13th Intelligent Ground Vehicle Competition

Design Report

Amigo2005

HOSEI UNIVERSITY

Autonomous Robotics Laboratory

Faculty Advisor Statement

I hereby certify that the engineering design on Amigo2005 was done by the current student team and has been significant and equivalent to what might be awarded credit in a senior design course.

Date Signed

2005. May.24, Assoc. Prof. Kazuyuki Kobayashi

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1. Introduction

The Hosei University Autonomous Robotics Lab team (ARL) has developed the newest version of its Amigo vehicle for the 2005 Intelligent Ground Vehicle Competition (IGVC). The vehicles of Amigo series 2000, 2001, 2002, and 2004 achieved successful results in past IGVCs. The key concept of the Amigo series, common to all the models, is “Safe and intelligent”. The chassis of the Amigo is based on a commercially available electric wheelchair, and our goal is to develop an intelligent and safe electric wheelchair. To achieve our goal, we employed a novel omni-directional camera in our earlier models exhibited in past IGVCs. Figure 1 shows how the Amigo has developed.

Figure 1: Evolution of the Amigo

This year, in designing the Amigo, we have put most of our effort into improving the software as well as the optical filtering. Figure 2 shows the innovations introduced to the Amigo2005.

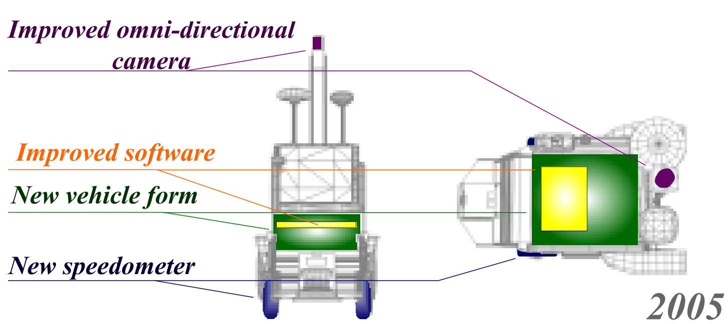

Figure 2: Innovations in Amigo2005

We have improved and refined the Amigo for the 2005 competition, providing it with higher-level functions than previous Amigo models.

2. Design Process

After considerable discussion by the members of ARL and in response to advice from faculty advisers, we employed the Rational Unified Process (RUP) based on Unified Modeling Language (UML) as a design process. As a design process methodology the RUP is newer than Guidelines for Rapid Application Engineering (GRAPPLE), which we employed in the design of Amigo2004. Employment of the RUP methodology allows team members to use their skills, plan efficiently, and share their knowledge. The design process allocated times and roles appropriately to each member under the correct recognition of their abilities. The RUP written UML promoted smooth communication between the team members.

2.1 Unified Modeling Language (UML)

The UML clearly defines standardized signs and meanings. Diagrams (schemes) written using the UML provides efficient means for each team member to carry out co-operative work. Schematic representation using the allowed diagrams provides for an intuitive and/or easy understanding of complicated concepts and processes. Moreover, the UML provides information about how the project is proceeding as a whole.

2.2 Improved RUP for the IGVC Project

The RUP is one of the well-known methods for developing design processes in UML. Originally, the RUP was considered for software development. The IGVC project includes not only software development but also hardware and system integration, so the conventional RUP could not be applied directly. Some modification or improvement of the RUP was required. Figure 3 shows the RUP for the modified IGVC project.

Figure 3: RUP for the IGVC project

1) Gathering of Requirements in Initial Planning

In order to develop the Amigo2005 based on the Amigo2004, we gathered requirements from (1) the IGVC rules, (2) advice from faculty advisors, and (3) information gained by interviewing members of earlier design teams. Based on the requirements gathered, we considered ideas and concepts that would fulfill the target specifications by brainstorming at collaborative design meetings. We decided not to change the basic concept from that of the Amigo2004. Instead, we would effectively improve the vehicle form, sensor system, and computer system, since we felt these areas were not completely satisfactory in the Amigo2004.

2) Simulation of the Prototype

After the requirements that were part of the initial planning were gathered and defined, we designed the initial prototype of the Amigo2005 on a PC. Based on the prototype, the process of gathering the detailed requirements was continued by small teams. That is, after the initial planning, we organized sub-teams, and they gathered specific requirements. The sub-teams consisted of the electrical team, mechanical hardware teams, and software teams for the navigation challenge and the autonomous challenge. For the Amigo2005 simulation, a structural modeling by 3-D CAD and renderings of Amigo2005 were created using the graphic software *Shade7* (e frontier), the CAD software *Autodesk Inventor* (Autodesk), and the engineering calculation software *MATLAB7* (MathWorks). Figure 4 shows the 3-D representations of the Amigo2005. Two new vehicles were created, as shown on the left and right in the figure, and we selected the vehicle on the right as our model.

Figure 4: Three-D representations of the Amigo2005

3) Concept of the Amigo2005

The structural features of the final vehicle are that a laptop PC is located under the chair of the vehicle and the electric circuit junction box is compact. This structure yields the following improvements: (1) increased stability of the vehicle by locating the relatively heavy PC in the lower part of the vehicle, (2) short and simple wiring between the PC and the vehicle controller, (3) complete protection of the PC from changing weather, including changing light conditions, and (4) reduction of the total weight of the vehicle. The final vehicle was even better than that imagined in the initial design planning. Figure 5 shows a CAD of the Amigo2005.

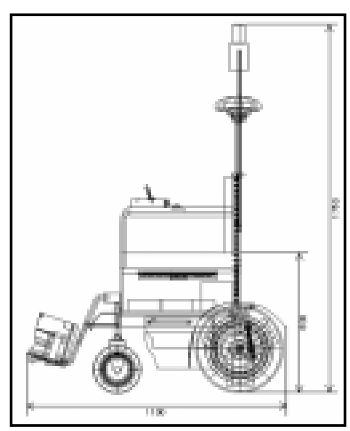

Figure 5: CAD of Amigo2005

2.3 Team Organization

All of the team members are cross-listed in the team roster shown in Table 1. Figure 6 shows the team organization chart. We estimate 2880 man-hours were spent on this project. All work was carried out by the responsible sub-groups.

Table 1: Team Members

Name	Major	Year
Yoshihumi Omata	System engineering	Graduate
Yoshihiro Miyazaki	System engineering	Graduate
Raise Mori	System engineering	Graduate
Shin Amano	System engineering	Graduate
Mikihiro Ando	System engineering	Graduate
Akira Saito	System engineering	Graduate

Name	Major	Year
Takeyoshi Sasaki	System engineering	Graduate
Manabu Shimizu	System engineering	Graduate
Yuki Tarutoko	System engineering	Graduate
Ryotaro Kotake	System and Control engineering	Senior
Shota Takiguchi	System and Control engineering	Senior
Yoko Yamauchi	System and Control engineering	Senior

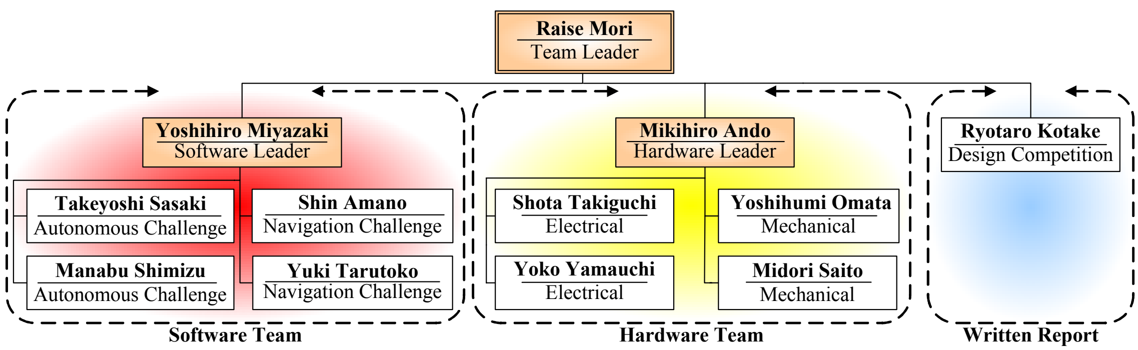

Figure 6: Team organization chart

3. Innovations

Through the "requirements gathering" processes, the problems with the old Amigo were clearly identified. The problems are summarized as follows:

(1) How to prevent bright sunlight from affecting image acquisition.

(2) How to stably control the high-speed autonomous driving.

(3) How to realize a safe, reliable, and versatile vehicle.

(4) How to speed up the signal processing to shorten the delay time in control.

In order to solve Problem (1), we employed a single omni-directional camera that is protected from bright sunlight by the use of a half-mirror film (an optical filter). To solve Problem (2), we employed new speedometers controlled by a rotary encoder. To solve Problem (3), we designed a new structure and form that would make the vehicle safer, more reliable, and more versatile than the old version of Amigo. To solve Problem (4), we designed efficient software.

3.1 Omni-Directional Camera That Uses a Half-Mirror Film

Here we describe the details of how to solve Problem (1). We found that image acquisition by the omni-directional camera was weak in glaring sunlight. The omni-directional camera can scan a 360-degree scene at once. If we install an effective countermeasure against the glare of sun shining, the image processing such as obstacle detection, path planning, and scene understanding became much easier and robust. Figure 7 shows the omni-directional camera whose window is covered by a sheet of half-mirror film to protect it from bright sunlight. The half-mirror film suppresses noisy light reflection such as from glass and direct sunlight and further enhances the intensity within any image. This simple strategy is very effective for the autonomous driving by images. Figure 8 shows an input image acquired by the conventional camera and the film-protected camera. The image with half-mirror protection seems a little gray, but the contrast seems clear. The middle part of the figure shows the image intensity map, and the bottom part shows the histogram of the intensities. From both images and graphs, one can see that the image with protection is not saturated and the contrast is clear. The advantage of the film-protected omni-directional camera is that it is robust in response to sunlight, and employment of a single camera yields faster image processing than that obtained with the use of dual omni-directional cameras.

Figure 7: Improved omni-directional camera

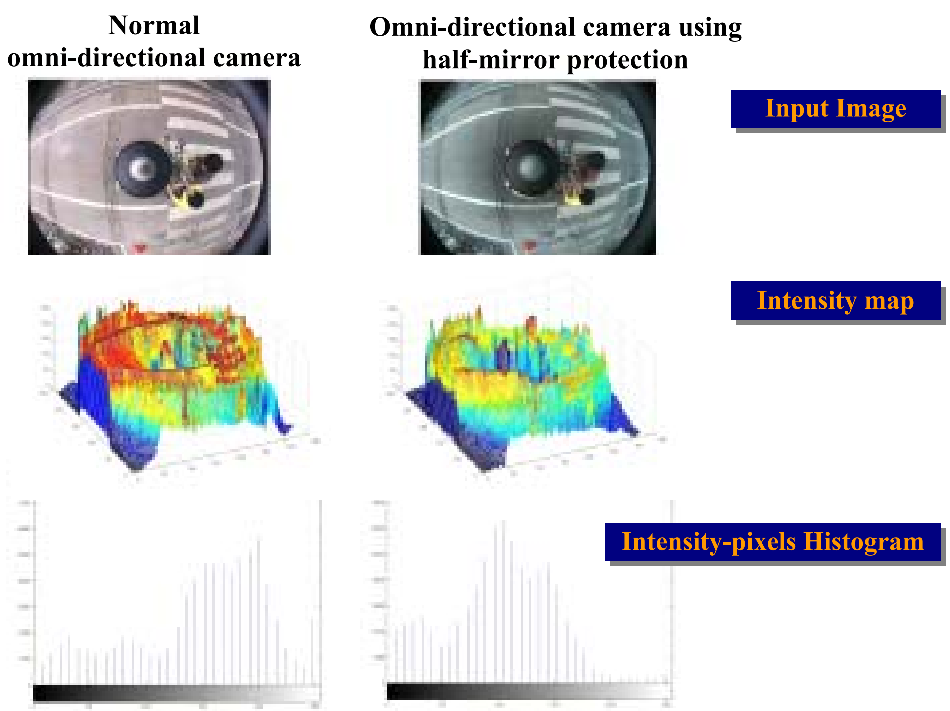

Figure 8: Images of the omni-directional camera with and without mirror film protection

3.2 New Speedometer Controlled by Contact-type Rotary Encoders

Here we describe the details of how to solve Problem (2). One of the key functions necessary for accurate autonomous driving is the accurate estimation of the vehicle's self-position and self-orientation. We tested the contact and non-contact speedometers and found that the stability and robustness of the contact speedometer was better than that of the non-contact speedometer. In Amigo2004, we used the non-contact speedometer. In developing Amigo2005, we employed the contact rotary encoders and thus solved the problems associated with the non-contact speedometer. Figure 9 shows the rotary encoder used.

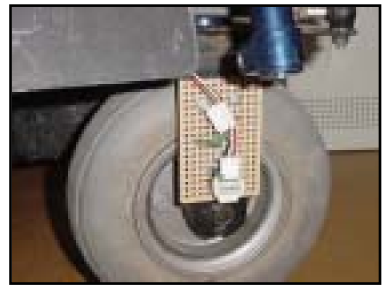

Figure 9: Rotary Encoder

4. Mechanical Design

Here we describe the details of how to solve Problem (3). The base vehicle employed is an electrically powered four-wheel wheelchair, the MC16P produced by SUZUKI. The maximum limited speed of the wheelchair was 6.0 km/hr (3.76 miles/hr). We tuned the controller so that the maximum speed is 7.0 km/hr (4.38 miles/hr).

4.1 Serviceable Design

In Amigo2005 we set the electrical circuit junction box, sensor devices, and laptop PC all under the wheelchair sheet. This simple change yields the following merits:

--Increase in reliability and durability

(1) The key electronics elements are protected from rain, wind, and vibration.

(2) The center of gravity of the vehicle is set low by setting the box under the seat.

--Increase in maintainability and safety

(3) The electric wires are shortened, by which the maintainability is improved.

(4) The previous Amigo had its center of gravity at the tail side, which was the cause of dangerous lifting of the front wheel. This problem is resolved.

4.2 New Junction Box

Figure 10 shows a developed new compact junction box. A junction box was designed to house all the electronics elements. An integrated control panel with multiple switches for the sensors and the power supply was installed. The control panel offers safety and maintainability.

Figure 10: New Junction Box

5. Electrical Design

During the requirements gathering process, we found problems of unreliability in the electrical circuit. A modular-based design strategy was employed to solve the problem. Each circuit is in its own waterproof plastic case. As a result, the electrical circuits of the Amigo2005 are robust, and, further, if a fault occurs in an element, we can quickly recover the system by replacing only the faulty element

5.1 Sensors

The sensors incorporated in the Amigo include a laser range finder (SICK LMS-200), an omni-directional camera (Sony CCD), two rotary encoders set to control the two front wheels, an optical fiber gyro which detects the angle of the vehicle, and a differential global positioning system (Trimble BD950) to locate the position of the vehicle with respect to the earth's latitude and longitude coordinates. The video images are captured using a USBcap2, converted into a digital format, and sent to the software programmed by *MATLAB* for image recognition. The average sampling interval of the laser range finder (LRF) is about 20 ms. Again, this information is sent to *MATLAB* for range profile recognition. Accurate speed measurement is important for accurate dead-reckoning control. The accuracy of the speed measurement was improved by employing the new rotary encoder. The accuracy of the differential global positioning system (DGPS) was also improved by employing a Trimble BD950, which is a dual-frequency version of the newest GPS receiver.

5.2 Computer

An industrial laptop PC driven with a 1.6-GHz Pentium M processor with 512 MB of memory under Windows XP OS is used for navigation and control of the vehicle. This new computer system was employed to shorten the image processing times.

5.3 Power System and System Integration

Figure 11 shows how the sensor signals and power supplies are connected and integrated. Video images captured by an image frame grabber are converted into a digital format and sent to a laptop PC by vcapg2. The omni-directional camera is connected to the PC via a USB 2.0. The LRF scans with 1/2° increments in the 180° plane in front of the vehicle. The LRF is connected to the PC via a high-speed serial RS-422 of 500 kbps. A DGPS is connected with the PC via a serial RS-232C. A rate gyro is connected with the PC via a serial RS-232C. The speedometer is connected with the PC via a PC card ADC connection.

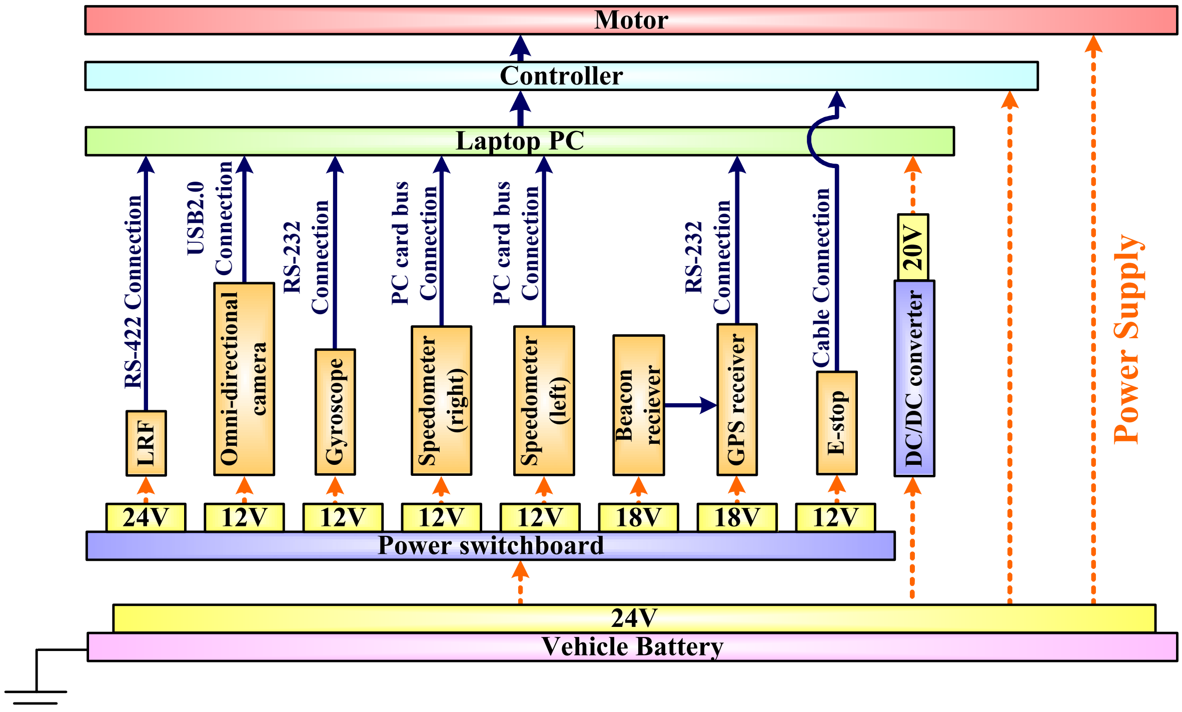

Figure 11: Outline of the electrical systems

5.4 Actuators

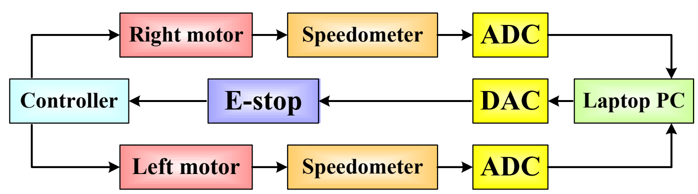

Figure 12 Actuator control

The actuators to drive the vehicle are two DC motors originally mounted on the electronic wheelchair. The motors have a maximum wattage of 50 watts; in the steady state, the driving power required is about 20 watts. The power for the motors is supplied by two 12-volt batteries. One more DC motor is mounted for the power steering. Figure 12 shows the actuator control signal block diagram. The control law for the vehicle was developed on the basis of the two-wheeled steering model. Speed differences in each wheel and power-assist steering can determine the direction of vehicle movement. Each wheel's speed is determined by the targeting direction, the speed of the vehicle, and sensing information.

6. Innovative Software Strategy

Here we describe the details of how to solve Problem (4). We developed a new image processing method that uses a template to match the spatial and temporal noise removal for lane detection for the autonomous challenge and path planning that uses the clothoid curve for the autonomous and navigation challenge.

6.1 *MATLAB*

The code *MATLAB* was selected as the base language in which to develop a new algorithm. The code provides functions of easy and seamless concentration of algorithms, development, simulation, and actual executable coding.

6.2 Software for the Autonomous Challenge

Lane lines detection is one of the important types of recognition necessary for accurate autonomous driving. The problems that occur most frequently in lane detection are caused by sunlight and/or shadow in the images and the existence of obstacles within the lanes. The innovation of this year's model with regard to lane detection is based on obstacles elimination from the image and detection of lane lines by applying the normalized template matching with spatial and temporal noise removal. The developed software can robustly detect lane lines and potholes regardless of the sunlight condition. Figure 13 shows the flow chart of the algorithm. The basic steps of the algorithm are summarized as follows:

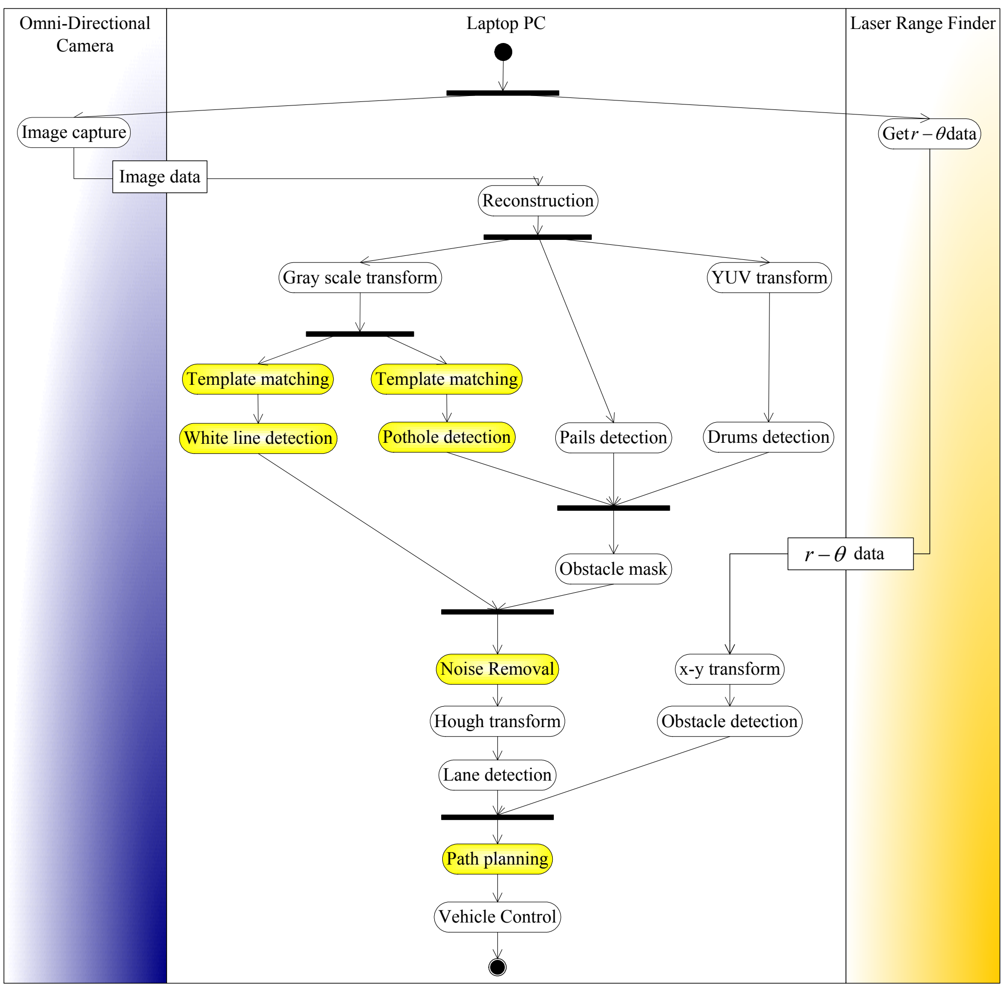

Figure 13: Process of autonomous challenge driving (Yellow markers are innovations)

[For image signals]

(Step1) Capture the omni-directional image.

(Step2) Recognize the obstacles and eliminate them from the image.

(Step3) Remove noises in the image both by spatial and temporal filtering.

(Step4) Hough transforms the image to detect the straight line.

[For range signals]

(Step5) Obtain range profile from the RLF.

(Step6) Recognize the obstacles.

Through above steps, the vehicle is controlled. The followings are description of innovations and improvements.

6.2.1 Detection of Drums

The white parts of the drum in image at the top of Figure 14 could be miss-recognized as the lane. To avoid this miss-recognition, we first recognize the existence of the drums. Two color components of the drum are treated. One is the R component, and the other is the U component, which can be transformed from RGB to YUV. Between the two components, the U component is most sensitive to the red color of the drum. By confirming this fact by experiments, we develop the algorithm to recognize the drum. After the recognition; the drum image is removed from the original image. Figure14 shows how the drum is recognized and how it is removed from the image.

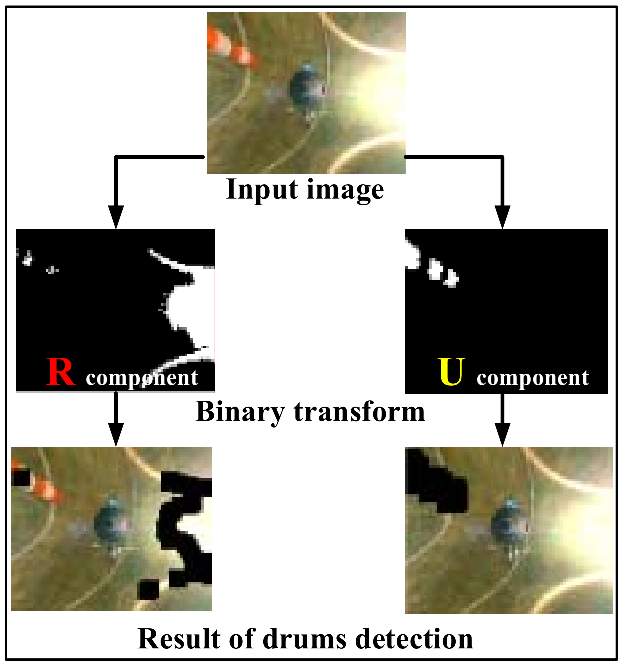

Figure 14: Drums removed image

6.2.2 Detection of Potholes

When the vehicle passes over a pothole, we lose 5 points. The detection and avoidance of potholes is important. We developed and tested the performance of three different pothole detection methods: (1) Detection by circularity, (2) Circular Hough transform, (3) Template matching. Table 2 summarizes the results. The template matching was best.

Table 2: Pothole recognition rate

Method	Correct rate	Failure rate
Detection by using degree of circularity	23%	0.50%
Detection by using Hough transform	49%	4.70%
Detection by using template matching	83%	1.60%

6.2.3 Detection of Pails

The omni-directional camera image is used to detect the pails which will newly appear in IGVC 2004. The pails include "pure white" not found in the natural color environment; thus we can detect the existence of the pails by detecting the "pure white".

6.2.4 Detection of Lane Lines

Earlier vehicles of the Amigo series have detected white lines only from the gray level. However, when exposed to reflected sunlight or white withered grass, the old Amigo frequently miss-recognized them as the white lane lines. This was the main reason for failing the obstacle course. To make the lane detection algorithm robust, we employ template matching with two different templates, since the matching technique has the function of direction sensitivity by selecting the proper template. Figure 15 shows the templates for lane line detection.

0	0	0
0	0	0
0	0	0
1	1	1
1	1	1
1	1	1
0	0	0
0	0	0
0	0	0

Width of white line

1pixel:0.05[m]

0	0	0	1	1	1	0	0	0
0	0	0	1	1	1	0	0	0
0	0	0	1	1	1	0	0	0

Width of white line

Figure 15: The templates

6.2.5 Noise Removal

Finally, to detect the clear lane images even by template matching, we must remove noises. The isolated scattering noises shown in Figure 16 substantially degrade the lane detection by the template matching method. The special filtering removes the isolated scattering. The temporal filter also removes the isolated noise by using the logical AND operation for two images of successive samplings. Figure 17 shown images whose noises have been removed by the conventional method and by the proposed new method. Table 3 shows the white lane lines recognition rate by both methods.

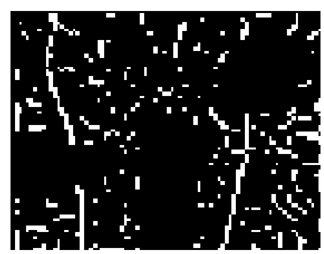

Figure 16:
Noise problem

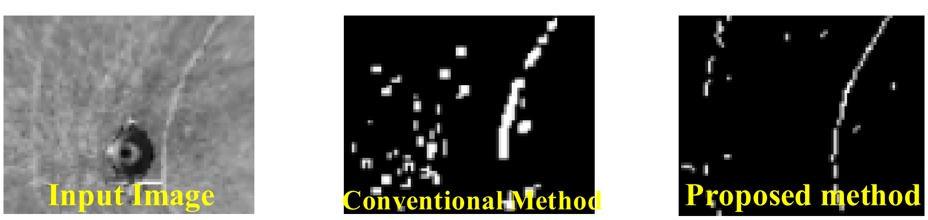

Figure 17: Result of lane detection in dry grass area

Table 3: Lane recognition rate

Method	Correct rate	Failure rate
		(Detected anything that was not white lane lines)
Conventional method	49%	12%
Proposed method	68%	13%

6.2.6 Lane Lines Detection by the Hough Transform

We applied the linear Hough transform to the binary image whose scattering noises are removed as much as possible. The Hough transform found the lines in the image. But if there is line noise caused by the lens reflection, as shown in the first column, first row image in Figure 18, the transform miss-recognizes the reflection to be a lane. To avoid this miss-recognition, we use that fact that in most of the area, the two lanes are parallel. If there are two parallel lines, we consider them to be the lanes. Figure 19 shows how the lanes are detected.

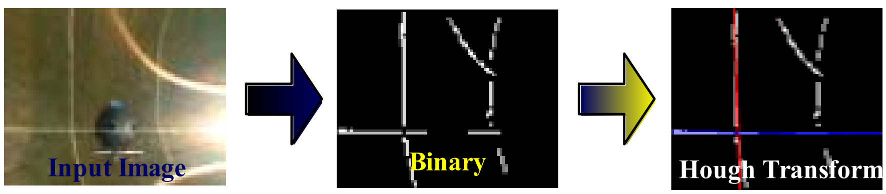

Figure 18: The failure case in which noise was detected as lane lines

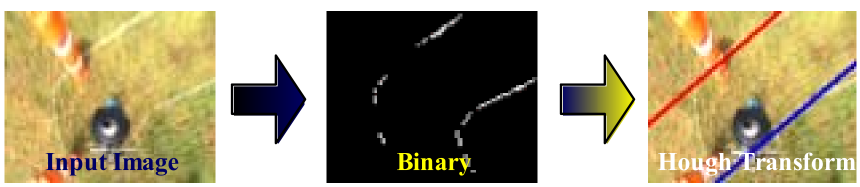

Figure 19: The successful case in which correct lane lines were detected

6.3 Software for the Navigation Challenge

The basic algorithm for waypoint navigation is almost the same as that used in the Amigo2004; the only difference is that we employ path planning, which will be explained in the next section. Figure 20 shows the flow chart of the algorithm. The steps of the basic algorithm are as follows:

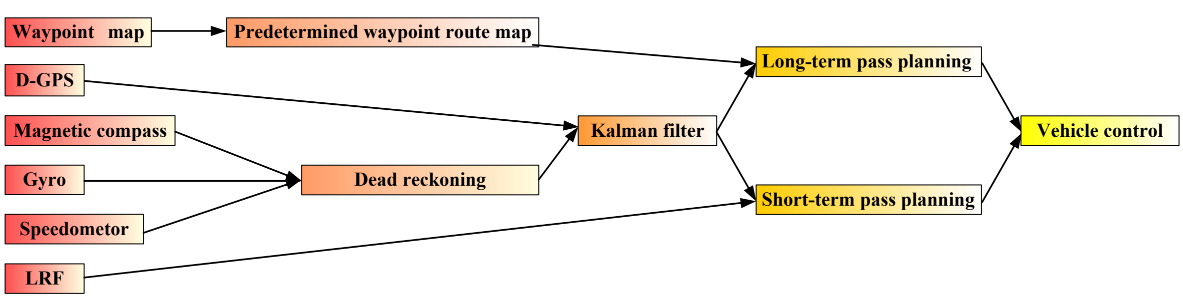

Figure 20: Process of navigation challenge driving

(Step1) Solve the traveling salesman problem to find the shortest route.

(Step2) Estimate the position of the vehicle in local coordinates from data of the inertial navigation system (INS) realized by the optical fiber gyro, LRF, speedometer, and magnetic compass.

(Step3) Estimate the global position using the DGPS.

(Step4) Combine the data of both the local and global co-ordinates by Kalman filtering.

(Step5) Obtain the coordinates of the obstacle position from the LRF.

(Step6) Plan the short path based on the information in (Step4) and (Step5)

(Step7) Plan the long path based on the information in (Step1) and (Step5).

(Step8) Drive the vehicle following the long-term path planning or the short-term path planning, depending on the external situation.

6.4 Path Planning Using the Clothoid Curve

Path planning for route navigation is important. To enhance the maneuverability of the Amigo2005, the appropriate selection of path planning methods is necessary. The path planning methods can be classified into two categories, long-term path planning and short-term path planning. The long-term path planning is determined based on a prescribed route course before navigation. The short-term path planning is determined ad hoc based on environmental conditions. We decided to try a new method of short-term path planning that employs a clothoid curve. The clothoid path tracking can minimize the lateral acceleration of the vehicle. To achieve smooth and smart control, we divide path expressions into 3 types, i.e., line segments, circular arcs, and clothoid arcs. The appropriate control scheme is selected depending on the different path expressions to minimize lateral force to the vehicle caused by the lateral acceleration. Figure21 shows an example of path generation based on the proposed method.

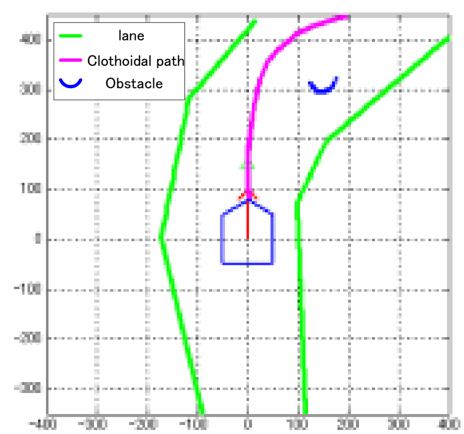

Figure 21: Clothoidal path generation

6.5 Vehicle Control

The control scheme of the Amigo2005 is same as that of the Amigo2004.

7. Analysis of Predicted Performance and Results

The overall performance of the Amigo2005 is much better than that of the Amigo2004. Both reaction time and distance at which obstacles were detected were improved by the software design. These differences are depicted in Table 4.

Table 4: Analysis

	Amigo2004	Amigo2005
Speed	6 k/hr (3.76 miles/hr)	7 k/hr (4.38 miles/hr)
Ramp climbing ability	8 degrees	8 degrees
Reaction times	0.2 sec	0.1 sec
Battery life	6 hours	4 hours
Distance at which obstacles are detected	3 m, 8 m	6 m (Autonomous Challenge), 10 m (Navigation Challenge)
How the vehicle deals with dead ends, potholes ,and traps	Dual omni-directional camera LRF	Half-mirror omni-directional camera LRF
Accuracy of waypoint navigation	0.25 m to 0.5 m	0.25 m to 0.5 m
Remote emergency stop capability	100 m [maximum]	100 m [maximum]

8. Cost

The cost involved in the development of the Amigo2005 is summarized in Table 5.

Table 5: Cost

Cost and time of vehicle's design		
Item	**Cost**	**Remarks**
DGPS receiver	$10,000	Trimble (BD950)
LRF	$8,500	SICK (LMS-200)
Electric powered wheelchair	$5,000	SUZUKI (MC16P)
Hyper omni-directional camera	$4,600	
Laptop personal computer	$2,000	FUJITSU (Intel Mobile Pentium M 1.6 GHz)
Battery	$530	YUASA
Electronics parts	$480	
CCD camera	$360	SONY
Mechanical parts	$280	Frame steel
Transceiver	$180	
Automobile wireless engine starter	$160	
Router	$150	
Body cover	$120	Aluminum plate
Omni-directionality antenna	$55	Effective distance 145 m
Wireless LAN	$25	
Total	**$32,440**	

9. Conclusion

This report describes how the "Amigo2005" was developed and constructed. To design Amigo2005 based on the experiences with the Amigo2004, we used the improved RUP oriented for the IGVC and the UML design process approach. The major improvement is the development of effective and efficient software for the high recognition rate and high-speed sensing. And stability of hardware is also improved through the RUP. This system overcomes several weak points of the Amigo2004. With a maximum speed of 7 km/hr, the vehicle can perform image processing, obstacle detection and avoidance, sensor fusion, waypoint navigation, and path planning. We are convinced that the Amigo2005 will be the best performer at the 2005 IGVC.