12th Intelligent Ground Vehicle Competition

Design Competition Written Report

AMIGO2004

HOSEI UNIVERSITY

Signed **Date**

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1. Introduction

The autonomous vehicle, AMIGO 2002, successfully demonstrated autonomous movement and waypoint navigation at the 10th IGVC (Intelligent Ground Vehicle Competition). However, despite its impressive success, the AMIGO2002 showed a few shortcomings. It failed to arrive at its destination on the Autonomous Challenge course and missed one waypoint in the Navigation Challenge.

Since the outbreak of SARS in June 2003, we were unable to attend the 11th IGVC due to the recommendation of the University. In the fall, 13 students set out to redesign the AMIGO 2003, and the team was formally organized in March 2004. The task for the team is to complete all competitions.

We refer to our newly designed AMIGO as an "Intelligent Wheelchair", expressive of the vehicle's design concept. Figure 1 shows the final design image of the AMIGO.

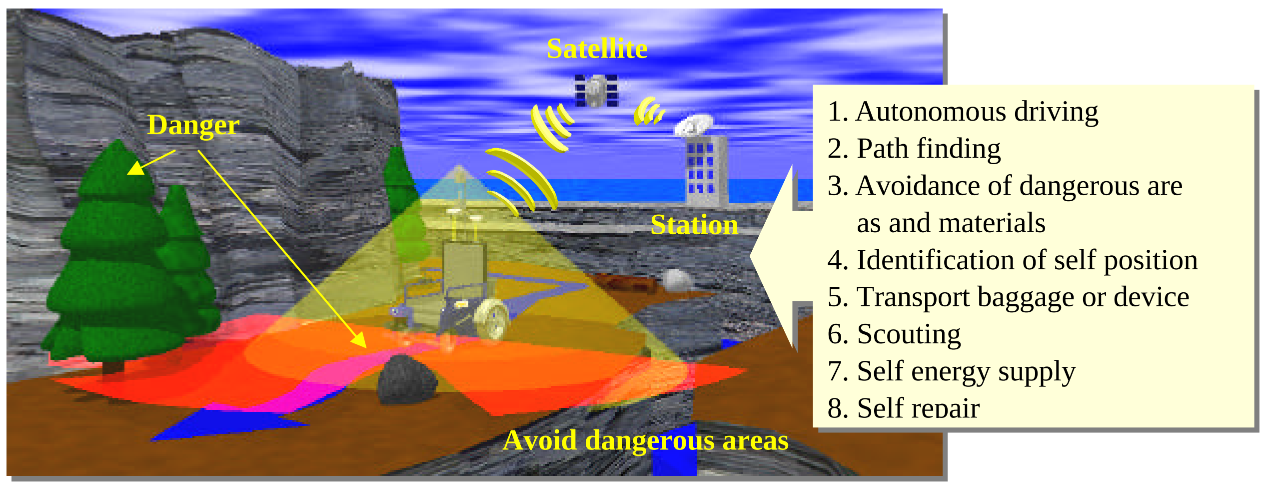


Figure 1: The image of AMIGO upon completion

This design feature, "smart sensing" which yields higher reliability and a simplified control scheme to ensure the highest degree of precision. In order to realize the smart sensing using a new design procedure, we use an efficient system integration to enhance the vehicle's reliability and durability. The most important improvement is a new design procedure using an object-oriented design approach based on UML (Unified Modeling Language). Many improvements and refinements were made to increase the performance of the AMIGO in the 2004 competition.

Table 1 lists the fundamental functions and sub-functions for each version of AMIGO from 2000 to 2004 shown with a circle ? in the column.

Table 1: Functions realized in the AMIGO 2000, 2001, 2002 and 2004, and the ultimate functions

Main Functions	Functions	Sub-functions		2000	2001	2002	2004	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	Option	?	Electrical
		Passability (Sensor fusion)						?	Electrical
	Vehicle mobility	Ramp angle (°)		8	8	7	8?	?	Mechanical
		Maximum speed (Km/hr)		6	6	4.5	6?	?	Mechanical
		Minimum gyration radius (m)		0.58	0.58	0.58	0.58	?	Mechanical
		Propulsion power (kgf)		15	15	15	15	?	Mechanical
	Vehicle control	Autonomous driving		?	?	?	? ?	?	Software
		Follow the leader			?	Option	? ?		Software
		Remote driving				Option	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
			dual hyper omni				?	?	Electrical
		Obstacle	Position	?	?	?	? ?	?	Software
			Name					?	Software
		Target	Position		?	?	? ?	?	Software
		DGPS				?	? ?	?	Electrical
		Environment information	Temperature			Option	Option	?	Electrical
			Humidity			Option	Option	?	Electrical
			Lightning condition	?	?	?	?	?	Electrical
			Acoustic signal			Option	Option	?	Electrical
		Position	Self position		?	?	? ?	?	Software
			Map construction			Option	Option		Software
			Passed route		?	?	? ?	?	Software
	Information transmission					?	?	?	Electrical
Transport Capacity	Weight (Kg)			10	10	100	100		Mechanical
	Size	Width (m)		-	-	0.55	0.55		Mechanical
		Depth (m)		-	-	0.65	0.65		Mechanical
		Height (m)		-	-	1.2	1.2		Mechanical
	Passenger transportable					?	?	?	Mechanical
Durability	Temperature (?)			60	60	60	60	?	Mechanical
	Humidity (%)			90	90	90	90	?	Mechanical
Environment Resistance	Wind			?	?	?	?	?	Mechanical
	Rain			?	?	?	?	?	Mechanical
	Sunshine protection				?	?	?	?	Mechanical
Safety function	Emergent automatic stop					Option	Option	?	Electrical
	Emergent manual remote stop		Wireless		?	?	? ?		Electrical
			Optical			Option	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.								

2. Design Process

2.1 Design Methods

The design process is a key element that frequently determines how effectively the engineering project can be organized and carried out. The "waterfall model" shown in Figure 2 is a well-known conventional model used during the design process. A problem regarding the design process using the waterfall model is that the process does not proceed to the next developmental stage until the current stage is completed. The process is sequential, thus the design is unified only when it arrives at the final stage.

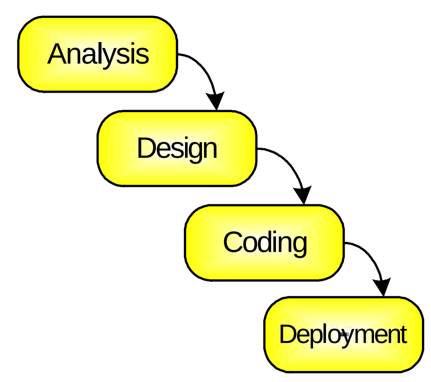


Figure 2: Waterfall model

In order for the AMIGO 2004 team to effectively utilize the unified architecture system, a new conceptual development processes GRAPPLE (Guidelines for Rapid Application Engineering) and UML were used, which consists of 5 segments connected by solid arrows as shown in Figure 3.

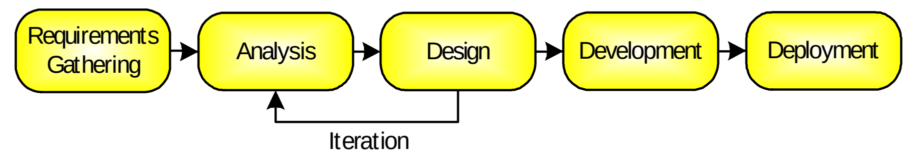


Figure 3: Design Process

GRAPPLE is a guideline for the design process. GRAPPLE provides only the framework of the development process, and can be used very effectively by means of UML in a specific context. The advantage of UML is that it has high expression ability and expansibility. Moreover, it can transmit information with only minimum explanation if the team members have a common understanding of UML even when changes, additions and revisions occur in design process. UML is an optimal notation system for carrying out communication smoothly between the developers.

The result in each segment is called a work-product. UML diagrams are work-products for these segments. The “Requirements Gathering” segment is the most important segment in the process shown in Figure 3. The construction of a desirable system is due to the understanding of the requirements. Sensor stability is required in this project. The “Analysis” segment probes the requirement, and an issue is grasped in more detail. Next, the “Design” segment is conceived based on the results of “Analysis”. Work is repeated in the feedback loop of the “Analysis” and “Design” segments until the design is completed. In the “Development” segment, the coding is done on basis of the work-product. Finally, in the “Deployment” segment, the system is installed in the appropriate hardware, and the test is carried out.

2.2 Team Organization

All of the team members in this chart are cross-listed in the team roster shown in Table 2. Figure 4 shows the team organization chart. We estimate 3000 man-hours were spent on this project. Responsibilities in each area, the work is carried out with GRAPPLE.

Table 2: Team Members

Name	Major	Year
Miwako Amemiya	System engineering	Graduate
Hiroki Iikura	System engineering	Graduate
Yosuke Ito	System engineering	Graduate
Mitsuhiro Imamura	System engineering	Graduate
Shinnosuke Yoshida	System engineering	Graduate
Raise Mori	System engineering	Graduate
Yoshihiro Miyazaki	System engineering	Graduate

Name	Major	Year
Takeyoshi Sasaki	System and Control engineering	Senior
Manabu Shimizu	System and Control engineering	Senior
Yuki Tarutoko	System and Control engineering	Senior
Sin Amano	System and Control engineering	Senior
Kazuyuki Kumakura	System and Control engineering	Senior
Kazuhisa Nagasawa	System and Control engineering	Senior

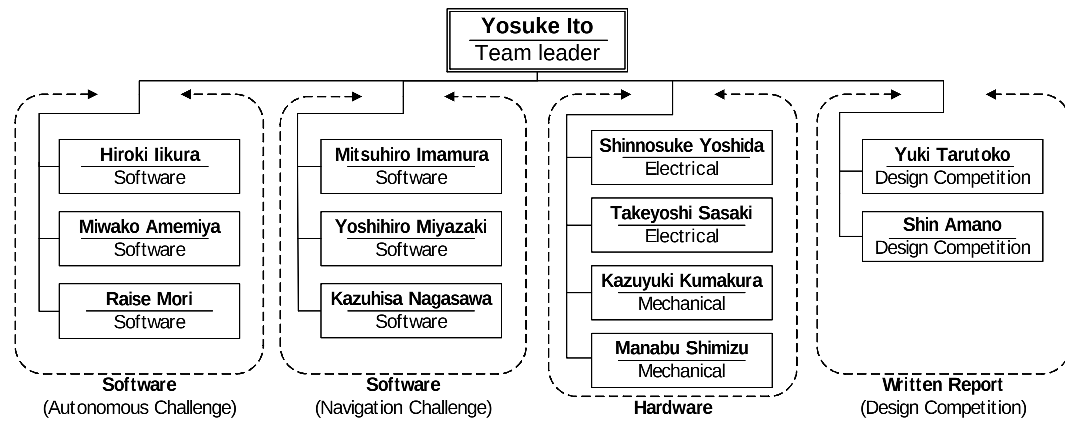


Figure 4: The team organizational chart

3. Dual Sensing Innovations

Through the "Analysis" segment, problems were identified in the previously designed vehicle. The main problem in the Autonomous Challenge was that it did not detect the lane with stabilized accuracy, and, errors often occurred in the self-position estimation in the Navigation Challenge. In order to solve these problems, we employ a dual sensor system for efficient sensor integration. Table.3 summarizes the sensors employed, and their functions.

Table 3: Sensor Integration

Main sensor	Alternative
Laser rangefinder	Dual omni-camera
Gyro+Speedometer	Dual Speedometer

1) Dual Omni-directional camera:

Since 1999 we have used an omni-directional camera situated on the top of the vehicle, which can scan a 360-degree scene at once, and is useful for vehicle navigation. Through "Analysis" and "Design" segment, we selected the strategy of two perpendicularly installed omni-directional cameras as shown in Figure 5. The ability to detect lanes is adjusted by the omni-directional camera's height. If we install the omni-directional camera at a high position, distant objects can be observed. If we install the camera at a low position, we can observe closer areas at higher resolution. The installation heights of the omni-directional cameras are very important. The advantages of perpendicularly dual omni-directional camera are, (1) its ability to measure distant obstacles without dead angles, and (2) the ability to capture an image even if one of the cameras looses its functionality. The distance measurement to obstacles only by laser range finder produces error due to the ruggedness of road surface. Thus, (3) it is possible to reduce measurement error by using (1). The dual omni-directional camera can enhance the whole system of a vehicle's reliability.

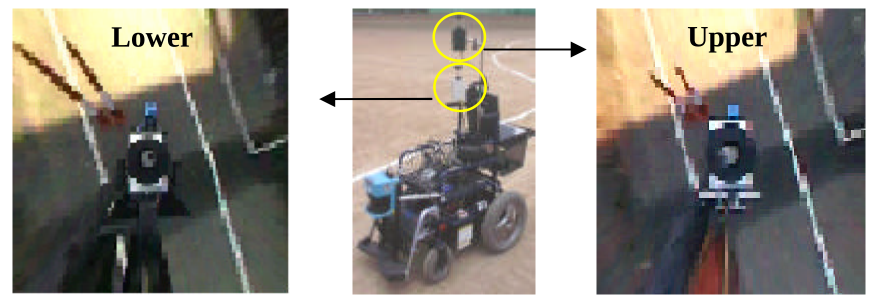


Figure 5: Dual omni-directional camera system

2) Dead-Reckoning by Dual Speedometer:

One of the key abilities necessary for success in the Autonomous Challenge is the accurate estimation of self-position as well as self-orientation. Previously, we used the integration of an optical gyroscope and contact-type speedometer to determine the relative coordinates of the vehicle. This year, in order to improve reliability and durability, we developed and installed two non-contact type speedometers in each driving wheel as shown in Figure 6. By using the developed dual speedometer, we can estimate the vehicle's self-position and orientation. In order to convert the sensor data to the global x-y coordinate system, following equations can be used:

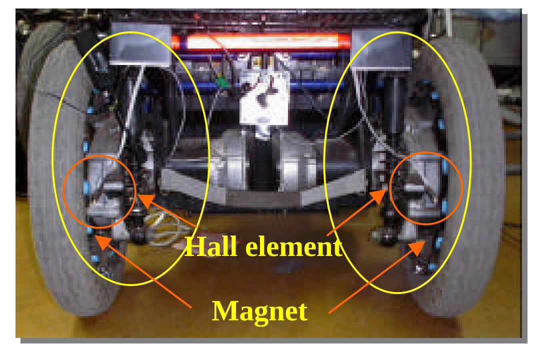


Figure 6: Dual Speedometer

(1) Optical fiber gyroscope + One speedometer

$$x(t_{n+1}) = x(t_n) + \sin q \cdot v \cdot \Delta t$$

$$y(t_{n+1}) = y(t_n) + \cos q \cdot v \cdot \Delta t \qquad v = \frac{v1 + v2}{2}$$

q = Angle data from optical fiber gyroscope

(2) Dual speedometer

$$x(t_{n+1}) = x(t_n) + \sin q \cdot v_{ds} \cdot \Delta t$$

$$y(t_{n+1}) = y(t_n) + \cos q \cdot v_{ds} \cdot \Delta t$$

$$q(t_{n+1}) = q(t_n) + \tan^{-1}\frac{(v1 - v2)t}{L}, q(0) = 0$$

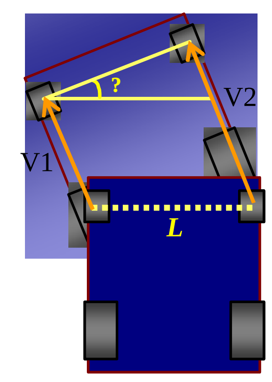


Figure 7: The conversion from speed to angle

Depending on the situation as well as the availability of the signals, we can choose one of the two schemes to determine the vehicle's self-position and orientation.

4. Mechanical Design

4.1 Vehicle Mobility

The base vehicle employed is an electrically powered four wheel chair, MC16P, which is made by SUZUKI, as used for AMIGO 2002.The only difference between the specifications of the current vehicle and those of the AMIGO 2002 is ramp angle ability due to the change of vehicle weight. The ramp angle of AMIGO2004 can climb 8 degrees. The maximum speed is same as that of the previous version, 6k/hr (3.76miles/hr). Figure 8 shows the base vehicle.

Figure 8: SUZUKI base vehicle

4.2 Driving Durability and Safety

AMIGO2004 is designed to carry a maximum load of 100kg, operates at is under 60 degrees C and under 90% humidity. Moreover, a 6-hour run on one charge is possible. The form which considered both the safety of people and the vehicle itself were developed.

Figure 9: The vehicle's form

5. Electrical Design

5.1 Sensor Integration

The new sensors incorporated in the AMIGO2004 include a laser range finder, two omni-directional cameras, a DGPS, a gyroscope, and two non-contact-type speedometers. An outline of its power supply system and the integration of the sensor are shown in Figure10.

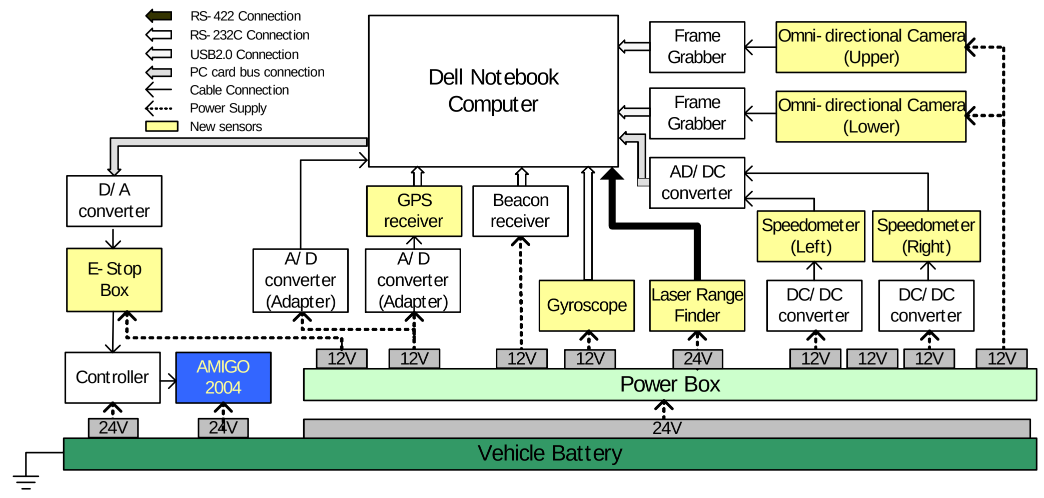


Figure 10: The outline of electrical systems

Video images are captured by an omni-directional camera using an image frame grabber. Then, the images are converted into a digital format to be sent to a notebook PC. The omni-directional camera communicates with the PC via a USB 2.0 connection. A laser range finder (Sick LMS-200) scans a 180° plane in 1/2° increments in front of the vehicle in order to detect obstacles. The laser range finder communicates with the PC via a high speed serial (RS-422 500kbps) connection. A differential GPS locates the vehicle's position in the latitude and longitude co-ordinates and communicates via a serial (RS-232C) connection to the PC. A gyroscope detects the vehicle's angle, which communicates with the PC via a serial (RS-232C) connection. The speedometer measures the vehicle's velocity at each wheel and communicates with the PC via a PC card ADC connection.

Table 4: Major improvements in data acquisition

	AMIGO2002	AMIGO2004	speed improvements
Frame grabber	USB1.0	USB2.0	400 times
Laser rangefinder	RS232C(19200bps)	RS422(500kbps)	25 times

5.2 Hardware Integration

Through "Analysis" and "Design", we made the following improvements to the previous vehicle:

(1) To simplify wiring and miniaturization, we produced junction boxes which integrate power supply circuit, speedometer and E-stop in one.

(2) All fuses in the electric circuits are replaced by poly-switches intended to protect the electric circuit from shorts. This poly-switch is a radial-leaded fuse which can be reset, opening circuits including batteries when the temperature and current abruptly increase, and can eliminate the labor of the exchange.

(3) 12V DC sockets are prepared along with a spare socket, in case an increase in sensors is needed.

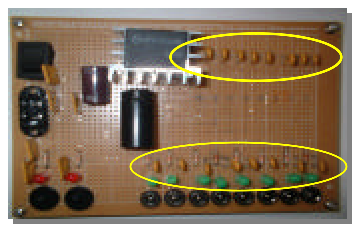


Figure 11: Poly-switches

5.3 Actuators and Signal Processing

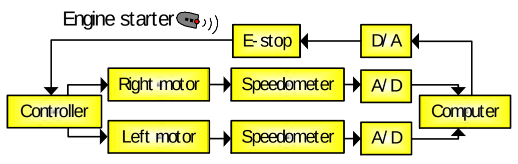
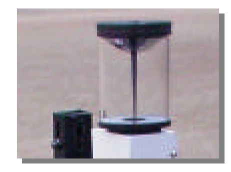


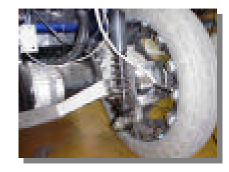
Figure 12: Signal processing

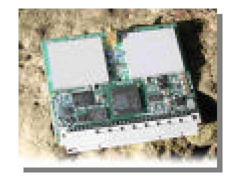
The power for AMIGO 2004 is supplied by 2x12V batteries. The control method for the vehicle was developed on the basis of the two-wheel steering model. Speed differences in each wheel determine the direction of movement. Each wheel speed is determined by targeting direction, the speed of vehicle, and sensing information. The signal flow is shown in Figure 12.

5.4 Sensors

The sensors incorporated in the AMIGO include the laser range finder (SICK LMS-200), the dual omni-directional camera which consists of two cameras (Sony CCD), the speedometer, the optical fiber gyro, and the Trimble Differential Global Positioning System (DGPS). The video images are captured using an USBcap2 and converted into a digital format and are sent to the software developed on *MATLAB* for image recognition. The laser range finder's average sampling interval is about 20 [msec], which is almost 25 times faster than which was used in the AMIGO 2002. Again, this information is sent to the software developed on *MATLAB* for range recognition. The accuracy of the speedometer is important for accurate dead-reckoning. Accuracy improved due to the development of a new non-contact magnetic speedometer called a magnetometer, which replaced the contact-type speedometer previously used. The magnetometer is set near the left and right wheels. In order to measure the rotation speed of the wheels, we put several magnets on the each wheel. The final sensor is the DGPS unit. The accuracy of the DGPS was also improved by employing a Trimble BD950 which was a dual-frequency version of the latest GPS receiver. With this array of sensors, we expect that the AMIGO 2004 will complete impressive runs in all competitions.







5.5 Computers

An industrial laptop PC driven by a 1.9 GHz Pentium 4 processor with 256 MB memory under Windows XP OS is used for the vehicle's navigation and control. This computer system and other components were selected for their inherent reliability.

6. Software Strategy

6.1 Introduction of MATLAB

MATLAB, developed by Mathworks, was selected as the base language to develop a new algorithm for the AMIGO for its further abilities such as concentration of algorithm development, seamless development, simulation, and actual executable coding.

The operation managers are newly rewritten in MATLAB 6.5 with a GUI (Graphic User Interface) function. Through GUI information, data regarding velocity, the location of detected obstacles and other parameter plots can be easily sent to the operator. Gathered data can be saved for later review in each simulation mode.

6.2 System Integration

A typical view of the operation manager for navigation is shown in Figure 13. Inputs to the operation manager come from the laser range finder, the dual omni-directional camera, the DGPS, the gyro and the dual speedometer. All information gathered is collected and translated into the self-position estimation and the optimum path-planning map, which graphically represents the course ahead of the vehicle.

Two important elements are required to control vehicle. One is recognition of the current position, and the other is path planning. Three elements are used to recognize the current position: "dead-reckoning", "latitude and longitude detection", and "lane detection". Obstacle detection is required for path planning. Traveling control is carried out based on these elements.

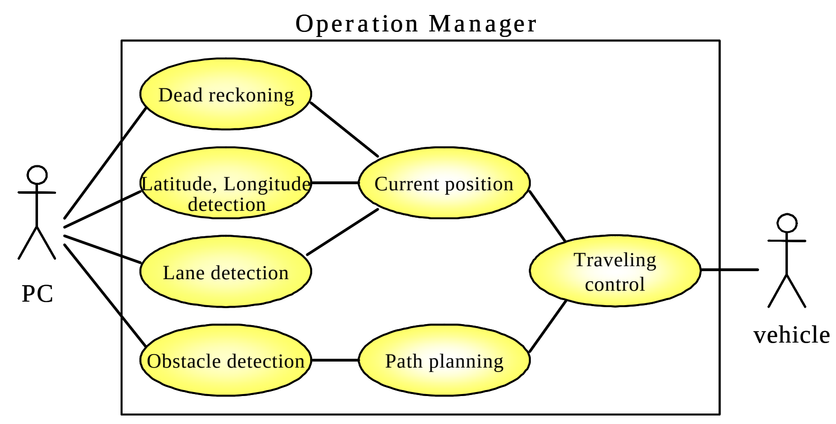


Figure 13: Operation manager for navigation

6.2.1 Autonomous Challenge

A typical view of the operation manager for the Autonomous Challenge is shown in Figure 14. Inputs to the operation manager come from the laser rangefinder and the two omni-directional cameras. All information collected is translated into a position error and vehicle view angle form lane, which can visually represent the current data processing situation.

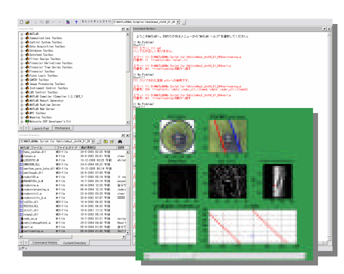


Figure 14: Main screen shot

6.2.1.1 Plan for Path following (both solid & dashed lines)

(1) Lane detection method

Lane detection is the most important recognition goal necessary for accurate autonomous movement. The problems that often occur in lane detection are often caused by sunshine and/or shadow effects in an outdoor environment. The discrimination of lane or obstacle has frequently failed, since in obstacles and lanes were painted by the same color, white. We developed a new process in order to overcome these problems that eliminates obstacle from the image, and improves the accuracy of lane detection by Hough transform. This process requires the real-time processing of the omni-directional image and data obtained from the laser rangefinder. It is possible to obtain the desirable detection result without asking solid or dashed lines. The work-product of "Design" is described in Figure 15 showing, the data-processing process and the elimination obstacle images.

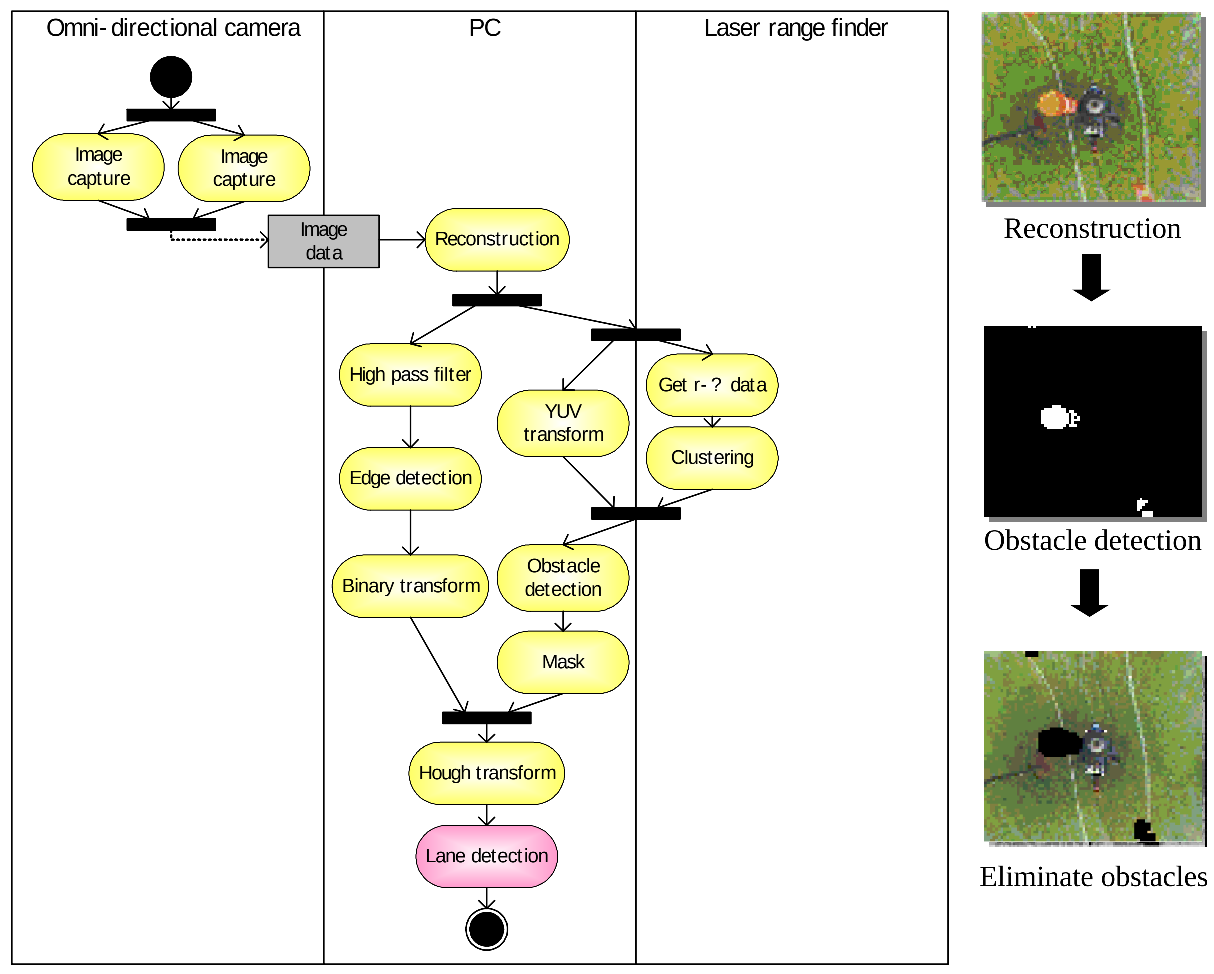
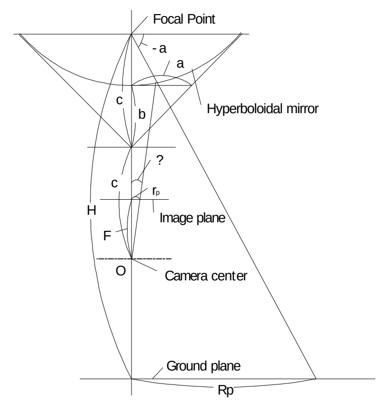


Figure 15: Process of Lane detection and processed images

(Step1) The omni-directional image is captured.

(Step2) The omni-directional image captured in Step 1 in relation to the plane true ground image is reconstructed by using the geometrical relation shown in Figure 16.



b, c: parameter which is determined by hyperboloid curve

H : distance from mirror to the ground

r_p : distance of image (input)

R_p : distance of ground plane (output)

Figure 16: The relationship between the omni-directional camera image and the true ground image

(Step3) Obstacles are detected based on the data from the range finder and the image in Step 2.

(Step4) Shadow effects are removed by the high pass image filtering of Step 3.

(Step5) The lane edge is detected by the 8x8 Laplacian filtering of the image in Step 4.

(Step6) The Hough transform is applied to the binary image obtained in Step 5.

(Step7) The lane position in relation to the vehicle's position is detected by applying the Hough transform to the image as described in Step 6.

(Step8) The vehicle is controlled based on position error and vehicle view angle obtained in Step 7.

(2) Pot-hole detection based on omni-directional images

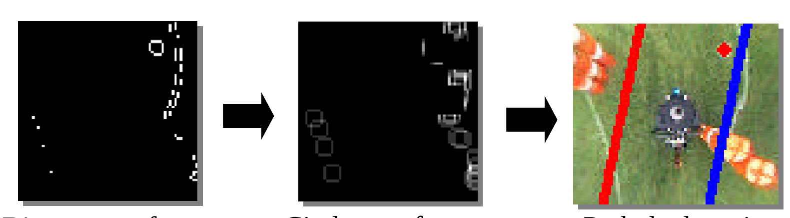
Pot-holes are detected by applying circle Hough transform in the image that presented in Figure 14 process binary images. The data-processing process and image of each step is shown below

(Step1) The omni-directional image is transformed into the projected ground image.

(Step2) Obstacles in image in Step1 are eliminated and the laser range profile data.

(Step3) The circle Hough transforms are applied to the binary image obtained in Step 2.

(Step4) The pot-hole is detected.



Binary transform   Circle transforms   Pothole detection

6.2.1.2 Plan for control decisions

The control scheme of the AMIGO 2004 is same as that of the AMIGO 2002. The major difference between the AMIGO 2002 and the AMIGO 2004 is their sensing capability and judging function, which yields stable autonomous movement. An enhanced pass-tracking algorithm leads to accurate navigation without tracking oscillation due to the feedback control. Figure 17 shows the pass-tracking algorithm. The algorithm yields the detection of self-position and angles at the present time and predicts its future position.

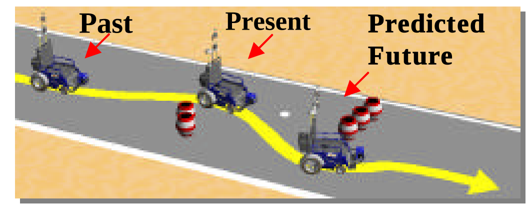


Figure 17: Pass-tracking algorithm

6.2.2 Navigation Challenge

We developed a new vehicle waypoint navigation method that can navigate autonomously in crowded outdoor areas or congested streets without colliding with obstacles. The proposed method consists of two functions. One is long-term path planning to plan optimal route for reach a goal. This function is based mainly on information obtained from the DGPS and the speedometer. The other is the short-term path planning which ensures safe movement without colliding with obstacles. Short-term planning temporarily changes the vehicle's course in order to avoid obstacles based mainly on information obtained from the laser rangefinder. The long-term planning or the short-term planning is selected according to the situation. Through "Analysis" and "Design", in order for the vehicle to navigate autonomously during the navigation challenge, we integrate the following four specific processes in so that AMIGO 2004 has more accurate self-position and self-orientation than AMIGO 2002.

1) Dead-Reckoning Process:

The estimation of the vehicle's relative position is based on a dead-reckoning method. The relative position co-ordinates can be calculated based on data obtained from the speedometer and the angular output of the gyroscope. The co-ordinates are defined as follows:

$$x_{dr}(k+1) = v(k) \cdot \Delta t \cdot \cos q_{dr}(k) + x_{dr}(k)$$

$$y_{dr}(k+1) = v(k) \cdot \Delta t \cdot \cos q_{dr}(k) + y_{dr}(k)$$

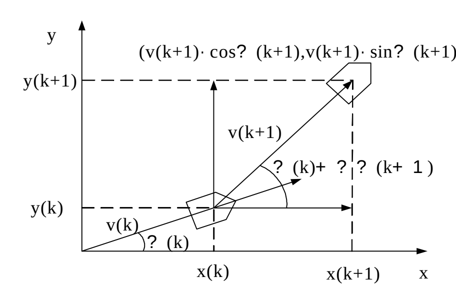


Figure18: Dead-Reckoning

2) DGPS Process:

This process is responsible for reading a list of waypoints by which the vehicle's current global position is estimated. Then the distance to the desired waypoints is calculated. When the vehicle receives the updated DGPS information every second, we check the vehicle's position co-ordinates. Positioning error was improved from 17feet to 5feet. The Kalman filtering technique is employed to cancel any measurement error.

3) Laser rangefinder:

The laser rangefinder detects the range profile of the vehicle's surroundings. It is used mainly to detect obstacles and it makes possible to avoid obstacles by this.

4) Kalman filtering process:

We use a method that fuses the DGPS and the signals of the local sensors by using a Kalman filter. The Kalman filter is a digital filter intended to predict or estimate a true value from discrete-time that involves errors. Information of sensors for the dead reckoning and Kalman filter were used to eliminate a system noise and an observation noise.

7. Analysis of Predicted Performance and Results

The result shows that the error was small, thus the filtered data was reliable. Since the speedometers, the DGPS, and the laser rangefinder were completely replaced and/or improved in relation to those used in the previous, the overall performance of the AMIGO 2004 is much higher quality than that of the AMIGO 2002. Theses differences are depicted in Table 5.

Table 5: Analysis

	AMIGO 2002	**AMIGO 2004**
Speed	6k/hr (3.76miles/hr)	6k/hr (3.76miles/hr)
Ramp climing ability	7 degrees	8 degrees
Reaction times	0.2 sec	0.2 sec
Battery life	4 hours	6 hours
Distance at which obstacles are detected	3m ~ 5m	3m ~ 8m
How the vehicle deals with dead ends, Traps,and potholes	Omni-directional camera, Laser range radar	Dual omni-directional camera, Laser range radar
Accuracy of arrival at navigation waypoints	0.5m to 1m	0.25m to 0.5m
Accuracy of headway and Lateral deviation maintenance	0.04m /10m ,± 4% 1.5 degrees	0.02m /10m ,± 2% 1.5 degrees
Remote emergency stop (E-Stop) capability	15m (Maximum)	100m (Maximum)

8. Other Design Considerations

8.1 Reliability, Durability and Safety

Data on the vehicle's reliability, durability and safety are contained in Table 7.

Table 7: vehicle's reliability, durability

	Improved sensors and functions			
Reliability	*Lane detection	DualOmni-directionalcamera Laser range finder	*Self-position and orientation	DualSpeedometer DGPS
Dulability	*DualSpeedometer *Vehicle's operating range *Power supply circuit			
Safety	*E-Stop capability *Vehicle's form			

These improvements increase the sensor stability, which was required in AMIGO2004.

8.2 Estimated Cost

The cost involved in the development of the AMIGO 2004 is summarized in Table 6.

Table 6: Cost

Cost and time of vehicle's design		
Item	Cost	Remarks
Electric Powered WheelChair (SUZUKI co.Lt	$5,000	Base Vehicle
PersonalLaptop Computer (Dell)	$2,000	InterlMobile Pentium 4 1.9GHz
GPS receiver	$10,000	Trimble BD950
CCD camera	$360	SONY CCD
Omni-DirectionalCamera	$4,600	
Automobile Wireless Engine Starter	$160	
Transceiver	$180	
Laser Range Finder	$8,500	SICK LMS-200
Electronics Parts	$480	
MechanicalParts	$300	Frame Steel
Body Cover	$150	Aluminum Plate
Battery	$480	
Total	**$32,210**	

9. Conclusion

This paper has described the design process, development, and construction of the "AMIGO 2004". In order to upgrade the redesigned AMIGO 2004 from the AMIGO 2002, we used GRAPPLE and UML design processes. The major improvement is the result of the employment of the dual omni-durational camera and dual speedometer, as well as enhancing the sensing speed. The design process has also facilitated further improvements in the stability of the software as well as the hardware. This system overcomes the weak points of the AMIGO 2002. The "AMIGO 2004" vehicle is a general product developed by applications from the fields of control engineering, electrical engineering, and computer science. With a maximum speed of 6 km/h, the vehicle can process images, detect and avoid obstacles, sensor fusion, navigate via waypoint, and plan paths. We did our best to develop the AMIGO2004.