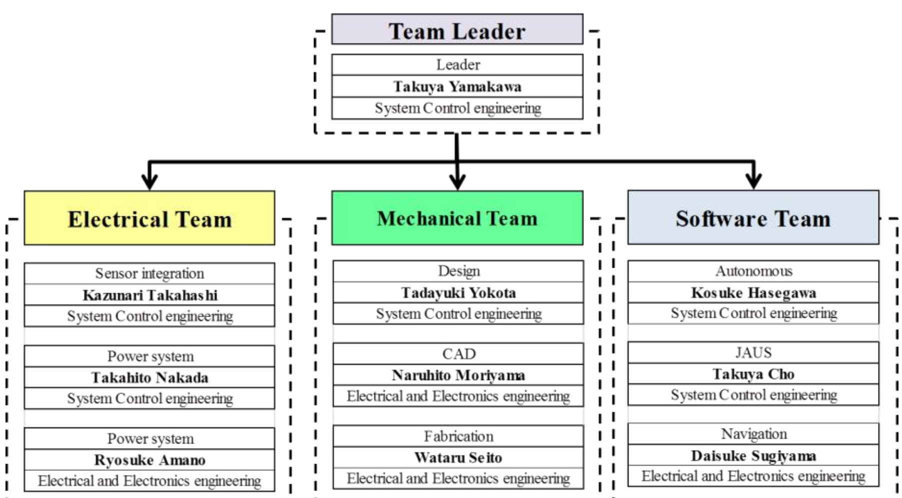


Figure 3 Team organization

4. Hardware

Based on team discussions, it was decided that the required hardware improvement was vehicle speed. In order to achieve this, we applied the following two approaches:

(1) Reduction in vehicle weight from 118 kg to 48 kg.

Table 3 Vehicle weight

	Active2011	Orange2010
Base chasses	28.5 kg (63 pounds)	56.3 kg (124 pounds)
Electrical housing box	4.4 kg (9 pounds)	6.0 kg(13 pounds)
Battery	3.6 kg (8 pounds)	31.0 kg(68 pounds)
Various Sensors	13.5 kg (30 pounds)	25.2 kg(56 pounds)
Total	50.0kg(110pounds)	118.5kg(261 pounds)

In addition to reducing the vehicle weight, we also took into account the weight distribution to improve the vehicle running stability.

(2) Selection of larger-diameter driving wheels to improve running stability

Table 4 Drive wheel size

	Active2011	Orange2010
Front wheels	7 inch	6 inch
Rear wheels	24 inch	16 inch

Employment of 24 inch wheels achieve stable straight running.

4.1. Electrical design

4.1.1. Power system

In order to reduce the weight and dimensions of the battery while retaining long-time operation, we decided that the secondary battery should be a lithium-ion type (25V×11.2Ah) instead of a nickel-hydrogen type (24V×6.7Ah). This battery is connected in series to supply 25 V for controlling the motor.

Table 5 Different of Battery

Battery type	 Lithium-ion type	 Nickel-hydrogen
Mileage per charge	18mile	9mile
weight	3.6kg(7.94pounds)	2.9kg(6.4pounds)
capacity	25V*11.2Ah	24V*6.7Ah

The supplied 25 V from the battery is stepped down to 12 V for the sensors (for the laser rangefinders, DGPS, optical fiber gyro, omni-directional camera and 3D range image camera) and laptop computer. The control signal from the laptop computer is processed by a PSoC microcontroller through an RS232 interface to generate the appropriate voltage signal for controlling the electric wheelchair. The PSoC microcontroller is also used for emergency stop. According to the rules, two different types of emergency stop (E-stop) are implemented. One is a remote-controlled E-stop and the other is a vehicle-mounted E-stop push-button. The signal of the remote-controlled E-stop is transmitted by an XBee transmitter/receiver through the PSoC microcontroller. The maximum open-space communication distance for the XBee transmitter/receiver is about 100 feet.

4.1.2. Sensor

As a result of lengthy team discussions on last year's performance, we concluded that the sensing devices are the key for robust and stable autonomous navigation. The following are major improvements in sensing devices compared to last year.

Table 6 Major improvements in sensing devices

	Active2011	Orange2010
Laser rangefinder	**Dual HOKUYO UTM-30LXs**	SICK LMS200 and HOKUYO UTM-30LX
Camera	**Omni-directional camera and 3D range image camera**	Only omni-directional camarea
Speedometer	**Rotational encoder as a vehicle speed by using PSoC microcontroller.**	Rotational encoder and converted to vehicle speed by an H8 microcontroller

Figure 4 shows how the sensor signal cables and power supply wires are connected and integrated.

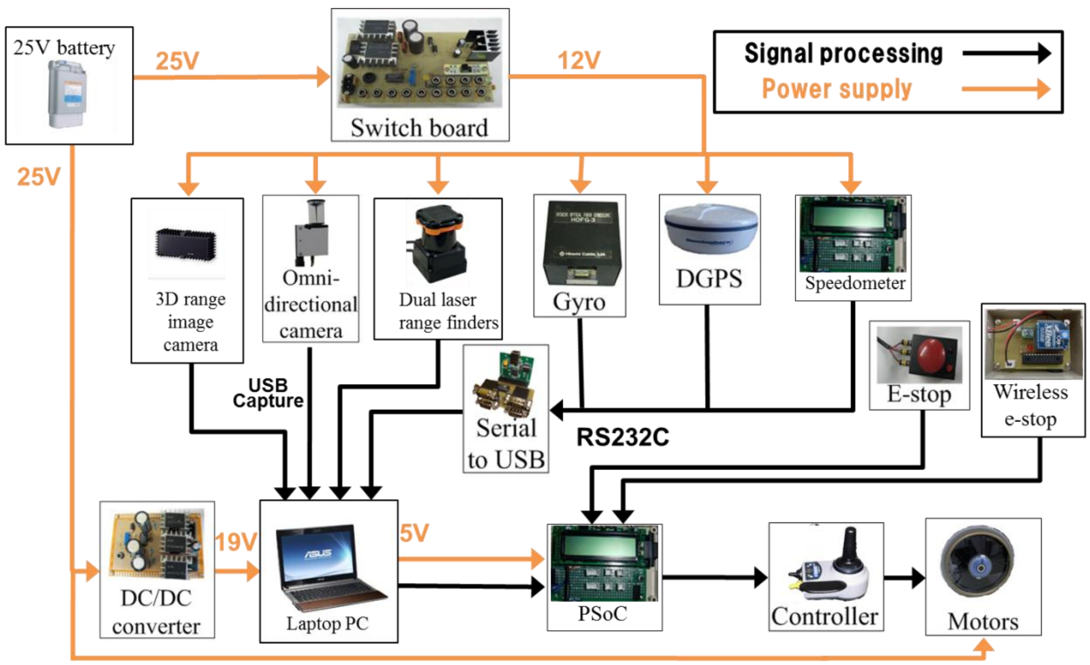


Figure 4 Sensor integration

(1) Laser rangefinders

Last year, we used two different types of laser rangefinders for detecting three-dimensional obstacles. This year, to reduce the weight of Active2011, we used dual HOKUYO UTM-30LX laser rangefinders instead of the combination of a SICK LMS200 and a HOKUYO UTM-30LX. Thanks to the dual HOKUYO UTM-30LX

Figure 5 Laser rangefinder

laser rangefinders, laser rangefinder weight was reduced by 90% and volume by 85%. In addition, due to the different specifications of each laser rangefinder, the angle resolution and scanning ranges have changed. The angle resolution has been improved from 0.5° interval to 0.25° interval, and the scanning range has been enlarged from 180° to 270°. As a result, obstacle detection is significantly improved compared to last year’s vehicle.

(2) Omni-directional camera and 3D range image camera

To enhance the cognitive performance of the vision system, we employed two different types of vision sensors. One is for the omni-directional camera (SONY CCD EVI-370 with hyperbolic mirror) which can acquire a 360° image with no dead angle, and the other is the 3D range image camera (Optex ZC-1070U) which can measure three-dimensional distances even outdoors. The omni-directional camera is used for lane following and simultaneous map building, while the 3D range image camera is used for obstacle detection, complementing the dead angle in the laser rangefinder.

(a) Omni-directional camera

(b) 3D range image camera

Figure 6 Vision sensors

(3) DGPS

A differential global positioning system (Hemisphere A100) provides latitude and longitude information on the vehicle’s position. The receiver is an all-in-one enclosure type with sampling interval of up to 20 Hz. The horizontal accuracy of this GPS is 0.6 m in DGPS mode.

Figure 7 DGPS

(4) Speedometer

Since each of the drive wheels of Active2011 has a rotational encoder, we interpret the signal from the rotational encoder as the vehicle speed by using the PSoC microcontroller.

(5) Gyro

To detect the relative orientation of the vehicle, we used an optical fiber gyro (HITACHI HOFG-3), which can input an angular speed of up to 100° per second.

Figure 8 Optical fiber gyro

4.1.3. Computer

We used a laptop computer (ASUS U33JC) with a 2.53-GHz Intel Core i5 processor with 2 GB of memory and 1G NVIDIA GeForce 310M, running Microsoft Windows XP Professional. All sensor information comes through USB cables.

4.2. Mechanical Design

We developed our vehicle based on the commercially available YAMAHA electric wheelchair (JW-Active) using the same robotic chassis as in Orange2010. The prototype design for Active2011 was developed using Autodesk Inventor 2011 CAD. While retaining the functionality of the original electric wheelchair, we arranged the location of the necessary sensors and electrical housing box through 3D CAD simulation. Figure 9 shows the Active2011 model that we designed by CAD and Photo 1 shows the Active2011 that we actually developed. The dimensions of Active2011 are 650 mm wide by 1100 mm long by 1780 mm tall; it weighs approximately 68 kg (149 lb) excluding payload.

Photo 1 Active2011

Figure 9 CAD render of Active2011

4.2.1. Chassis

A significant change from last year’s vehicle is the base chassis. To achieve a lightweight robotic vehicle, we chose a YAMAHA electric wheelchair (JW-Active). This wheelchair has in-wheel motors, thus eliminating the additional reduction gearbox and resulting in a simple frame and lightweight configuration of the base chassis.

4.2.2. Electrical housing box

In autonomous mode, to prevent tipping accidents due to a sudden change in direction and/or sudden acceleration, we needed to change the weight distribution in the vehicle. To set the center of gravity at the lower part of the vehicle, we rearranged the weight distribution focusing on the electrical housing box to stabilize the vehicle running dynamics.

In the initial design, we had planned to set the electrical housing box under the wheelchair seat to improve the weight distribution. However, due to crossing steel tubes in the base chassis frame design, we could not set the electrical housing box under the seat. To overcome this space problem, we decided not to use a conventional aluminum-based electrical housing box. Instead, we newly designed a protective cover for the electrical devices, using Autodesk Inventor 2011 CAD software.

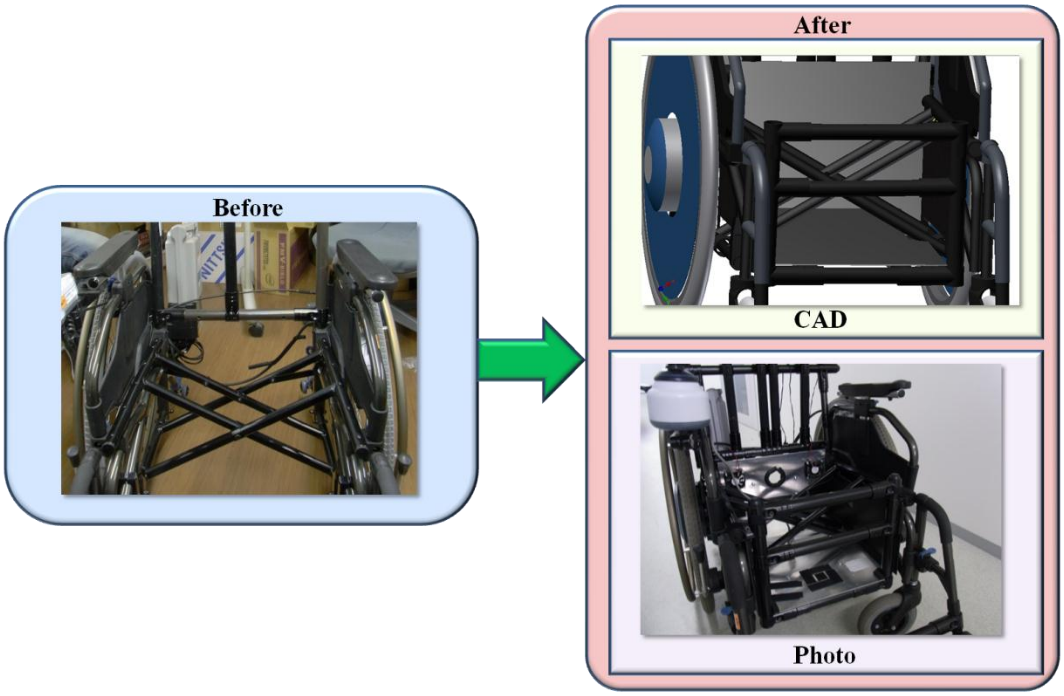


Figure 10 Electrical housing box

4.2.3. Actuator

Both the left and right side of the wheels are controlled by an in-wheel type AC servo motor. These in-wheel motors simplify the vehicle configuration and enhance the freedom of vehicle frame design. Table 7 summarizes the actuators for our vehicle.

Table 7 Overview of actuators

Actuators	
Propulsion	2WD in-wheel direct driven
Wheel size	24inch
Maximum Current	24V 120W × 2

5. Software design

The major changes made to the navigation challenge and autonomous challenge course are as follows:

(1) In the navigation challenge, a starting/goal box is newly introduced.

(2) The autonomous challenge course requires waypoint navigation in a free-space area.

In order to adopt these changes and new rules (mapping and course memorization is allowed), we developed a navigation program and autonomous program from scratch. Figure 11 shows the flowchart of our vehicle control program.

Since mapping and course memorization are now allowed, an SLAM algorithm and potential field based A* search path planning algorithm are implemented for both programs.

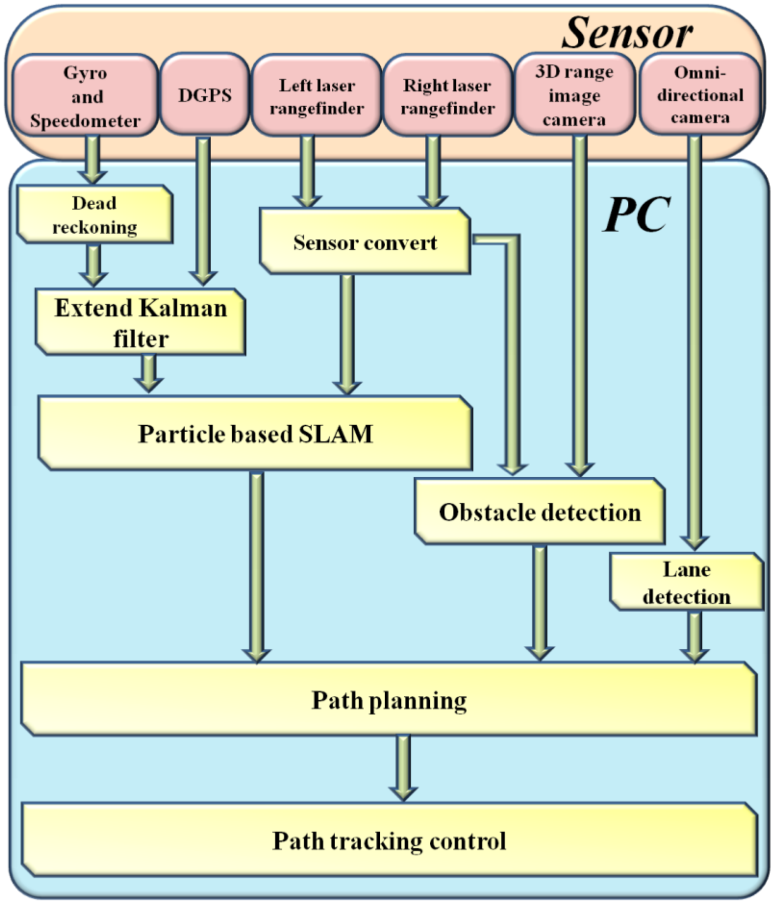


Figure 11 Flowchart of vehicle control program

5.1. Obstacle detection/avoidance

For obstacle detection, we use dual laser rangefinders and one 3D range image camera. The roles of these sensors are explained below.

(1) For SLAM algorithm

To apply the SLAM algorithm, we newly employed two laser rangefinders to detect obstacles around the vehicle. Figure 12 shows the arrangement of the rangefinders.

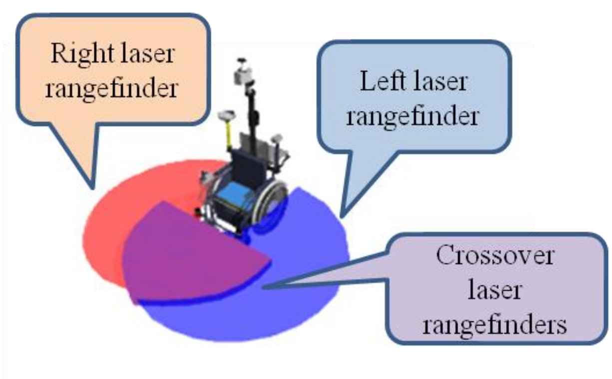


Figure 12 Arrangement of dual laser rangefinders

(2) Obstacle avoidance

The laser rangefinder cannot detect the three-dimensional shape of an obstacle since it captures only a two-dimensional distance profile. To overcome this problem, we introduced a 3D range image camera capable of detecting distant obstacles with three-dimensional shapes. Figure 13 shows a typical image captured by the 3D range image camera. By using both dual laser rangefinder and 3D range image camera, we can ensure robust, safe and stable navigation without collisions against obstacles.

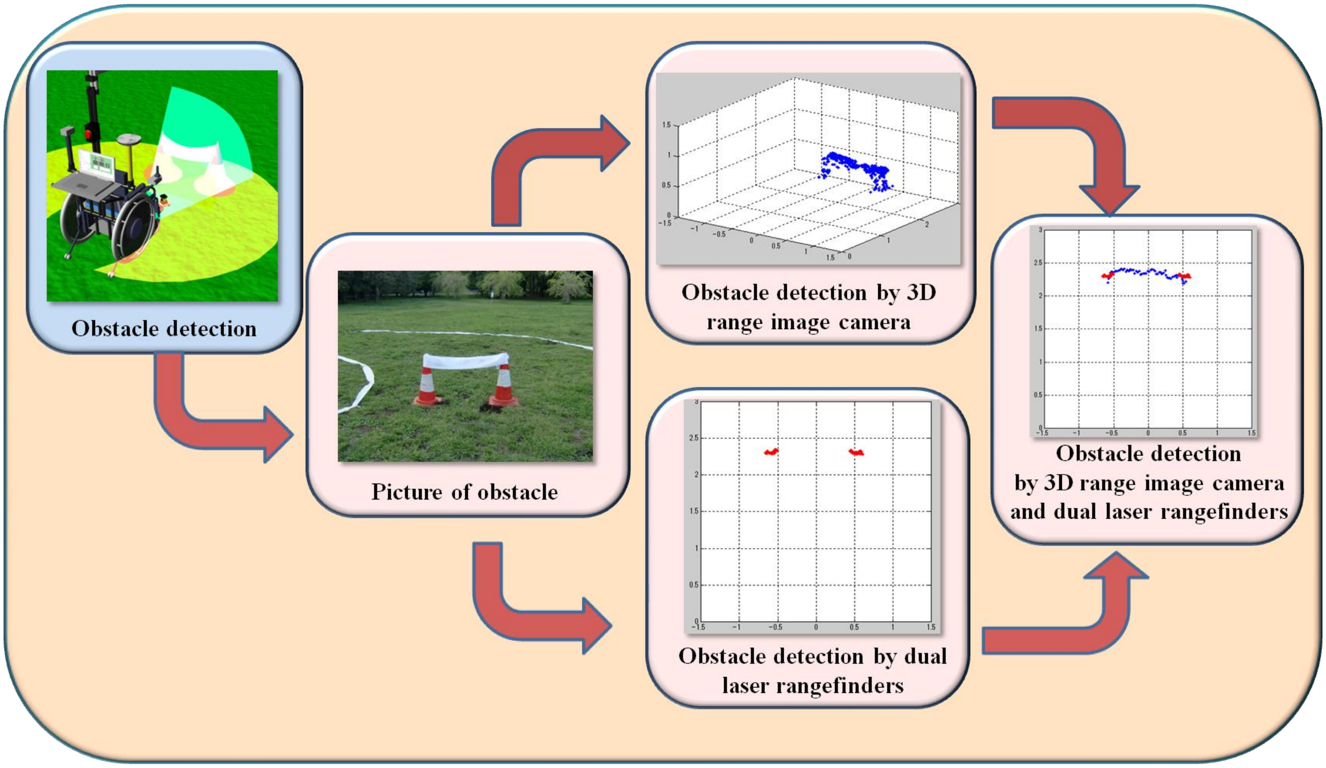


Figure 13 Obstacle detection

5.2. Mapping

Due to the new rule allowing mapping and course memorization, we completely rewrote both the autonomous challenge program and navigation challenge program by applying the SLAM technique. The data from dual laser rangefinders and the speedometer and optical fiber gyro data are fused by applying the EKF technique. The important sensor for the proposed SLAM method is the laser rangefinder. In SLAM, we use the laser rangefinder not only for obstacle detection but also to detect landmarks to generate a waypoint map. In Active2011, to enhance the capability of the SLAM algorithm, we arranged dual laser rangefinders to be able to measure 270° of surrounding obstacles at once. To achieve stable and robust map generation, a particle-based SLAM algorithm was applied.

Figure 14 shows the architectural diagram for the proposed SLAM algorithm. The algorithm was extensively tested in simulations and actual field experiments in Japan. The results of the field experiments showed robust and stable map generation.

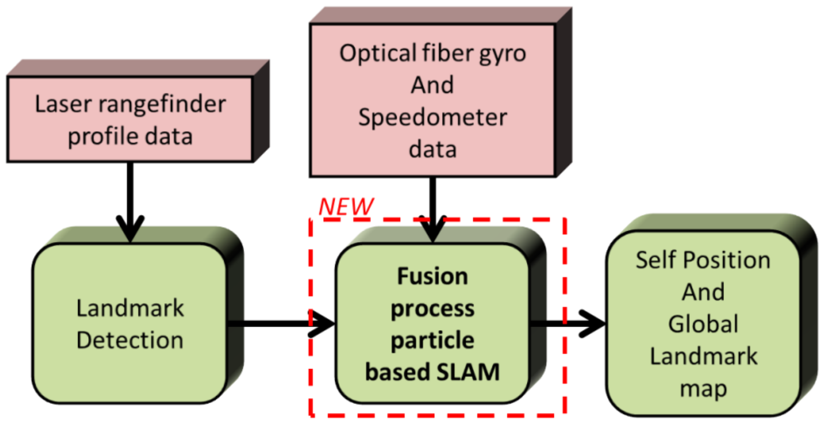


Figure 14 Architectural diagrams for proposed SLAM algorithm

5.3. Lane detection

The omni-directional camera is used for 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 may 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. This year, we implemented a new lane line detection algorithm called RANSAC (RANdom SAmple Consensus) instead of the Hough transform that we used until last year. Compared to the Hough transform, RANSAC is suitable for real-time lane line detection.

Figure 15(a) shows an image captured by the omni-directional camera. Figure 15(b) shows the reconstructed ground image. After reconstruction, the RGB color image is converted to a grayscale image using only the B component. Figure 15(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 the thresholds. Figure 15(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 15(e) shows the logically filtered image. Finally, the RANSAC technique, which extracts straight lines in images, is applied to detect lane lines. The detailed steps of this RANSAC procedure are as follows:

Step1: Randomly select two points in the image.

Step2: Estimate the parameters (slope and intercept).

Step3: Determine how many data items fit the model using a parameter vector within a user given tolerance; call this *K*.

Step4: If *K* is big enough, accept the fit and exit with success.

Step5: Repeat Steps 1–4 many times.

Implementing such sophisticated lane-detection algorithms, Active2011 proved to be reliable at detecting lanes even in cases where they were hidden by obstacles or drawn only by dashed lines. Figure 15(f) shows a typical example of the region-segmented results. The quadtree decomposition method is used to distinguish both lane areas and other areas. Figure 15(g) shows the lane enhancement results. Lane enhancement is achieved based on the labeling results for removing small isolated areas. Figure 15(h) shows the plots in the RANSAC and the detected lane. The detected lane lines can be stored as sets of starting points and endpoints and line-crossing points.

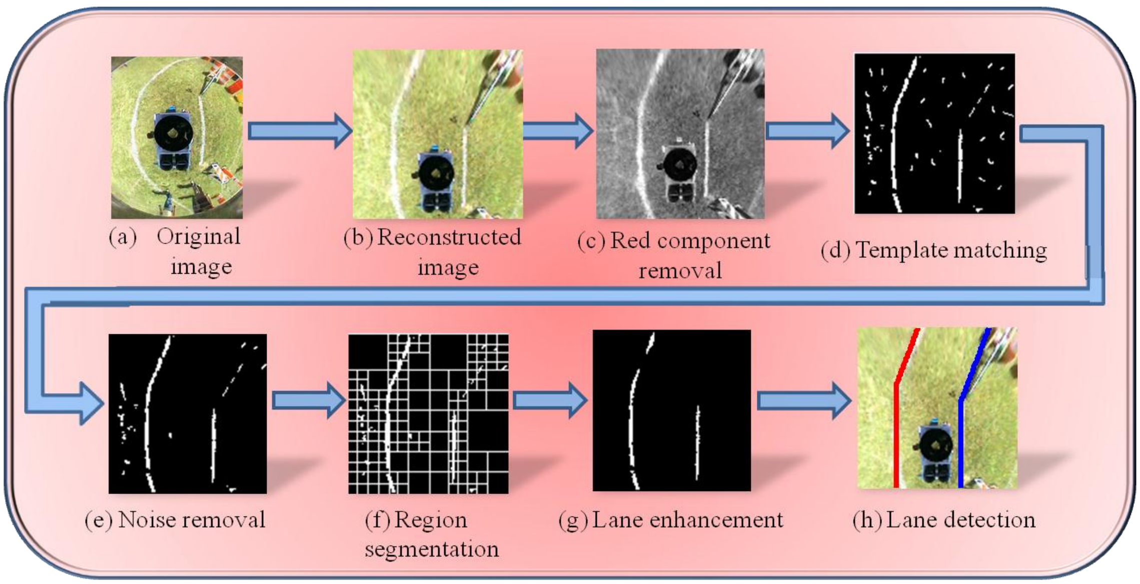
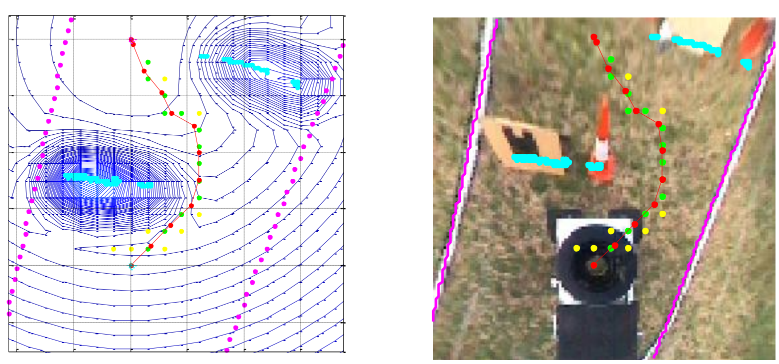


Figure 15 Lane detection

5.4. Path planning

In order to generate a safe and smooth path to the target destination, the potential field method with modified A* search algorithm is employed.

The proposed method creates an artificial potential field such as mountains and valleys using dual laser rangefinders profile and vision sensor.



(a) Potential field (b) Generated path planning

Figure 16 Actual experiment of the proposed method

Figure 16 shows the actual experiment of the proposed method. The circles indicate the obtained path nodes, and the continuous line indicates the generated path planning. The proposed modified A* search algorithm significantly reduces the search paths that may not be related to the optimal path. The combination of potential field method with modified A* search algorithm contributes to faster path generation regardless of the complexity of the obstacle course. As shown in Figure 16, the path generated by applying our new modified A* search algorithm successfully reached the target destination.

5.5. JAUS

We successfully accomplished 60 points, which satisfied all requirements for the JAUS Challenge 2010 except for the time trial. This year, we improved the vehicle speed and JAUS software to accomplish the task for the JAUS Challenge 2011. In our JAUS control system, the message commands from the COP (Common Operating Picture) via an RF data link are received by laptop computer. 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. Received data is interpreted by using the Python-based program stored in the shared memory. The MATLAB program is mainly used for vehicle control and to check the current status through the shared memory when necessary to achieve stable asynchronous communication.

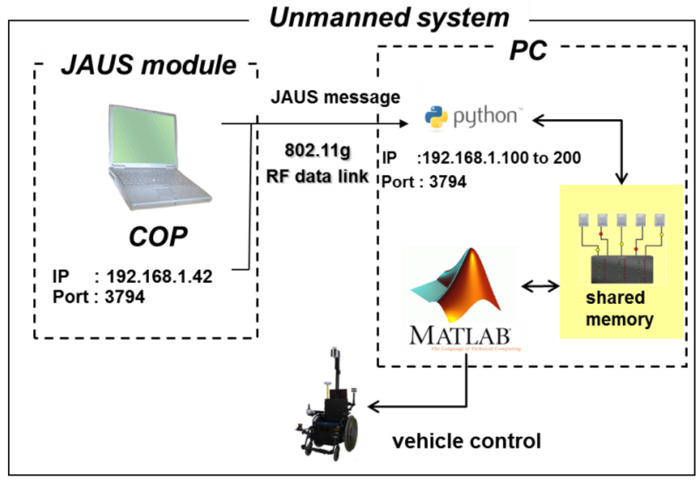


Figure 17 JAUS control systems

6. Performance

Table 8 shows vehicle performance comparison between Active2011 (predictive) and Orenge2010 (actual).

Table 8 Vehicle performance

	Active2011(predictive)	Orange2010(actual)
Vehicle weight	48 kg (105 lb)	118 kg (260 lb)
Maximum speed	4.1 mph (6.5 km/h)	3.6 mph (5.8 km/h)
Ramp climbing ability	10° incline	9.8° incline
Reaction time	0.15 to 0.25 seconds	0.30 to 0.40 seconds
Battery life	6 hours	4.4 hours
Obstacle detection distance	10 meters	10 meters
Lane detection distance	4.5 meters	4.5 meters
Waypoint accuracy	±0.14 meters	±0.14 meters

The overall performance of Active2011 is substantially enhanced compared to last year's Orange2010. The vehicle battery has been changed from a lead storage battery to a lithium-ion battery, which saves on weight while retaining the 1.6-hour operation time. The in-wheel motors have also simplified the chassis frame and reduced the vehicle weight.

The positioning accuracy of navigation waypoints was tested and evaluated. The accuracy of Active2011's arrival at navigation waypoints is limited only by the standard deviation of the DGPS, which navigates with error of less than ±0.14 meters.

7. Safety, Reliability, Durability

7.1. Safety

According to the new rules (wireless E-stop distance of 100 feet, addition of safety light) in IGVC 2011, we developed a wireless emergency stop and LED light for autonomous mode identification. Due to the distance of the wireless emergency stop, we also developed an XBee module-based controller.

In order to enhance the visibility of the LED light, we placed an LED ribbon strip around the vehicle, as shown in Figure 18. This ribbon strip enables full color light emission controlled by the PSoC microcontroller. In autonomous mode, the solid indicator light turns on whenever the vehicle power is turned on. The light from the LED ribbon strip changes from solid to flashing when the vehicle is in autonomous mode; as soon as the vehicle comes out of autonomous mode, the light becomes solid again.

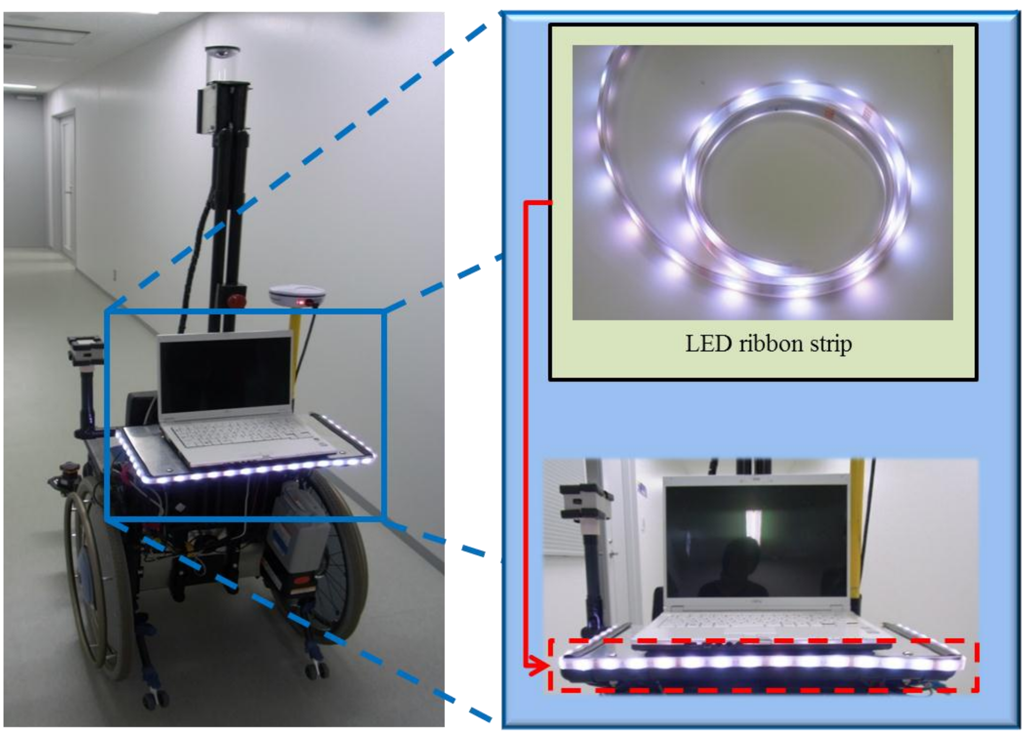


Figure 18 Safety light

7.2. Reliability

The reliability of Active2011 has been improved by totally redesigning the electrical circuit housing and using a chassis. In the electrical design, the power supply jack has been designed to prevent connection to wrong voltages due to human error.

7.2. Safety and Durability

The improved weight distribution has also enhanced the safety and durability of Active2011. The lower position of the electrical housing box lowers the center of gravity and thus increases the moving stability.

8. Cost

The costs involved in developing Active2011 are summarized in Table 7.

Table 9 Estimated development costs for Active2011

components	Retail Cost	Team Cost	Description
YAMAHA JW-Active	$5,600	$5,600	Electric wheelchair
OPTEX ZC-1070U	$6,500	$6,500	3D range image camera
HOKUYO UTM-30LX ×2	$8,000	$4,000	Laser rangefinder
SONY EVI-370	$360	$0	CCD camera
Hyperbolic mirror	$4,600	$0	
I-O DATA USB-CAP2	$123	$0	USB video capture cable
HITACHI HOFG-3	$5,800	$0	Optical fiber gyroscope
Hemisphere A100	$2,414	$0	DGPS
ASUS U33JC	$1,100	$1,100	Laptop personal computer
Mechanical parts	$536	$536	Various mechanical components
Electronic parts	$158	$158	Various electrical components
Total	$35,191	$17,894	

※reused from Orange2010

9. Conclusion

This report described the design process, development, and construction of Active2011. In the design process, we introduced a new approach called AAR. Through analysis using AAR, the vehicle weight was significantly reduced. Innovative features include the in-wheel type motor with new chassis, 3D range image camera, dual laser rangefinder, and particle-based SLAM algorithm. These features will help establish new standards in the field of next-generation intelligent robotic vehicles. We believe that Active2011 will be a major contender at IGVC 2011.