Amigo2009

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Faculty Advisor Statement

I hereby certify that the engineering design on Omnix2006 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 ～小林 一行～ Date May/18/2009

Prof. Kazuyuki Kobayashi   May 18, 2009

1. Introduction

The Autonomous Robotics Lab (ARL) team of Hosei University is proud to present Amigo2009, an innovative vehicle designed for entry into the 2009 Intelligent Ground Vehicle Competition (IGVC). We believe that the Amigo2009 will continue to build upon Hosei University's successful performance in the IGVC.
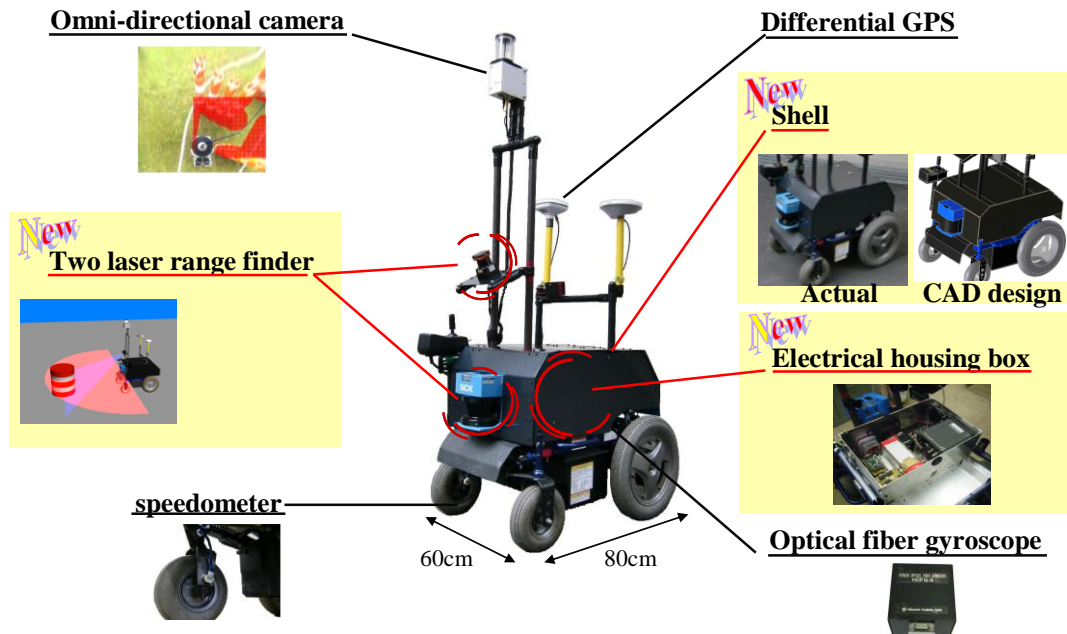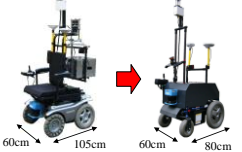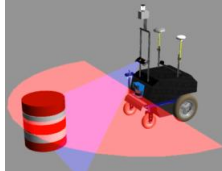

Fig. 1 Amigo2009

2. Effective innovation

Through team discussion, we evaluated the Omnix2008 to determine its weak points. Table 1 shows three aspects of the vehicle required improvement.

Table 1 Aspects of the vehicle required improvement

Problem	Solution
Vehicle size A smaller sized vehicle may have an advantage in passing through the complex obstacle area.	In order to pass through the complex obstacle area, we change based chassis from Omnix to Amigo.
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.
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 Change-based chassis

In order to pass through the complex obstacle area in the Autonomous Challenge, we decided to change to a smaller platform from the Omnix-based chassis to the Amigo-based chassis. The Amigo platform was originally developed by the ARL team and used at IGVC from 2000 to 2005. The features of the Amigo platform include light weight and

60cm   105cm   60cm   80cm

Fig. 2 Change-based chassis

power-assisted steering. The vehicle's overall length is reduced by approximately 25% compared to the Omnix2008. In order to change the platform from Omnix to Amigo, we completely redesigned the electric circuits as well as other sensing device arrangements. The development process is described in Section 4, "Mechanical design."
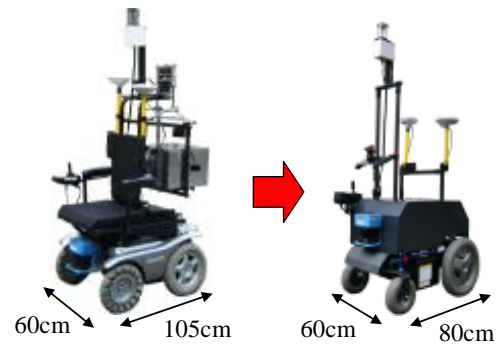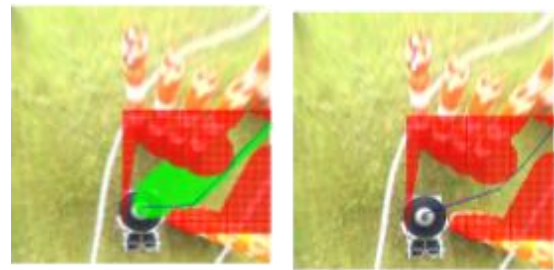
2.2 New algorithm for passing through obstacle area

We introduced a new environment detection and path search method for a path planning algorithm that uses omni-directional images by applying Heuristic search method. The system employs an omni-directional camera and laser range finder to detect the environment, based on which an appropriate path is

(a) A*search   (b) Proposed method

Fig. 3 New pass planning algorithm

generated by applying the proposed heuristic search algorithm. Our approach consists of three main steps. In the first step, the Hough transform and color segmentation technique is used to detect the obstacle course. Hough transform is applied to detect curved lane edges. When the lanes are hidden by obstacles, we apply color segmentation based on PCA (principal component analysis) to detect the lane course. In the second step, a watershed algorithm is used to find the appropriate path to the target destination. In the third step, we apply a newly modified A* search algorithm that processes in real time to find a sub-optimal path to the target destination. The effectiveness of the proposed algorithm has been simulated and tested by applying actual sensor data. The detailed algorithm is described in Section 6, "Autonomous Challenge Competition."

2.3 Obstacle detection using two LRFs

In order to detect obstacles regardless of undulating surface, we newly employed two LRFs that can detect the three-dimensional shape of obstacles. One LRF is set up horizontally at a low position, and the other one is set up slightly tilted at a high position. The horizontal LRF detects obstacle in

the horizontal direction. The slightly tilted LRF takes the difference in the time-series data and detects obstacle in three dimensions. Regardless of the undulating ground surface, the vehicle can detect the three-dimensional shape of obstacles by fusing these two sets of LRF data. A detailed description is presented in Section 7, "Navigation Challenge Competition".
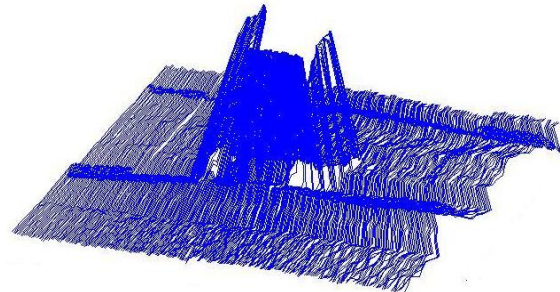

Fig.4　　Obstacle detection by 2 LRFs

Fig. 5 3-D environment structure

3. Design process

3.1 Team organization

The ARL2009 team now has a total of 11 members including 9 new members. Since the majority of members are new, we reconsidered the team organization. The new ARL2009 team was split into three sub-teams to focus on specific areas of the design. Deadlines and roles were appropriately allocated to each member according to their respective design abilities. The team organizational chart, including Mechanical, Electrical, and Software sub-teams, is shown in Fig. 6.
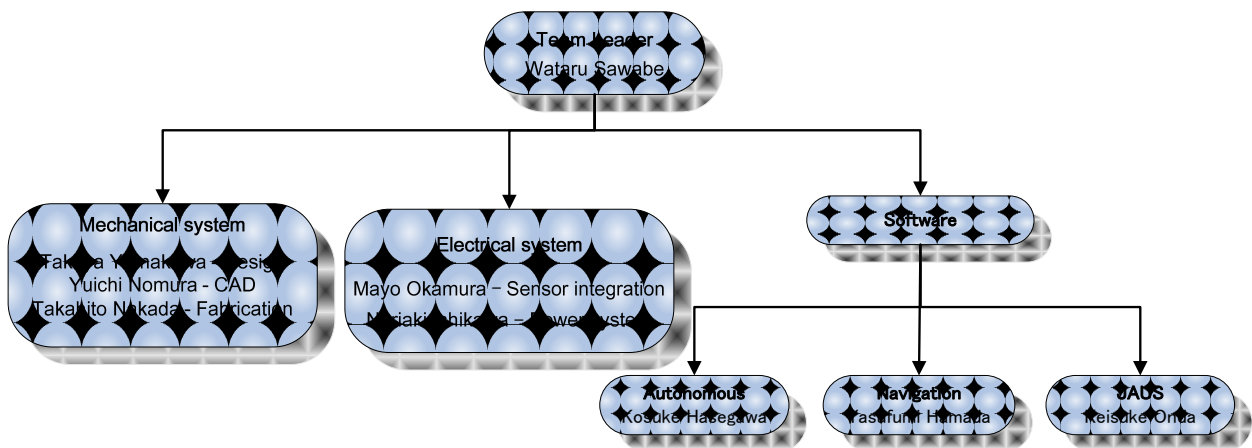

Fig. 6 Team Organization

3.2 Design process

With so many new members this year, we had to ensure effective communication. Therefore, for the overall design process, we decided to employ the Rational Unified Process (RUP) based on Unified Modeling Language (UML) that we had previously used in the design process. UML is an optimal

notation system for ensuring effective communication among team members. Additionally, because the mechanical design process is costly and time-consuming, we employed the waterfall method for this process instead of applying the RUP method. The waterfall model provides a specific cost and time for the entire project. Figure 7 shows our RUP for the modified IGVC project. The RUP was based on three groups: Mechanical System, Electrical System, and Software. Each of these design processes consisted of one or more iterations. Each iteration includes requirements for data gathering, analysis, design, implementation, testing, evaluation, deployment, and a final product, which grow incrementally from iteration to iteration. To ensure appropriate iteration of the design process, team members from other design groups confirm whether or not the developed system satisfies the requirements.
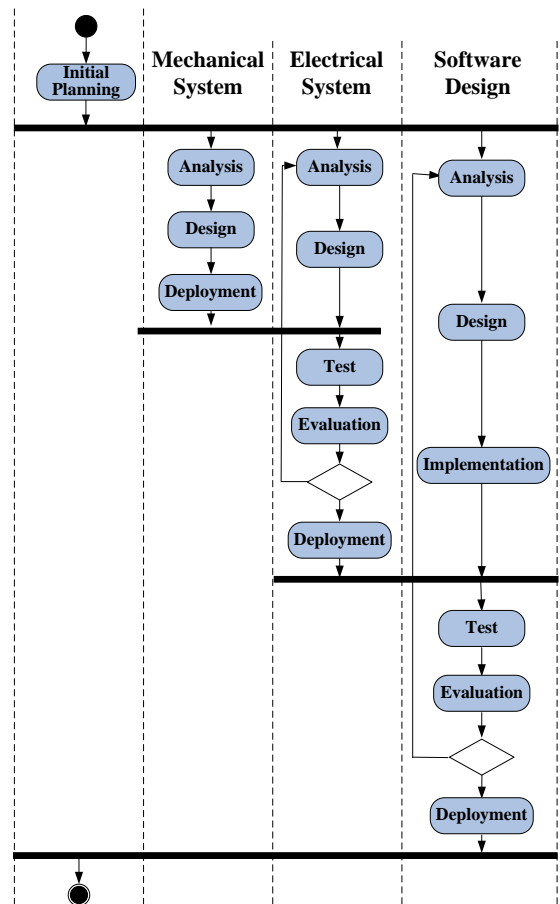

Fig. 7 Design process

4. Mechanical design

In order to drive a narrow path in the obstacle course area, the body size of the Amigo2009 was designed as compactly as possible while retaining the minimum required size for carrying the payload and necessary sensors and computer, since the IGVC course has become more complex every year. We also designed the arrangement of sensors and computer taking into account the Amigo2009's center-of-gravity position for enhanced maneuverability as well as stability.

4.1 Chassis

To ensure the 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 employed is an electrically powered four-wheel wheelchair, the MC16P produced by Suzuki. The maximum limited speed of the wheelchair is 6.0 km/hr (3.76 miles/hr). We tuned the controller so that the maximum speed is 7.7 km/hr (4.8 miles/hr).

Fig. 8 MC16P (SUZUKI)

4.2 Actuators

Three actuators are used for controlling and driving the Amigo2009. 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 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 190 W for 30 minutes. The power for the motors is supplied by two 35Ah 12-V batteries.
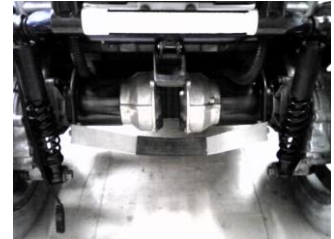

Fig. 9 Actuator

4.3 Shell

The shell is designed to be weatherproof and dustproof. The material of the shell is 5-mm-thick plastic sheet used as reinforcement to support the payload. Part of the shell is hinged to allow for easy access to the computer. The shell panels are black, to reduce the glare on the omni-directional camera.

Fig. 10 Shell

4.4 Electrical housing box

Figure 11 shows the newly developed junction box. The electrical housing box was designed to be as compact as possible while retaining the minimum required size as well as weight balance to the lower part that houses the necessary sensors and cables.

Fig. 11 Electrical housing box

5. Electrical design

5.1 System integration

The sensors and the laptop PC require a power supply. They gather information on the course environment, analyze the collected data and determine the vehicle's path. Figure 12 shows how the sensor signal cables and power supply wires are connected and integrated. The image signals from the omni-directional camera are transmitted to the PC via a USB image frame-grabber. The LRF (SICK) signal is transmitted to the PC via a high-speed 500-kbps serial RS-422 cable to a USB converter. The DGPS signal is transmitted to the PC via a serial RS-232C cable to a USB converter; the optical fiber gyroscope is also connected to the PC via a serial RS-232C cable to a USB converter while the LRFs (HOKUYO) are connected to the PC via USB.

Fig. 12 Sensor integration

5.2 Computer

Software installed in the laptop computer determines the navigation route off-line and generates on-line control signals from data obtained by the above-mentioned six sensors. The laptop computer has a 1.8-GHz Intel Core2 Duo processor with 2 GB of memory, running Microsoft Windows XP Professional.

5.3 LRF

The Amigo2009's source of obstacle detection is a SICK LMS200 LRF and a HOKUYO UTM-30LX LRF. The SICK LMS200 settings used for Amigo2009 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-30LN 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.

Fig. 13 Laser range finder

5.4 Camera

We used an omni-directional camera (SONY CCD EVI-370 with hyperbolic mirror) that captures 360° images. The video images are captured using a video capture USB (I-O DATA USB-CAP2), converted into digital format using VCAPG2, and sent to the software programmed by MATLAB for image recognition.

Fig. 14 Omni-directional camera

5.5 DGPS

A differential global positioning system (TRIMBLE BD950) provides latitude and longitude information on the vehicle's position. The DGPS is based on the dual-frequency GPS.

Fig. 15 D-GPS

5.6 Speedometer

The speedometer estimates the wheel velocity of the vehicle, using rotary encoders. The velocity of the vehicle is measured by the rotary encoders and converted to vehicle speed by an H8 microcontroller.

Fig. 16 Speedometer

5.7 Gyro

To detect the relative orientation of the vehicle, we used an optical fiber gyro (HITACHI HOFG-3). The device is capable of inputting angular speed of up to 100° per second.

Fig. 17 Optical fiber gyro

6. Autonomous challenge competition

To successfully pass through the complex obstacle area, we introduced a new path planning algorithm that applies Hough transform and color segmentation based on PCA. Figure 18 shows the procedure for the proposed path planning method. The target destination is generated by applying a watershed algorithm. Based on the detected target destination, a sub-optimal path is generated in real time.
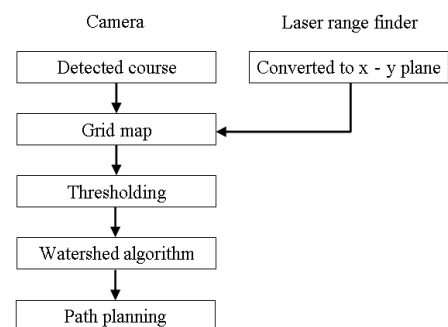

Fig. 18 Procedure of proposed path plan method

6.1 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. The reconstruction of images grabbed by the omni-directional camera to ground images enhances the lanes so that their determination is not influenced by the shadows in the original image. Figure 19 shows the images grabbed by the omni-directional camera. Figure 19 (b) shows the reconstructed ground image. After the reconstruction, an 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 that correspond 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 piece-wise linear segments. Implementing such sophisticated lane-detection algorithms, Amigo2009 proved reliable at detecting lanes even in cases where the lanes were hidden by obstacles or drawn only by dashed lines. Figures 19 (f) and (g) show the plots in the Hough domain and the detected lane, respectively. The lane lines detected can be stored as sets of starting points and end points and line-crossing points.
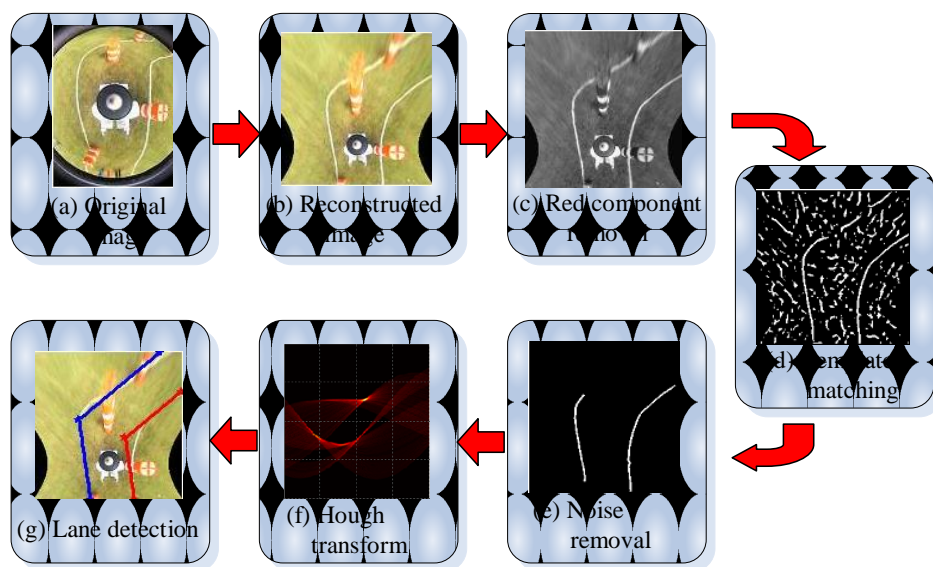

Fig. 19 Lane detection

6.2 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 on correlated colors in the grassy ground area that indicate the lane course instead of detecting the lane edge. 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 is for extracting RGB values of ground color from the vehicle rear part of the image.

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

Step 3 is for removing the isolated noise in the binary image using morphological thinning processes, 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.

Fig. 20 Course detection based on watershed algorithm
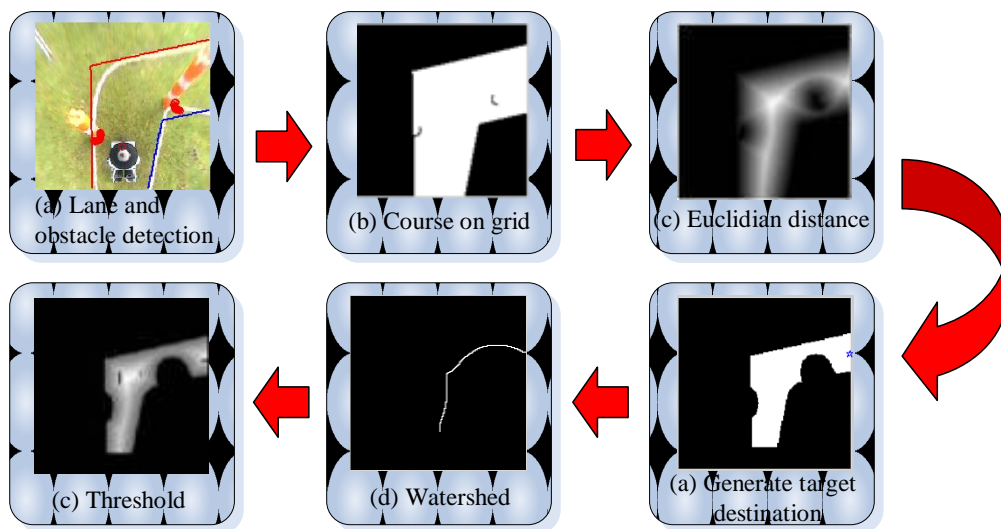
6.3 Path planning

6.3.1 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 of the image. 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 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 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 allocated on the watershed farthest from the vehicle.
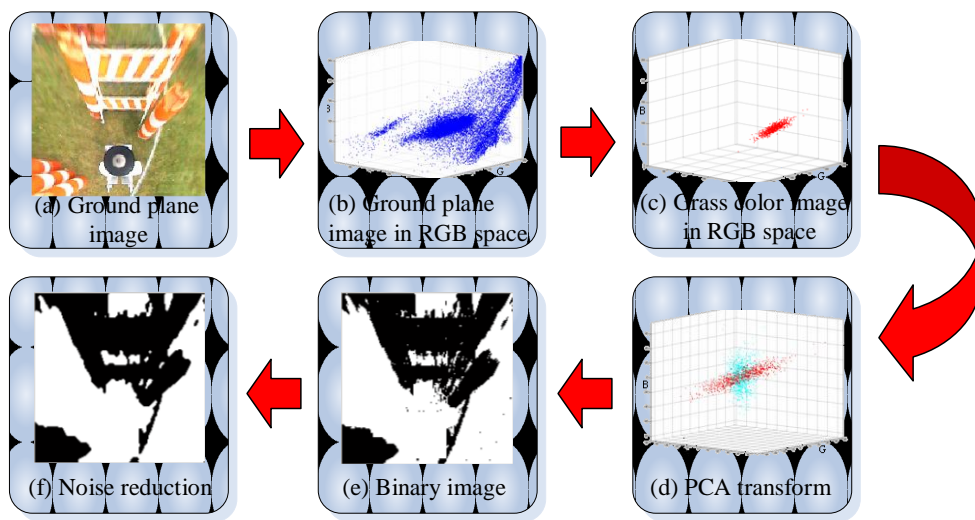

(a) Ground plane image	(b) Ground plane image in RGB space	(c) Grass color image in RGB space
(f) Noise reduction	(e) Binary image	(d) PCA transform

Fig. 21 Course detection based on watershed algorithm

6.3.2 A* search algorithm

We applied a newly modified A* search algorithm that is able to process in real time, 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 up to node n and   is the estimated cost of the shortest route from node n until reaching the goal. In order to reduce the
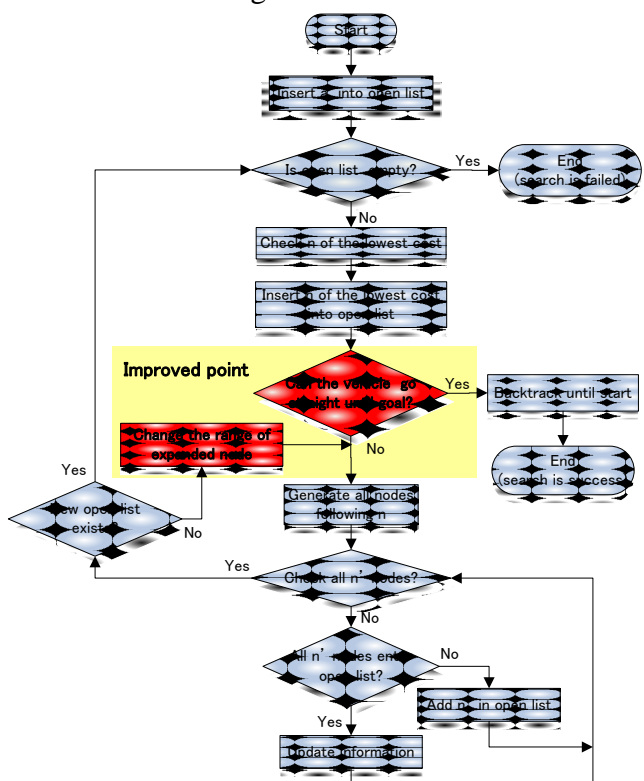

Fig. 22 A* search algorithm

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 vehicle can go 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 to be 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

Fig. 23 Simplified path

the obtained path nodes. The sky-blue line shows the simplified path up to a node that can pass straight through.
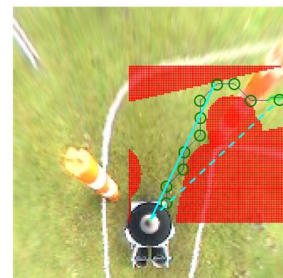
7. Navigation challenge competition

To improve the obstacle detection ability, we newly employed two LRFs. The primary range finder uses obstacle detection. The secondary range finder is angled down towards the ground at approximately 30° to intersect the ground 10 m ahead of the vehicle. When the vehicle is driving a course, the combination of two LRFs enables detection of the three-dimensional shape of obstacles. Figure 24 shows an activity diagram of the navigation system for the Navigation Challenge. Data on the primary LRF, which is arranged horizontally, is transformed from polar coordinates into x-y coordinates, and the clustering method is
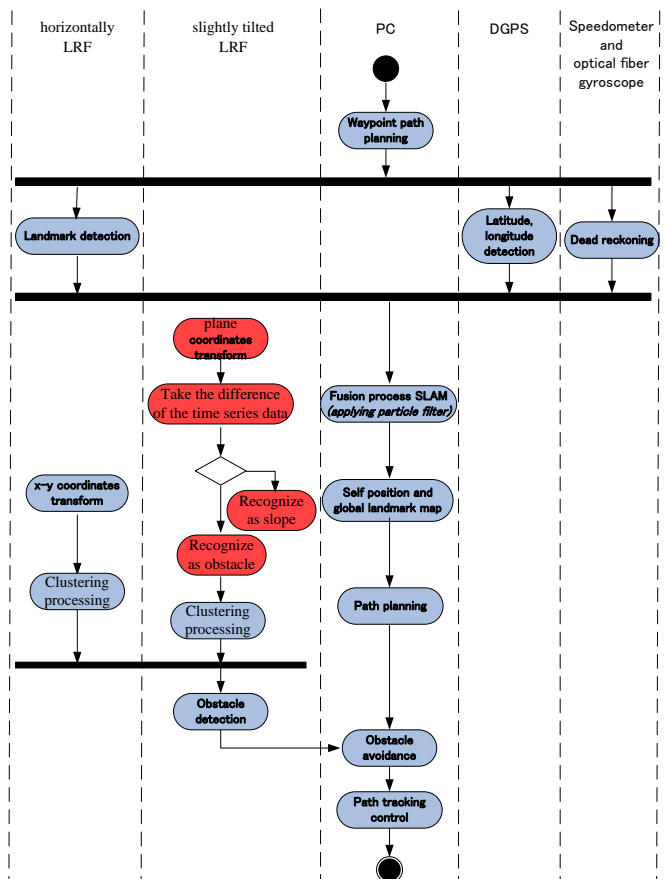

Fig. 24 Activity diagram of navigation system
for Navigation Challenge Competition

applied to the data. Data on the secondary LRF is transformed into plane coordinates for acquiring the difference in time-series data compared to the primary LRF. Depending on the difference in time-series data, it is possible to detect not only the three-dimensional shape of obstacles but also the angle of the slope in front of the vehicle.

8. JAUS Challenge

Last year, we succeeded in implementing JAUS Level III and satisfying 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 operator control unit (OCU) via an RF data link are received by a wireless Ethernet
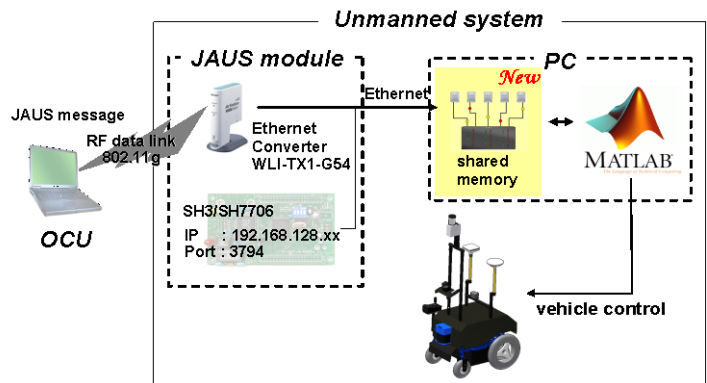

Fig. 25 JAUS control system

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. The shared memory approach can achieve stable and robust asynchronous communication between the microcontroller board and PC.

9. Safety, durability, reliability

9.1 Safety and durability

For safety and durability, we designed Amigo2009 from different perspectives of mechanical and electrical design. In the mechanical design, to prevent exposure of the wiring harness, the body shell is newly designed and developed for the Amigo2009. To enhance stability and durability, we designed and arranged the electric circuit housing at the center of the electric wheelchair to avoid vibration under driving conditions. 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 on the rear of the vehicle so that it can be easily found and accessed.

9.2 Reliability

The reliability of the Amigo2009 has been improved by completely redesigning the electrical circuit housing. The center of gravity is low and laterally symmetric, contributing to vehicle stability. To reduce the risk of a thermal heat problem inside the shell in the Amigo2009, we installed an electric fan to bring air into the airflow path in the shell.

10. Analysis of predicted performance and results

Table 1 shows the 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	5.0 mph (8.0 km/h)		4.8 mph (7.7 km/h)	
Maximum swing speed	137 deg/sec		132 deg/sec	
Ramp climbing ability	9.0 degree incline		8.8 degree incline	
Reaction times	0.15 seconds	0.20 seconds	0.15 to 0.26 seconds	0.20 to 0.26 seconds
Battery life	5.0 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 capability	250 meters [maximum]		100 meters [maximum]	

10.1 Reaction time

Under normal operating conditions, the Amigo2009's obstacle detection reaction time is 0.15 seconds. At the complex obstacle area in the Autonomous Challenge, the reaction time slowed to 0.21–0.26 seconds by applying the new algorithm. In the Navigation Challenge, by using the two LRFs, the reaction time slowed to 0.20–0.26 seconds. However, since the safety level has been improved by the effective innovation, there will be no problems with navigation. In the emergency avoidance mode, the reaction time will drop to 0.06 seconds.

10.2 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

Fig.26   Performance analysis

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.

10.3 Dead ends, traps, and potholes

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

10.4 Accuracy of arrival at navigation waypoints

The positioning accuracy of navigation waypoints was tested and evaluated as shown in Photo 3. The accuracy of Amigo2009'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.

11. Cost

The costs involved in developing the Amigo2009 are summarized in Table 2.

Table 3   Estimated development costs for the Amigo2009

Components	Remarks	Retail Cost	Team Cost
GPS receiver *	TRIMBLE (BD950)	$10,000	$0
Laser range finder *	SICK (LMS-200)	$8,500	$0
	HOKUYO (UTM-30LN)	$2,000	$2,000
Optical fiber gyroscope *	HITACHI (HOFG-3)	$5,800	$0
Electric powered wheelchair *	SUZUKI (MC16P)	$5,000	$0
Battery	ADVANCE (SEV35-12V)	$410	$410
Hyperbolic mirror *		$4,600	$0
Laptop personal computer	FUJITSU (Intel Core2duo 1.8GHz)	$2,000	$2,000
Isolated analog output module for USB	CONTEC (DAI12-4(USB)GY)	$600	$0
CCD camera *	SONY (EVI-370)	$360	$0
Automobile wireless engine starter *	SANTECA (RS-1500)	$160	$0
USB video capture cable *	I-O DATA (USB-CAP2)	$123	$0
Wireless ethernet converter	BUFFALO (WLI3-TX1-AMG54)	$104	$104
Microcontroller	RENESAS (SH3 H8)	$140	$140
Rotary encoders *	IWATSU	$34	$0
Mechanical parts		$364	$364
Electronic parts		$327	$327
Total		$40,522	$5,345

* reused from Amigo2005 and Omnix2008

12. Conclusions

This report has described the design process, development, and construction of the Amigo2009. For improved vehicle performance, we decided to change from the Omnix-based chassis to the Amigo-based chassis with a newly developed electric housing box that was designed based on our experience with the Omnix2008. As a result, vehicle driving mobility and stability have been enhanced and improved. 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 accuracy of obstacle detection by employing two LRFs to detect the three-dimensional shape of obstacles. Despite the limited period for development, the IRUP approach facilitated effective communication between team members. We believe that the Amigo2009 will perform brilliantly at IGVC2009.