10th Intelligent Ground Vehicle Competition

Design Competition Written Report

AMIGO2002

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1. Introduction

A vehicle nicknamed AMIGO has been developed to scout the environmental situation and to autonomously drive for the purposes of safe transportation of cargos and human in undefined fields. Fig.1 shows the ultimate specification of the AMIGO, which was designed to drive autonomously, perform scouting, and provide transportation. Among these functions, the scouting and autonomous functions require the vehicle to be able to perform environment recognition, pass finding, vehicle mobility, vehicle control, self repair, and self energy supply. If we describe the scout function in detail, it requires the vehicle to perform visual image acquisition, identify obstacles, find targets, and acquire environmental information, such as the temperature and humidity of its surroundings, as well as the presence of any dangerous areas and materials. The vehicle must also be able to identify its own position.

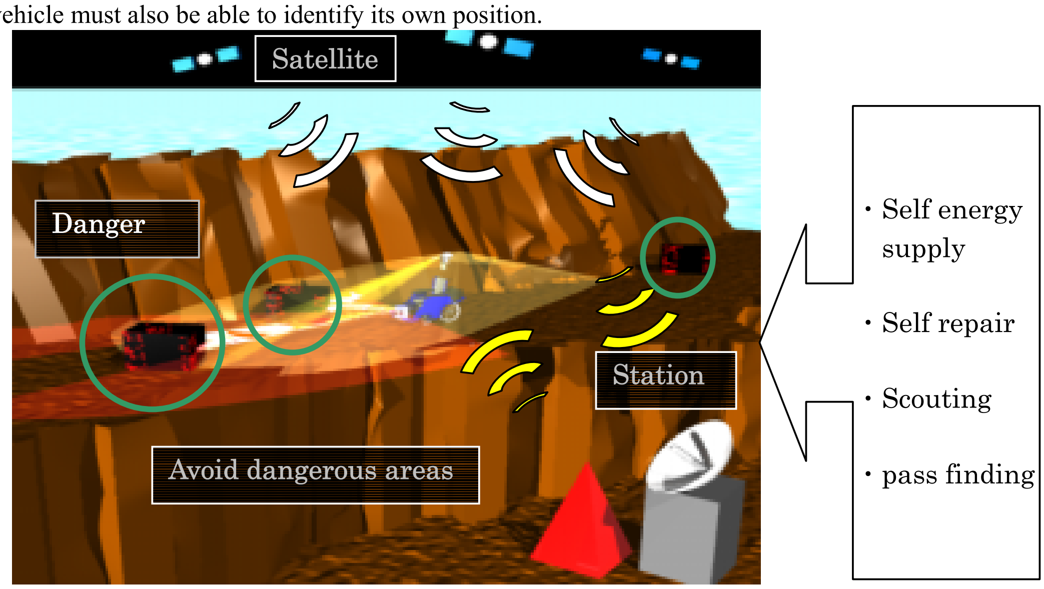


Fig. 1: The ultimate figure of AMIGO

The required fundamental functions and sub-functions are listed in Table 1. The circle ○ in the ultimate column in Table 1 shows the ultimate functions required, and the columns labeled 2000, 2001, and 2002 and circle ○ in the columns show the version (year) number of the AMIGO and the functions that were realized in that year. The AMIGO 2000 was the first version, and had the fewest functions. The AMOGO 2001 was improved by adding the follow-the-leader function and the GDP function, by which self and target positions were easily identified. The AMIGO 2002 ,which has been entered in this year is based on the AMIGO 2001, but was improved by newly employing a hyper-omni-directional camera, through which the accuracies of lane detection and the range finding function have been improved. The most advanced feature of the AMIGO 2002 in comparison with the AMIGO 2001 is its ability to transport humans and cargo. Furthermore, an information transmission function, which investigates and checks the condition of the cargo and the humans on board, has been added. The transmission function is not, however, used to remote-control the vehicle, in order to satisfy the prohibition provision in the IGVC regulations.

Table 1: Functions realized in the AMIGO 2000, 2001, and 2002, and the ultimate functions

Main Functions	Functions	Sub-functions		2000	2001	2002	Ultimate	Design
Autonomous function	Pass finding	Visual lane detection (CCD camera)		○	○	○↑	○	Software
		Electric lane detection (GPS/DGPS)				Option	○	Software
		Pass point detection (GPS/DGPS)			○	○↑	○	Software
		Goal point detection (GPS/DGPS)			○	○↑	○	Software
	Environment recognition	Obstacles (Laser range finder)		○	○	○↑	○	Electrical
		Dangerous area (Sensor fusion)					○	Electrical
		Temperature/humidity				Option	○	Electrical
		Passability (Sensor fusion)					○	Electrical
	Vehicle mobility	Ramp angle (°)		8	8	7↓	○	Mechanical
		Maximum speed (Km/hr)		6	6	4.5↓	○	Mechanical
		Minimum gyration radius (m)		0.58	0.58	0.58	○	Mechanical
		Propulsion power (kgf)		15	15	15	○	Mechanical
	Vehicle control	Autonomous driving		○	○	○↑	○	Software
		Follow the leader			○	Option		Software
		Remote driving				Option	○	Software
	Repairability	Self repair					○	Mechanical
		Fault information transmission					○	Software
	Energy supply	External energy supply		○	○	○		Mechanical
		Self energy supply					○	Mechanical
Scout function	Information acquisition	Visual image	One direction					Electrical
			Sphere omni	○	○			Electrical
			Hyper omni			◎	○	Electrical
		Obstacle	Position	○	○	○↑	○	Software
			Name				○	Software
		Target	Position		○	○↑	○	Software
		DGPS				○	○	Electrical
		Environment information	Temperature			Option	○	Electrical
			Humidity			Option	○	Electrical
			Lightning condition	○	○	○	○	Electrical
			Acoustic signal			Option	○	Electrical
		Position	Self position		○	○↑	○	Software
			Map construction			Option	○	Software
			Passed route		○	○↑	○	Software
	Information transmission					◎	○	Electrical
Transport Capacity	Weight (Kg)			10	10	100		Mechanical
	Size	Width (m)		–	–	0.55		Mechanical
		Depth (m)		–	–	0.65		Mechanical
		Height (m)		–	–	1.2		Mechanical
	Passenger transportable					◎	○	Mechanical
Durability	Temperature (℃)			60	60	60	○	Mechanical
	Humidity (%)			90	90	90	○	Mechanical
Environment Resistance	Wind			○	○	○	○	Mechanical
	Rain			○	○	○	○	Mechanical
	Sunshine protection				○	○	○	Mechanical
Safety function	Emergent automatic stop					Option	○	Electrical
	Emergent manual remote stop		Wireless		○	○↑		Electrical
			Optical			Option		Electrical
			Acoustic	○				Electrical
	Emergent manual stop			○	○	○		Electrical
Remark	The double circle ◎ shows the newly realized function, the circle ○ shows the realized function and the arrow ↑ shows the improved function.							

The AMIGO 2002 does not always satisfy the ultimate specifications of the AMIGO, but does provides the basic technology necessary to develop a next-generation electric wheelchair, which must have the functions of being able to autonomously drive, automatically avoid obstacle avoidance, follow-the leader, and the transmit of information, such as the bio-signals emitted by the passenger and the environment in which the vehicle is being driving. The development such the wheelchair is one of the most important civil applications.

2. Team organization

The team to develop the AMIGO 2002 was organized in early April of 2002. In the autumn of 2001, four undergraduate students devised a new plan. The failures that had occurred in the IGVC 2001 formed the basis of this new plan. Fig.2 shows the team organization chart. All of the team members in this chart are cross-listed in the team roster shown in Table 2. We estimate 3500 man hours were spent on this project.

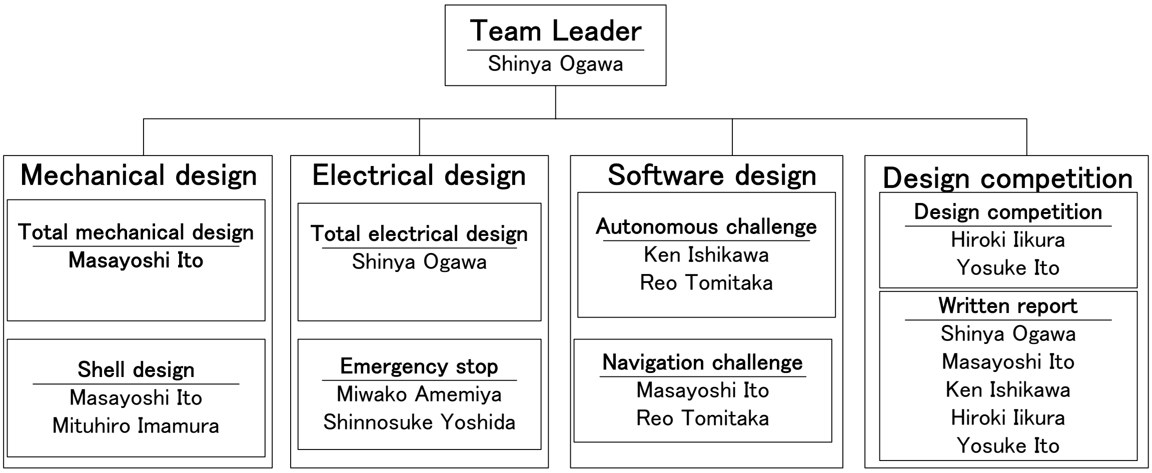


Fig.2: Team organization chart

Table 2: Team roaster

Function	Name	Major	Academic Level
Team Leader	Shinya Ogawa	System and control engineering	Graduate
Technical	Masayoshi Ito	System and control engineering	Graduate
	Ken Ishikawa	System and control engineering	Graduate
	Reo Tomitaka	System and control engineering	Graduate
	Miwako Amemiya	System and control engineering	Undergraduate
	Hiroki Iikura	System and control engineering	Undergraduate
	Yosuke Ito	System and control engineering	Undergraduate
	Mituhiro Imamura	System and control engineering	Undergraduate
	Shinnosuke Yoshida	System and control engineering	Undergraduate

3. Design process

The design was carried out to develop the mechanical equipment, electrical circuitry and software needed to satisfy and/or realize the functions listed in the 2002 column in Table 1.

The functions and sub-functions to be realized by the AMIGO 2002 are shown in Figs 3. Fig 3 (a) shows the tree structure of the main autonomous functions, and the sub-functions. Fig 3 (b) shows the main scout function, and the sub-functions. Fig 3(c) shows the main transport functions and the sub-functions. Fig 3 (d) shows how to realize the vehicular durability. Fig 3 (e) shows how the vehicle resists the stresses from the environment. Fig 3 (f) shows the safety functions.

These functions are designed and realized in the following design stages: (a) the mechanical design, (b) the electrical, (c) the software design, and (d) system design.

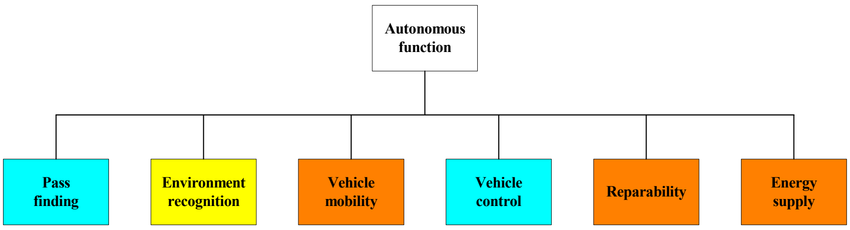
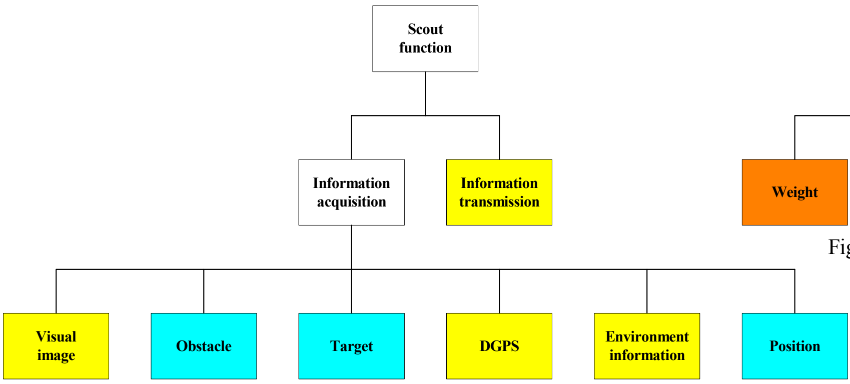


Fig.3(a) Autonomous function



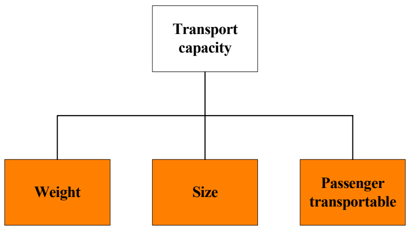


Fig.3(c) Transport capacity

Fig.3(b) Scout function

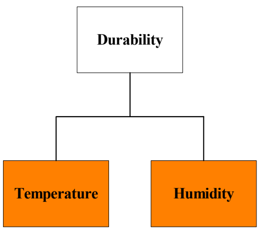


Fig.3(d) Durability

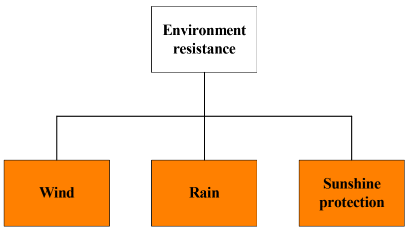


Fig.3(e) Environment resistance

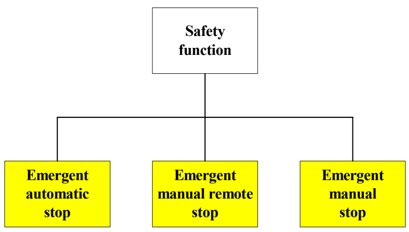


Fig.3(f) Safety function

Fig. 3: Classification of the functions

3.1 Mechanical design

In the mechanical design stage, (1) vehicle mobility in the autonomous function, (2) the transport capacity, (3) durability, and (4) the environmental resistance were treated.

3.2 Electrical design

In the electrical design stage, (1) the environmental recognition function, (2) visual imaging function, (3) DGPS function, (4) environmental information function in the information acquisition function, (5) information transmission function in the scout function, and (6) emergence stop function in the safety function were treated.

3.3 Software design

In the software design stage, (1) pass finding and (2) vehicle control in the autonomous function, (3) the obstacle identification and avoidance function, (4) the target finding function and (4) the self position identification function in the information acquisition part of the scout function were treated. The software design was essential in designing the AMIGO 2002 and a great deal of effort went into this stage of the design and development.

3.4 System design

The elements of the vehicle consist of the mechanical part, the electrical part, and the software part. The total vehicle is a system composed of these three elements above. In the system design stage, these three elements were appropriately synthesized.

4. Mechanical design

4.1 Vehicle mobility

The base vehicle employed is an electrically powered four wheel chair MC16P, which is made by SUZUKI. Most of the mechanical performances and specifications of this chair are listed by the wheelchair manufacturer. Those that are relevant to the vehicle mobility are as follows. The ramp angle that the AMIGO

2002 can climb is 8 degrees. The maximum speed is 6k/hr (3.76miles/hr), which is within the limitation speed listed in the IGVC's regulations. The minimum gyration radius is 0.6m, and the population power is 40kgf with a full load. Fig. 4 shows the base vehicle.

Fig. 4: Base vehicle

4.2 Transportation capacity

The maximum transportable cargo or human weight that can be transported is 100kg (220 pounds). The size of the cargo must be within 0.55m x 0.65m x 1.5m. According to the maximum allowable weight and size, a human being can be transported.

4.3 Durability

The vehicle can run under temperatures of 60 degrees centigrade, and under 90% humidity. It is possible to drive the vehicle for four hours on a bumpy road, after charging the vehicle electrically for eight hours. The maximum slope of the bumps in the road must be within 8 degrees, as described above.

4.4 Resistance to the Environment

The vehicle is protected against the rain, wind, and the sunshine. Fig. 5 shows the proposed protection for the AMIGO 2002.

Fig. 5: Proposed protection for the AMIGO 2002

5. Electrical design

5.1 Environment recognition function

The obstacle detection function in the AMIGO 2002 has been improved by employing a high resolution laser radar rangefinder. In order to detect obstacles with a width of 1.3 cm in the 3m front, we selected a rangefinder that has a minimum resolution angle of 0.25degree. The AMIGO 2001 was equipped with a rangefinder with an angle resolution of 0.5degree. Thus the resolution of the AMIGO 2002 is two times higher than the AMIGO 2001. Figs. 6 show the resolution angles by the laser radars.

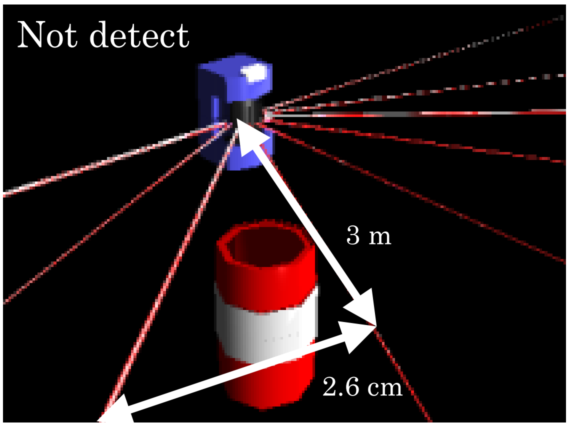


Fig. 6 (a) AMIGO 2001

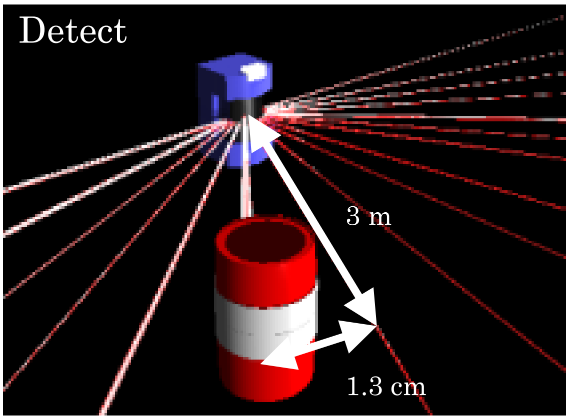
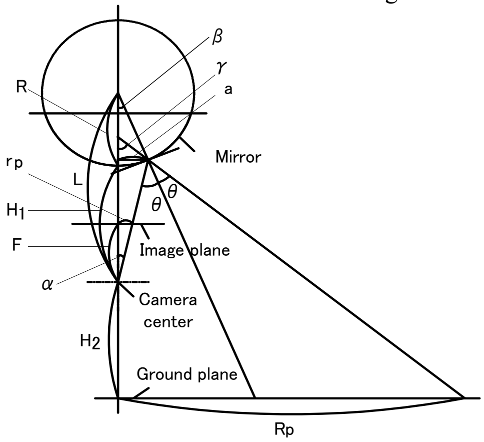


Fig. 6 (b) AMIGO 2002

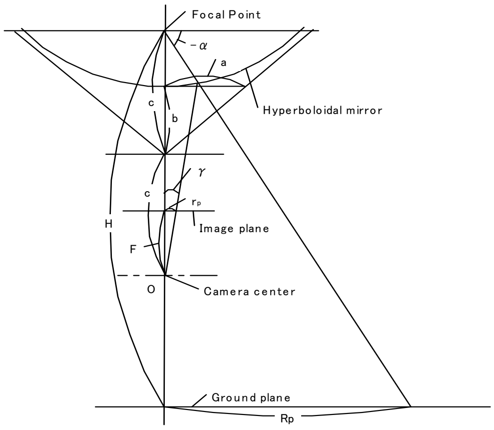
Fig. 6: The resolution angles by the laser radars

5.2 Visual image function

In order to obtain more accurate lane information, a more accurate omni-directional image must be acquired. An omni-directional camera with a miller with the shape of a hyperbolic function has been newly employed. The hyper omni camera always has one optical center. If the center is set to the center of the camera, the transformation of the deformed images reflected to the hyperbolic function into the plane world co-ordinate is easy and accurate. No calibration is required after setting the miller. In the AMIGO 2001, a spherical miller was used, which led to difficulty in the transformation that the calibration is always necessary after setting the miller to the camera. Fig.7 shows the relationship between the image obtained by the omni-directional camera and true image.



(a) AMIGO 2001(Spherical mirror)

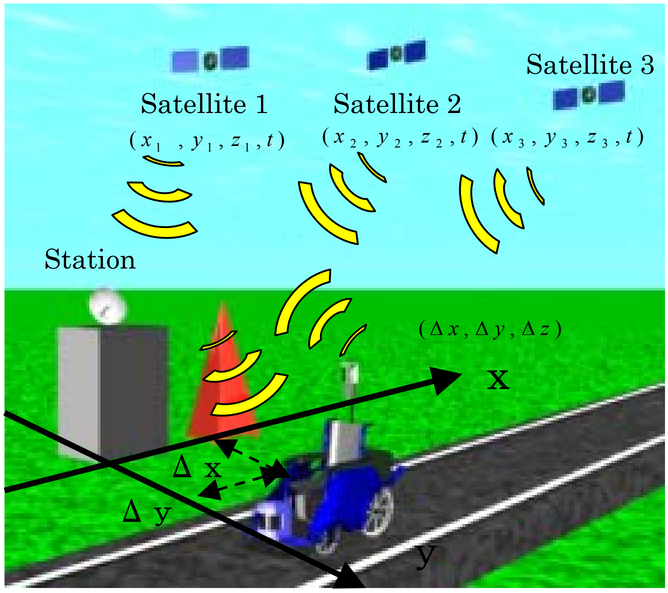


(b) AMIGO 2002(Hyperboloid mirror)

Fig.7: The relationship between omni-directional camera image and true ground image

5.3 DGPS function

The DGPS has been newly employed in the AMIGO 2002. In the AMIGO 2001, the GPS was used. The positioning error by the GPS is about 15m, whereas the positioning error by the DGPS is 5m, which is more accurate. Fig 8 illustrates the principle of the DGPS. The relative co-ordinate from the station can be obtained by which the errors are cancelled



FFig. 8: DGPS function

5.4 Environment information function

Among the types of information the vehicle can obtain on the environment, the AMIGO 2002 measures the strength of sunshine and controls the iris, depending on the lighting conditions.

5.5 Information transmission function

In order to transmit the vehicle conditions and the passenger's health status, a wireless LAN with a transmission speed of 10Mbbp is installed. Mutual communication between the base station and the moving vehicle is possible, but the function to remotely control the vehicle is frozen when this type of communication takes place.

5.5 E-stop function

Two different types of wireless manual emergency stop mechanisms have been designed and prepared. One is an E-stop, the design for which was based on the automobile wireless engine starter, and the other one is using the transceiver. The E-stop based on the engine starter is able to withstand environmental noise, but its maximum transmission distance is about 0.5 miles, whereas the stop mechanism based on the transceiver has a long transmission distance, up to 2 miles, but is noise sensitive. One of the E-stops will be used, depending on the environment. Fig. 9 shows the block diagram of the E-stop.

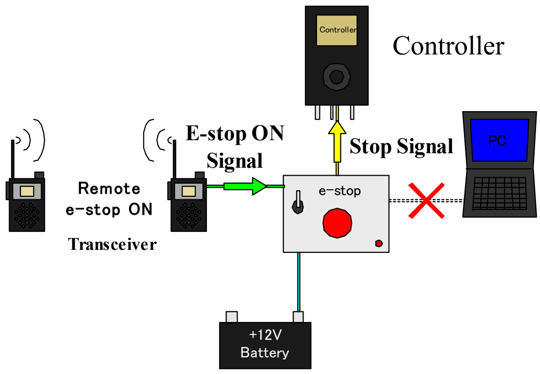


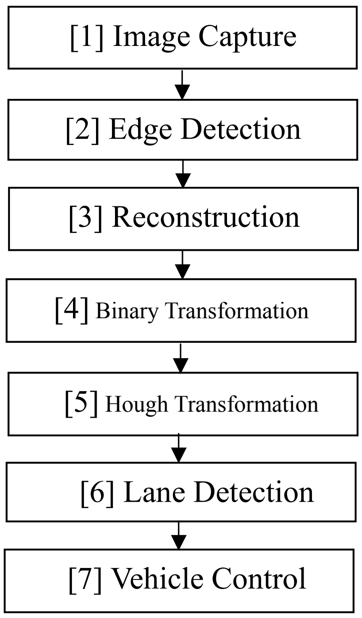
Fig. 9: Block diagram of E-stop

6. Software design

6.1 Pass finding function

The Pass finding function is divided into three sub-functions. These are (a) the visual lane detection by the CCD camera, (b) the pass point detection function, and (c) the goal point detection function by the GDP and/or the DGPS. The AMIGO 2001 had these functions, but there were some problems with them.

In the lane detection function (a) in the AMIGO 2001, the algorithm was designed following these steps : (step 1) transformation of the image obtained by the spherical omni camera into a plane image, (step 2) detection of the edge via the Sobel operator, (step 3) binary transformation of the image, and (step 4) Hough transformation to detect the lane. The algorithm was not effective, because 30% of the lane information was dropped, and the computation time was 0.2 sec for each sampling interval, which was too long to be used for a control. We solved this problem with the lane detection algorithm in the AMIGO 2002 by designing the algorithm as follows : (step 1) detection of the edge of the original image before transforming the image into the image in a plane co-ordinate, (step 2) transformation of the edge information into the plane co-ordinate, (step 3) binary transformation. The algorithm has the least information loss in the transformation, and the computation time becomes 0.16sec for each sampling interval. Fig.10 shows the algorithm that was used to detect the lane, and Fig.11 shows one example of the image obtained by the algorithm.



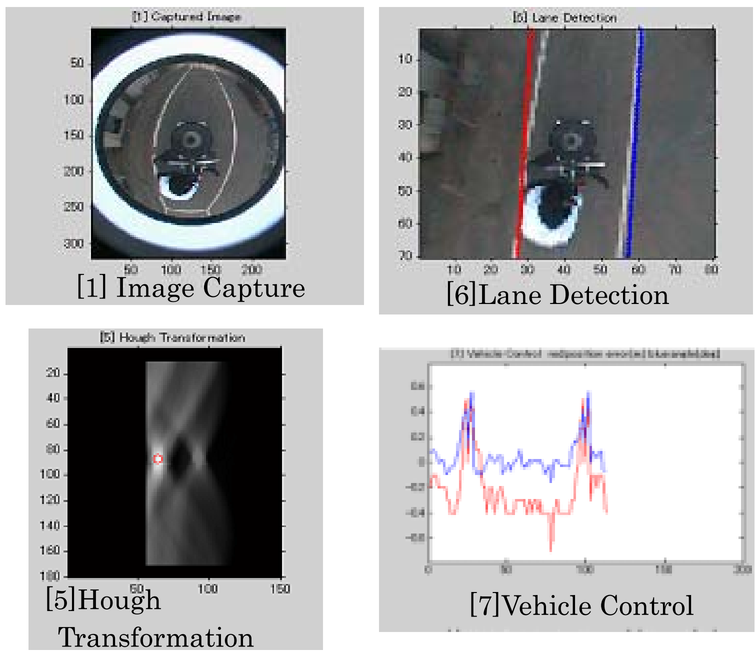


Fig.10: New algorithm to detect the lane

Fig.11: Image obtained by the new algorithm and control

In the pass point detection (b), the GPS was employed in the AMIGO 2001, whereas in the AMIGO 2002, the DGPS is used. New software for the DGPS has been developed. In addition, the accuracy of the transformation of the global co-ordinate into the local plane co-ordinate was improved in the AMIGO 2002. In the AMIGO2001, we assumed the earth was a pure sphere, whereas in AMIGO2002, we assumed the earth was an ellipsoid, which is more accurate than assuming it is a pure sphere, and though this change, the error was reduced for about 0.5m to1m.

In goal position detection (c), the accuracy of the AMIGO 2002 has been improved to the same degree as the pass point detection.

6.2 Vehicle control

The autonomous driving sub-function was considered anew and was improved. The control scheme in the AMIGO 2001 was based on the preview proportional control rule; the proportional gain was increased and/or decreased experimentally. In the AMIGO 2002, the control scheme was the same as that of the AMIGO 2001. As the preview proportional control can be interpreted as one of the optimal controls, by introducing the optimal control theory, the proportional gain was determined theoretically. Thus the experimental tuning is not necessary.

For the navigation challenge, the loci to be passed by the vehicle is pre-selected optimally ; in the sense that the steering angle becomes minimal in the AMIGO 2002, by which the feed-forward control is possible. The feed-forward control leads to a quick response, whereas the AMIGO 2001 did not have such the feed-forward functions. Fig.12 shows the pass tracking algorithm. It detects self position and angles at the present time and predicts position in the future.

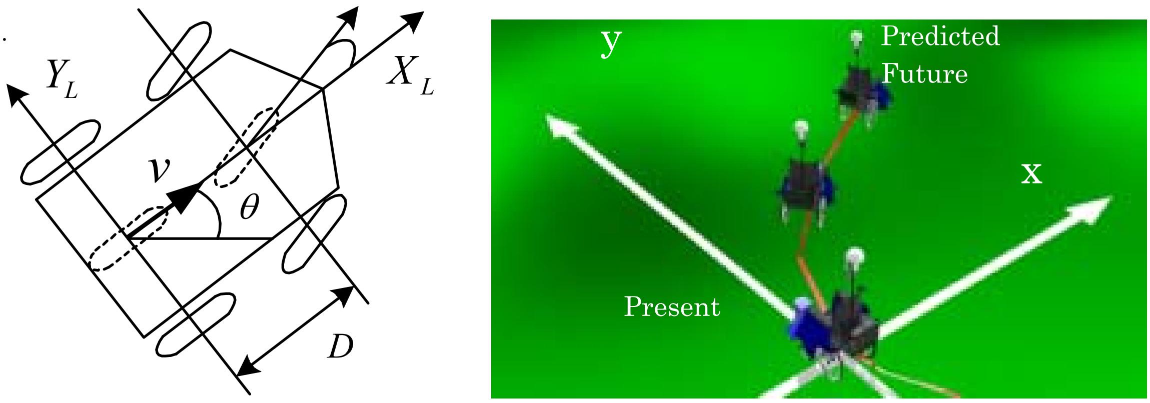


Fig.12: Pass tracking algorithm

6.3 Obstacle identification and avoidance function

In the AMIGO 2001, only the laser radar was used to detect and identify an obstacle, and thus, the radar failed to detect potholes. In the AMIGO 2002, we used not only the laser radar, but also the omni image. A pothole is detected by a circular image in the original image, which appears in the 1.5m or 2m front line from the vehicle. The AND operation of the circle image and laser radar is taken in order to avoid pothole. Fig. 13 shows the obstacle detection by the laser radar and image.

In the navigation challenge, the laser radar has been newly employed to detect the obstacle position.

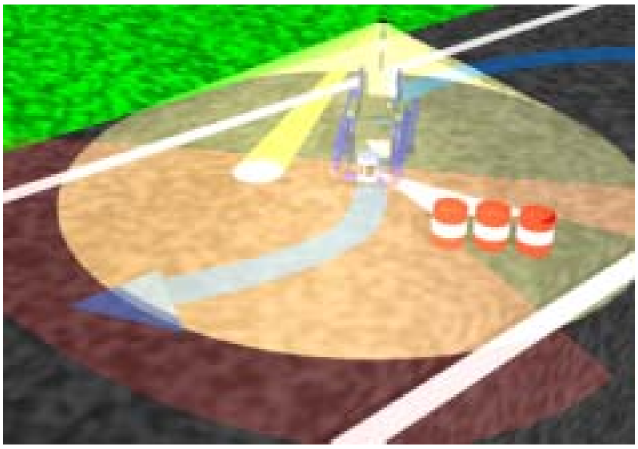


Fig. 13: Obstacle detection

6.4 Self position identification function

In the self position identification for the autonomous driving challenge in the AMIGO 2001, the front half image was used, whereas in the AMIGO 2002, the full image, including the front and rear area, is being used. The rear image provides the passed route by which the self position is more accurately estimated. Fig. 14 shows the error between the center of lane and the self position given by the center of the camera in a co-ordinate system.

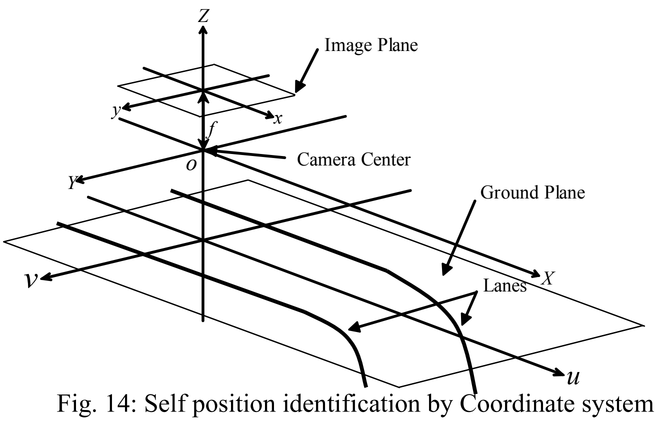
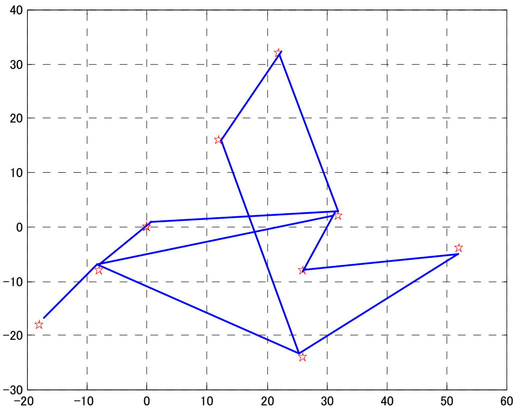


Fig. 14: Self position identification by Coordinate system

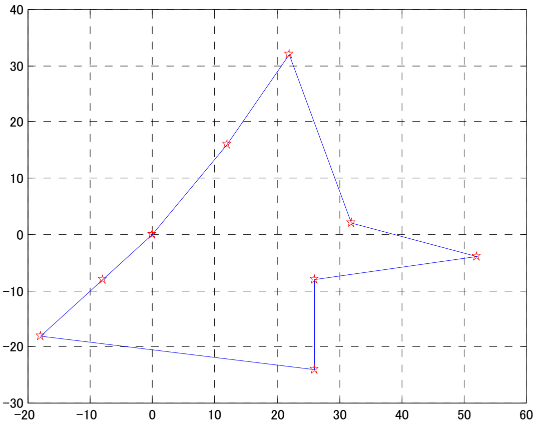
In the self position identification for the navigation challenge, two new improvements have been realized. These are (a) an accurate self position identification, and (b) finding the pass route.

For the accurate self position identification, the algorithm developed for the pass point detection was used. Furthermore, an optical fiber gyro was used for the first time to improve the accuracy of the self position identification. The gyro output signal and the signal from the DGPS were fused.

For finding the pass route, the problem was formulated as that of the *traveling salesman problem* and finds the optimal route, in the sense of the minimal traveling distance was found by the enumeration method. Fig.15 illustrates the principle of the traveling salesman problem.



(a) Under searching



(b) optimal route

Fig. 15: Traveling salesman problem

7. System design

Only the elements which are new or have been improved in the system design have been described. The system including all the necessary items is synthesized here. Fig.16 shows the total vehicle system synthesized.

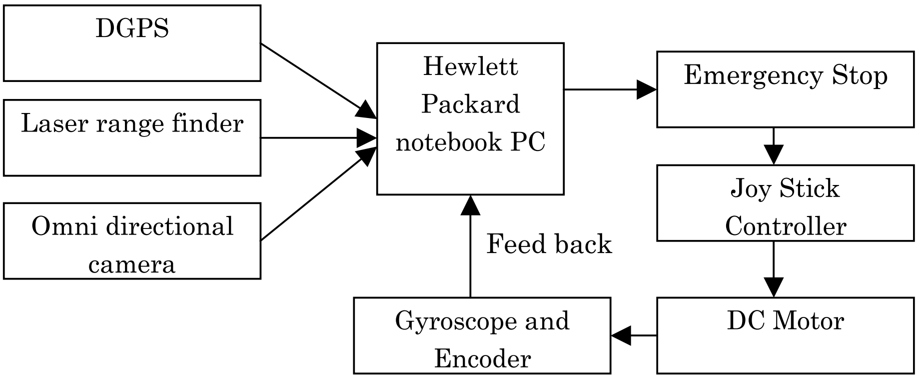


Fig. 16: Total vehicle system

8. Estimated cost

The cost to develop the AMIGO 2002 is summarized in Table 3. The most expensive item was the laser radar.

Table 3: Estimated cost

Cost and time of vehicle's design		
Item	Cost	Remarks
Electric Powered Wheel Chair (SUZUKI co.Ltd.)	$5,000	Base Vehicle
Personal Laptop Computer (Hewlett Packard)	$2,000	Intel Mobile PentiumⅢ 933MHz
CCD camera	$180	
Hyper Omni Directional Camera	$2,300	
Automobile Wireless Engine Starter	$160	
Transceiver	$180	
Laser Range Finder (SICK)	$8,500	
Electronics Parts	$480	
Mechanical Parts	$300	Frame Steel
Body Cover	$150	Aluminum Plate
Battery x 2	$480	Battery Life : 4 hours
Totals	$19,730	