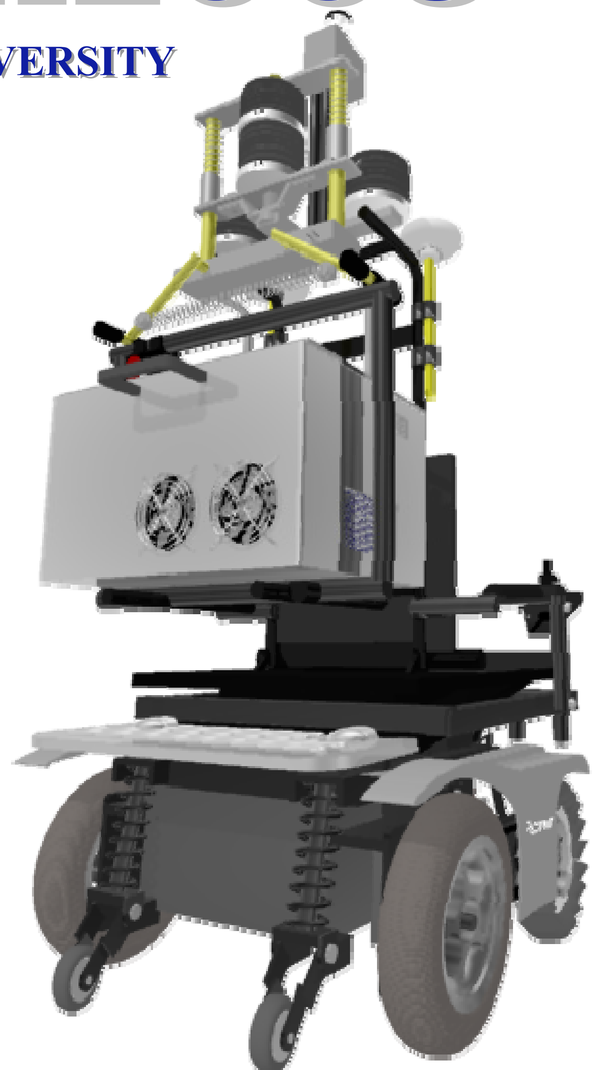
Omnix2008

HOSEI UNIVERSITY



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Faculty Advisor Statement

I hereby certify that the engineering design on Omnix2008 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 8, 2008

Associate Prof. Kazuyuki Kobayashi May 8, 2008.

1. Introduction

The Autonomous Robotics Lab (ARL) team of Hosei University is proud to present Omnix2008, featuring improved software and hardware, for the 16th annual Intelligent Ground Vehicle Competition (IGVC). Building upon previous successes, Omnix2008 has been redesigned to meet the IGVC 2008 rules with more intelligence and innovative features. We believe the new Omnix2008 will continue to build upon Hosei University's success in IGVC.

In Japan, society is aging faster than in any other country. Omnix was originally developed as a next-generation wheelchair for the elderly and/or handicapped persons as a universal intelligent vehicle. Universal intelligence requires safe driving through complex and irregular environmental situations. To achieve this, Omnix2008 employs the following sensing devices to control the wheelchair safely and intelligently:

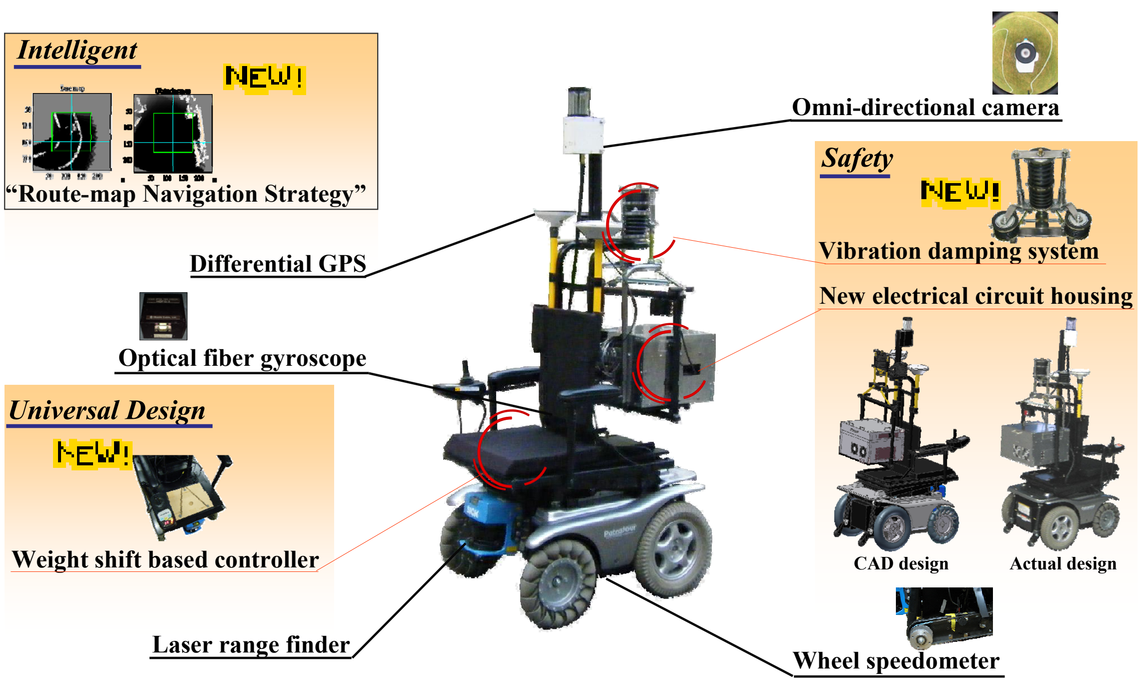


Figure 1 Omnix2008

The innovative features of Omnix2008 can be summarized as follows:

Software innovations	New simultaneous obstacle map building algorithm using both laser range finder and omni-directional camera New particle filter based waypoint navigation algorithm (improved accuracy of estimating self-position)
Hardware innovations	New stabilization mechanism for electrical circuit housing box with unique vibration absorber system Intuitive wheelchair control interface based on weight shift based controller.

In the rapidly aging society of Japan, the need for electric wheelchairs is increasing. However, because of the difficulty of operating electric wheelchairs, the number of operation-related accidents is also increasing. Most electric wheelchairs use a joystick as the control interface, but in order to use a joystick to control an electric wheelchair safely, substantial training is necessary. If we can develop an intuitive interface for controlling an electric wheelchair, we can reduce the training time.

Figure 2 Weight shift based controller

To improve operability and to prevent accidents, we developed a new weight shift based control interface system which is intuitive for electric wheelchair users. The intuitive operation is similar to riding a bicycle: to guide the bicycle to the right on a curved road, the rider shifts weight to the right side and/or turns the handles to the right.

2. Innovation

Last year's Omnix was excellent in almost every respect. It was carefully designed and fabricated for IGVC and we believed that it was the most rugged and reliable vehicle ever developed at Hosei University. Unfortunately, however, Omnix had several serious flaws caused by the frame:

1) Reduced reliability due to vibration of the electrical circuit housing
2) Stiffness due to the aluminum frame
3) Reduced stability due to the non-symmetrical weight distribution

To solve these three problems, we completely redesigned the frame structure and materials. We introduced a unique vibration damping system to improve the durability and reliability of the vehicle. This vibration damping system suspends the electrical circuit housing like a pendulum, and vibration is absorbed by three springs on the upper side. The springs expand and contract, and pendulum mechanics prevent the transmission of vibration to the electrical circuit housing. Additionally, to solve the stiffness problem of the vehicle, we employed a new frame for the vibration damping system. In Omnix2008, to improve the non-symmetrical weight distribution, the seat is positioned slightly further forward.

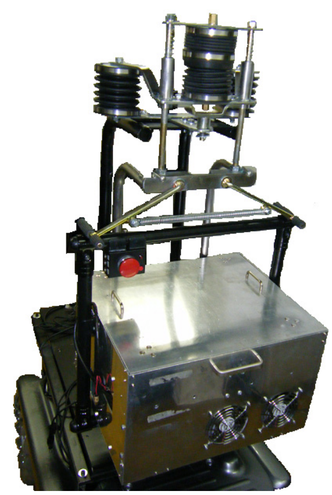
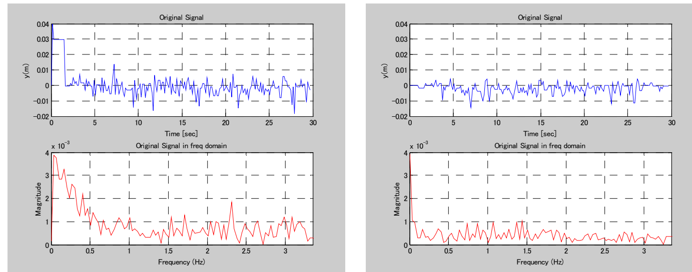


Figure 3 Vibration damping system

Figure 4 compares the performance of the new vibration damping system with last year's vehicle by using acceleration sensor when running on a bumpy road. Both demonstrations were carried out when traveling at a constant speed on a bumpy road. It is confirmed that the vibration damping system gradually reduces the vibration, thus improving the vehicle's reliability, durability, and stability on bumpy roads. The process of development of the vibration damping system is described in Section 4.2, "Chassis Modification".



(a) Omnix2007 (b) Omnix2008

Figure 4 Frequency spectrums of the sensor outputs

3. Design Process

3.1 Team Organization

The ARL2008 team now has a total of 13 members including 6 new members. Since ARL2007, a total of 12 members have been involved in the project, so we needed to reconsider the team organization and design process to match the team size. The new ARL2008 team was split into four sub-teams to effectively focus on specific areas of the design. Deadlines and roles were allocated appropriately to each member according to their respective design abilities. The team organizational chart, including Mechanical, Electrical, Software, and Design sub-teams, is shown in Figure 5.

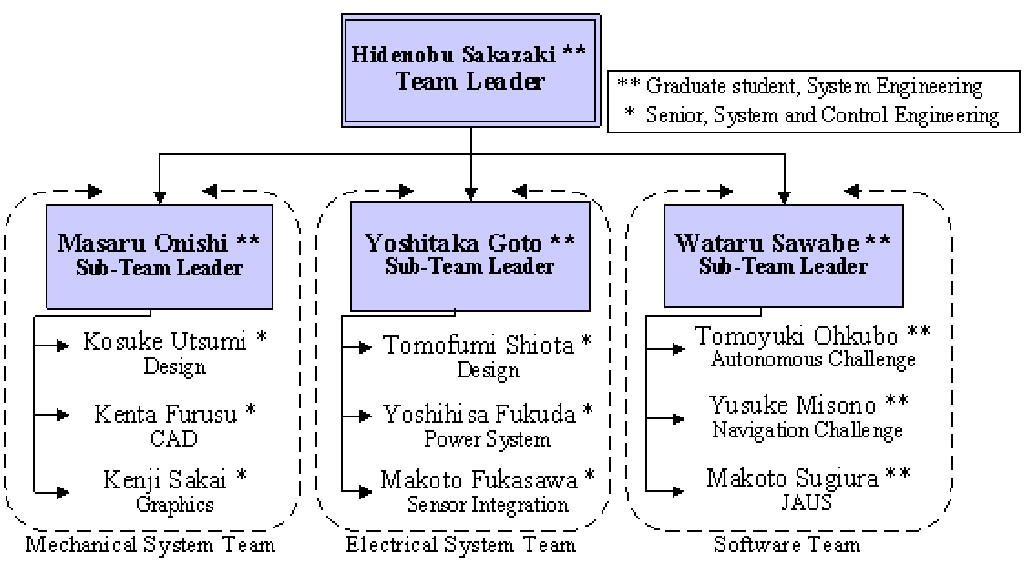


Figure5 Team organization

3.2 Model-based method

Because of the limited time and manpower for development, this year we chose a new design process called “model-based design process”. This process was originally developed by Mathworks and is used in various industries such as aerospace, defense, automotive, process control, and software development. Figure 6 shows the model-based method that we adopted in each development group for the modified IGVC project.

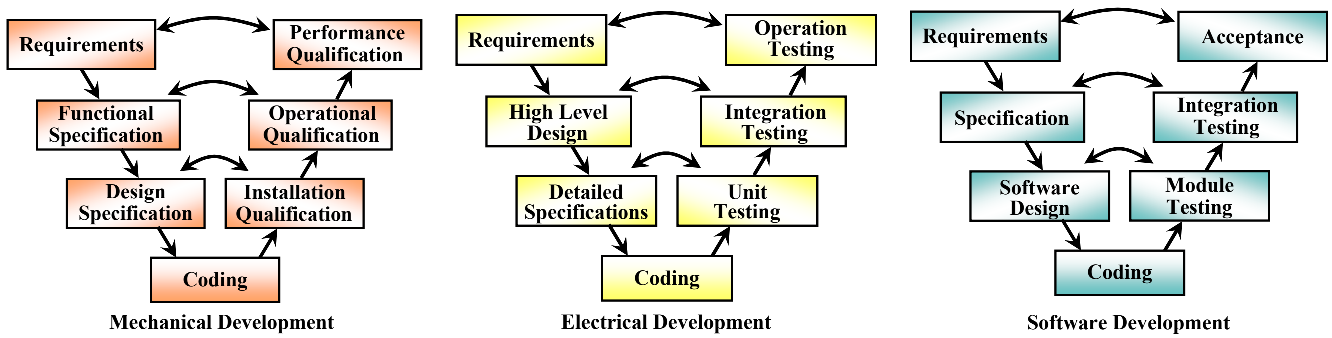


Figure 6 Model-based method for IGVC

In this figure, the left side is the design phase, and the right side is the verification phase. Each development process consistently uses visual data such as engineering drawings and system models. Additionally, to iterate the design process appropriately in the model-based method, team members from other design groups confirm whether the developed system satisfies the requirements, which improves the quality of the developed hardware and software.

Approximately 3600 man-hours were spent on this project. All works were carried out under the model-based method for the IGVC project.

4. Mechanical Design

Based on the model-based design process, the mechanical team designed the appearance and analyzed the strength of the elements using graphic software called Shade (e frontier) and the three-dimensional CAD software Autodesk Inventor (Autodesk). Shade was mainly used for designing the graphic appearance, while Inventor was used for the actual design of Omnix2008.

4.1 Base Vehicle

The base vehicle is shown in Figure 7. Named the Patrafour, it was made by Kanto Auto Works, Ltd. To ensure the mechanical reliability of the base vehicle since it had to be transported by air from Japan, we selected a commercially available electric wheelchair as the base vehicle.

Figure 7 Base vehicle

4.1.1 Actuators

The actuators to drive the vehicle are the two 24-volt DC motors originally mounted on the electric wheelchair. Each motor has a maximum rated power of 280 Watts for 30 minutes. Two 38-Ah 12-volt batteries supply power to each motor. A unique belt system is used to convey driving force from the rear motor to the front wheels. Thus, this system along with the omni-wheel design enables powerful zero-radius turning as a simple mechanism without a steering actuator.

4.1.2 Omni-wheels

Figure 8 shows the mechanism of the omni-wheels. Each omni-wheel consists of cups around the wheel. Each cup rotates laterally; thus, the omni-wheel can be driven laterally without a special steering control mechanism. When the wheelchair goes straight forward or backward, the cups do not rotate. When the rear wheels are instructed to turn, the cups rotate laterally and the wheelchair turns smoothly.

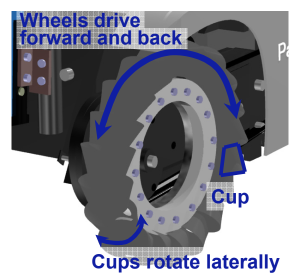


Figure 8 Omni wheels

4.2 Chassis Modification

To minimize vibration in the electrical circuit housing box, the mechanical team developed a new vibration damping system, which dramatically improves reliability by suspending the housing box like a pendulum. The vibration damping system consists of one strong spring and two air springs with a unique rubber accordion. The air springs are adjusted by two steel plates at the top and bottom of the rubber accordion.

Figure 9 Air spring

To prevent lateral vibration, the three damping springs are arranged as shown in Figure 10. The front two air springs attenuate backward, forward, and rotational vibration and the rear single strong air spring attenuates up-and-down vibration.

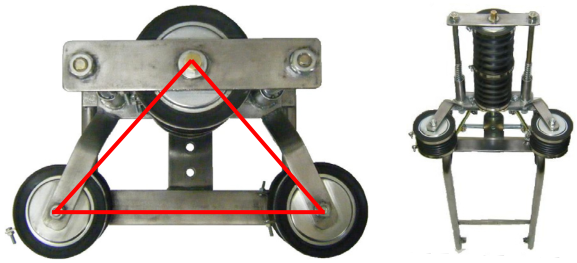


Figure 10 Three damping springs

Because the electrical circuit housing box is suspended like a pendulum, its center of gravity should be in the center. To achieve this, we rearranged the weight layouts of the electrical components and sensors to move the center of gravity near to the center of the box. Figure 11 shows the inside of the rearranged electrical circuit housing box.

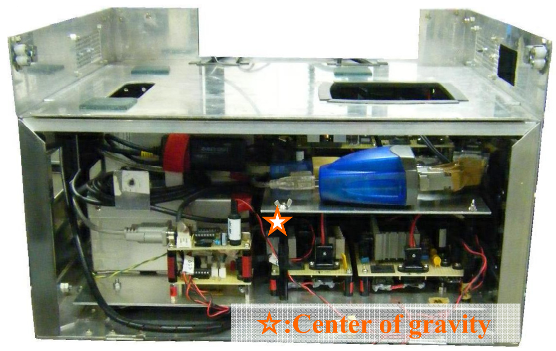


Figure 11 New electrical circuit housing

5. Electrical Design

Based on discussions in electrical team design meetings, we analyzed the requirements for Omnix2008 and the problems in last year’s vehicle by using the model-based method. We gathered information about last year’s problems, and redesigned the electrical circuits through simulation to improve the reliability and safety of the vehicle. In addition, to prevent human errors while connecting the electrical wiring, we used a different type of jack for each voltage so that the jacks could not be connected with the wrong voltage supply.

5.1 Power System

In accordance with model-based design, we analyzed last year’s power system by using "PSpice" to identify problems in the power system. As a result, we found that last year's power system was not able to supply a stable voltage when using all sensors at startup. To solve this problem, we redesigned the power supply circuit. Figure 12 compares the simulated current and voltage between the new power system and last year’s power system. The new power system improves the power conversion efficiency from 80% to 90%, thus improving the current supply with almost the same circuit size.

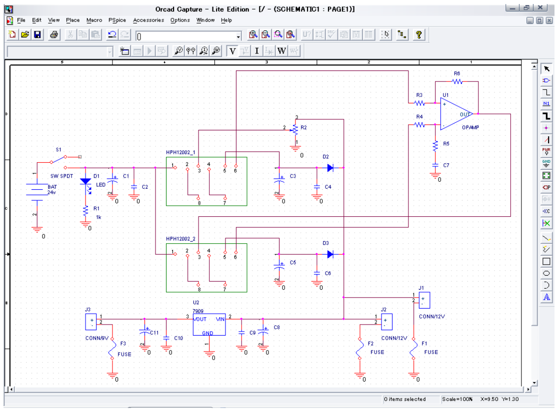
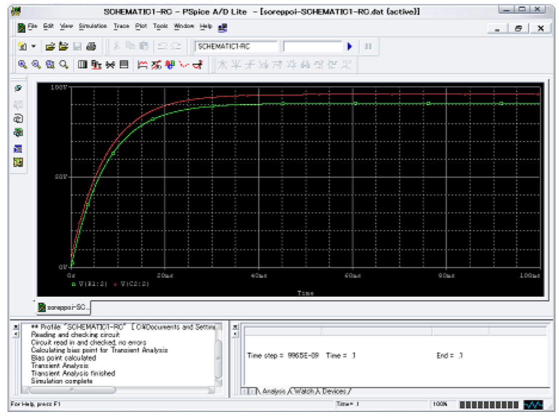
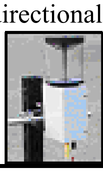
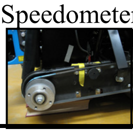
 

Figure 12 Current and voltage simulation results

5.2 Sensors and Computers

Six sensors are used in Omnix2008, as described in Table 1. Software in the laptop computer determines the navigation route in an off-line manner and generates on-line control signals from data obtained by the six sensors. The laptop computer has a 1.8-GHz Intel Core2 Duo processor with 1 GB of memory, running Microsoft Windows XP Professional.

Table 1 Summary of sensors

Sensor	Function
Omni-directional camera 	**Environment Sensing** An omni-directional camera (SONY CCD EVI-370 with hyperbolic mirror) captures 360-degree images with a hyperbolic mirror. Video frame images are grabbed using a video capture USB card (IODATA USB-CAP2), converted into digital format using VCAPG2, and sent to the software programmed by MATLAB for image recognition.
DGPS 	**Self-localization** A differential global positioning system (Trimble BD950) provides latitude and longitude information of the vehicle's position. The D-GPS is based on the dual-frequency GPS, and provides latitude and longitude information of the vehicle's position.
Digital Magnetic Compass 	**Vehicle Heading** A digital magnetic compass (Honeywell True Point) estimates the accurate absolute self-orientation of the vehicle.
Gyro 	**Angle Detection** An optical fiber gyro (Hitachi HOFG-3) detects the relative orientation of the vehicle.
Speedometer 	**Speed Detection** A 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 a PIC microcontroller.
Laser rangefinder 	**Obstacle Detection** The laser rangefinder gets information on obstacles. The average sampling interval of the laser rangefinder (SICK LMS-200) is about 20 ms, and this information is sent to MATLAB through an RS422 interface for range profile recognition.

5.3 System Integration

All sensors and the laptop PC need a power supply. They gather course environment information, analyze the collected data and decide the vehicle's path. Figure 13 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 laser rangefinder scans the front plane of the vehicle with 1/2 degree resolution in the 180-degree range. The laser rangefinder signal is transmitted to the PC via a high-speed 500-kbps serial RS-422 cable to a USB converter. A 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 speedometer and digital magnetic compass are connected to the PC via USB.

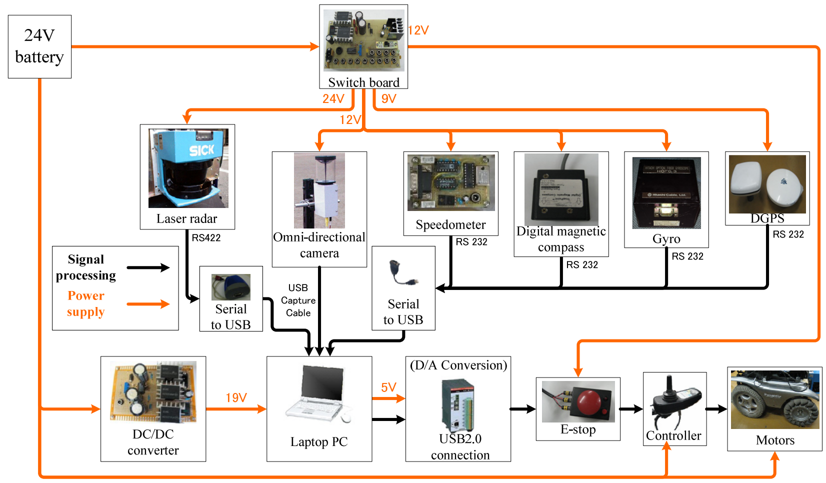


Figure 13 Power supply and sensor integration

6. Joint Architecture for Unmanned System

Last year, we succeeded in implementing JAUS level 2 and satisfying the JAUS requirements for the JAUS Challenge. This year, we attempted to upgrade from level 2 to level 3. Figure 14 shows the new JAUS system. In the level 3 JAUS system, to demonstrate that vehicles satisfy the Navigation Challenge waypoints rules, we redesigned the JAUS control system as a distributed function based system.

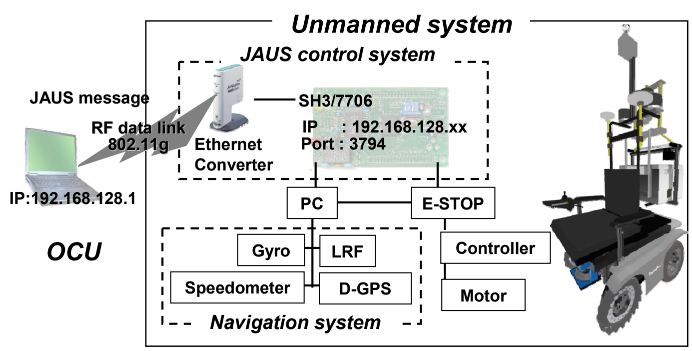
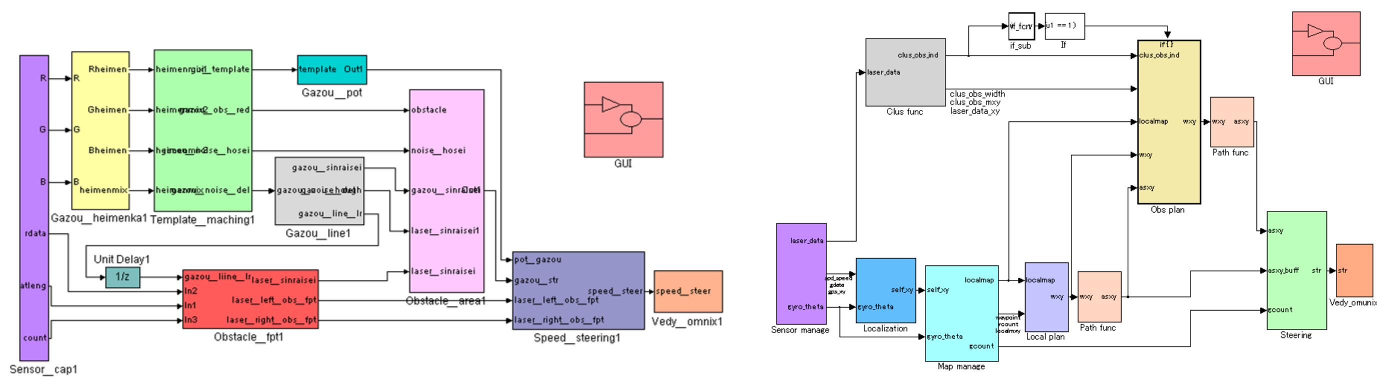


Figure 14 New JAUS system

In the new proposed JAUS control system, the JAUS message commands from the operator control unit (OCU) via an RF data link are received by a wireless Ethernet converter (BUFFALO WLI-TX1-G54) and the data is processed by a microcontroller board with Ethernet (RENESAS SH3/SH7706). To this JAUS control system, a D-GPS, speedometer, gyroscope and LRF have been newly added to satisfy autonomous running mode in the level 3 JAUS system.

7. Software Strategy

The software team used Simulink, which is a visual-based language, as both the simulation and implementation language. Because we developed the software based on the model-based design process, the efficiency of software development was greatly improved. Moreover, Simulink facilitated communication among the teams for development.



(a) Autonomous Challenge (b) Navigation Challenge

Figure 15 Software models by using Simulink

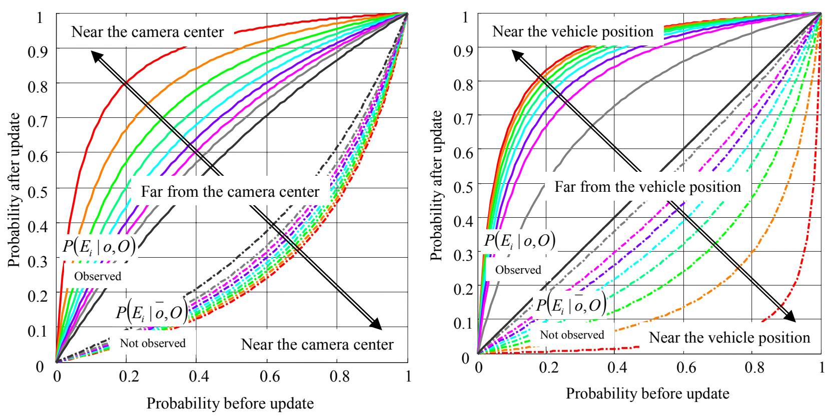
7.1 Autonomous Challenge

Last year, Omnix2007 could not complete the complex course of the Autonomous Challenge. We identified and analyzed the problems of last year's vehicle, and found the following disadvantage of the vision-based two-phased strategy algorithm implemented last year:

Disadvantage	It is difficult to detect white lanes when strong sunlight directly enters the omni-directional camera. Last year, we did not take into account the complex arrangement of the obstacles area.

To solve these problems, we devised a new algorithm called "route-map navigation strategy". In this strategy, the new algorithm generates the route map in real time by integrating the sensor information of the time series efficiency. The route map is generated based on the existence probability grid map for obstacles and the existence probability grid map for white-lanes. The former map builds the obstacle information from LRF, while the latter map builds the white-lane information from the omni-directional camera.

We gathered information of the self-position and direction of the vehicle by gyro and speedometer, and gathered observational information (obstacles and white-lanes) by LRF and omni-directional camera. We consider the probability of the existence of both obstacles and white-lanes in each grid map. The proposed route map can be built incrementally by updating depending on the existence of environmental probability. Figure 16 (a) shows an example of the obstacle grid map and Figure 16 (b) shows that of the white-lanes grid map. Both grid maps are environmental grid maps. The probability of obstacle existence is determined by LRF as shown in Figure 16 (a). The probability of white-lanes existence is determined by the omni-directional camera as shown in Figure 16 (b). We use a different probability curve depending on the characteristics of each sensor. Figure 17 is an example of the environmental probability map. By adopting this strategy, Omnix2008 was made more intelligent.



(a) lane map

(b) obstacles map

Figure 16 Grid update model

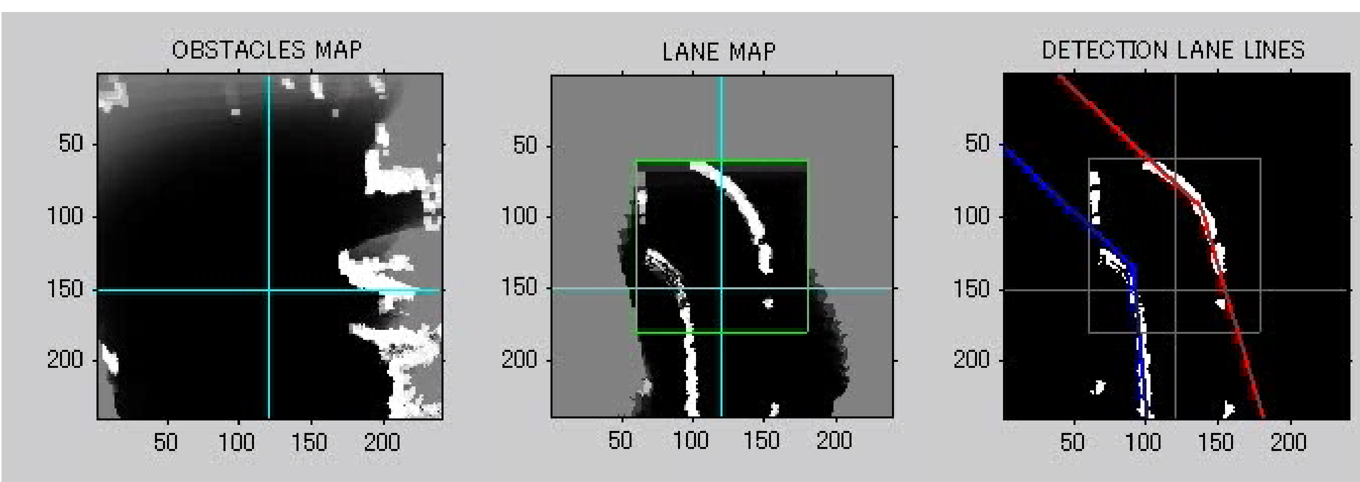
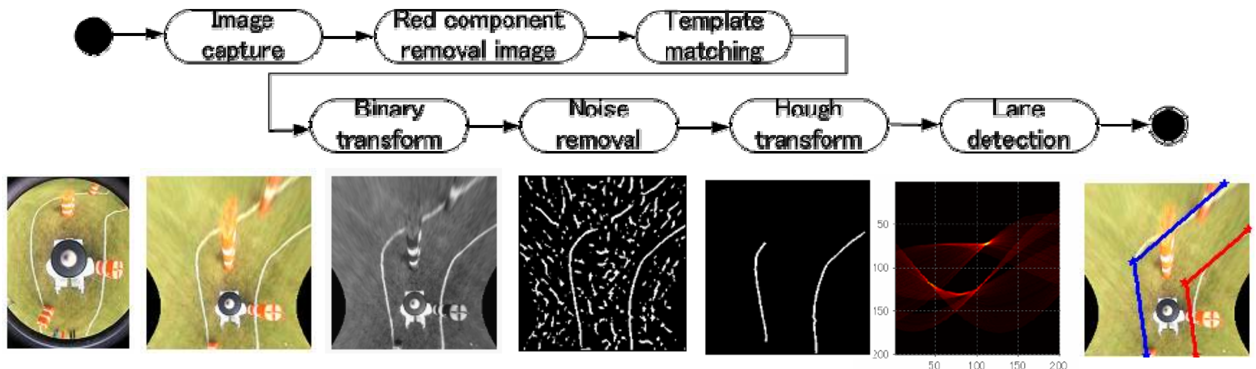


Figure 17 Environmental probability map

7.1.1Lane 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. 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 18 shows the lane detection activity diagram and images grabbed by the omni-directional camera.



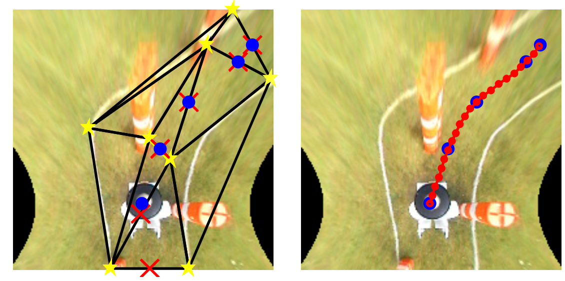
(a) Original image (b) Reconstructed image (c) Red component removal (d) Template matching (e) Noise removal image (f) Hough transform (g) Lane detection

Figure18 Lane detection

Figure 18 (b) shows the reconstructed ground image. After the reconstruction, we convert an RGB color image to a grayscale image using only the B component. Figure 18 (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 18 (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 18 (e) shows the logically filtered image. Finally, the Hough transform, 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 which correspond to multiple peaks in the ρ−θ Hough domain. Thus, if multiple peaks are detected in the ρ−θ Hough domain, the lane curve is approximated by piece-wise linear segments. Implementing such sophisticated lane-detection algorithms, Omnix2007 proved reliable at detecting lanes even in cases when the lines were hidden by obstacles or drawn only by dashed lines. Figure 18 (f) shows the plots in the Hough domain and Figure 18 (g) shows the detected lane. The lane lines detected can be stored as sets of starting points and end points and line-crossing points.

7.1.2 Path generation

To generate an appropriate path, it is necessary to assign path points and the direction of movement along the path. The path generation algorithm is based on the Delaunay triangulation method. The triangle in the method is determined by the lane lines and the edge of the obstacle area detected by both the omni-directional camera and the laser rangefinder. The lane-line area consists only of the features of the lane lines. The path direction can be easily defined by middle points on the Delaunay edge, which is connected by the left and right sides of the lane-line feature points. The obstacle area consists of several obstacle points as well as the features of the lane lines. Depending on the position of the obstacles and the lane lines, an allowable navigating direction can be determined and indicated. From the allowable navigating direction, a new Delaunay triangle can be generated according to the positions of the lane lines and obstacles. Modified path points are then generated based on the new Delaunay triangle. The modified path points generated by the algorithm thus described are shown in Figure 19 (a). After the path point generation, cubic-spline interpolation is applied to paths given by the sequence of path points. Figure 19 (b) shows a path generated by the proposed method.



(a) Path point generation (b) Path generation

Figure 19 Result of path generation

7.2 Navigation Challenge

Last year, we totally rewrote the autonomous navigation algorithm developed based on the Simultaneous Localization And Map-building (SLAM) technique by using detected obstacle positions, and Omnix2007 won second prize in the 2007 Navigation Challenge. However, Omnix2007 could not complete the course when the maximum speed parameters were set. Because of the sensor reliability of the speedometer, when the vehicle runs at maximum speed, the signal from the speedometer is often noisy and unreliable values are observed that may be caused by tires slipping on a bumpy course.

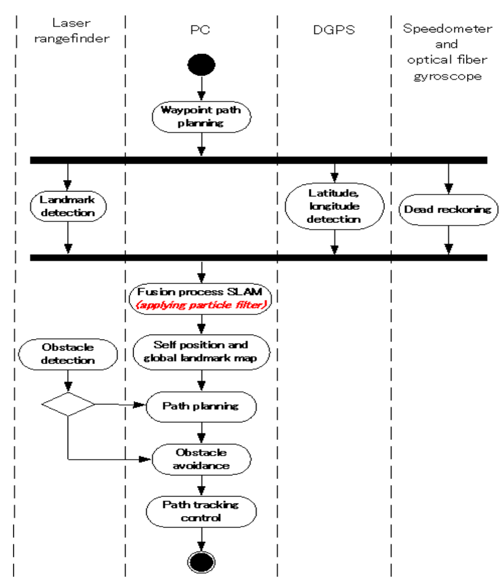


Figure 20 Activity diagram of proposed new SLAM method

The reliability of the speedometer is directly affected by the accuracy of route navigation by using the Kalman filter. This year, we took into account speedometer reliability, and newly implemented the particle filter. The particle filter can represent discrete and continuous states simultaneously and represent any distribution (including non-linear data). Figure 20 shows the particle based new SLAM algorithm and Figure 21 compares the running result when the maximum speed parameters are set, for both the Kalman filter and the particle filter. Omnix2008 can accurately estimate self-localization by using the new particle based SLAM algorithm. We believe that Omnix2008 will offer more reliable and stable performance in the navigation challenge than last year's Omnix2007.

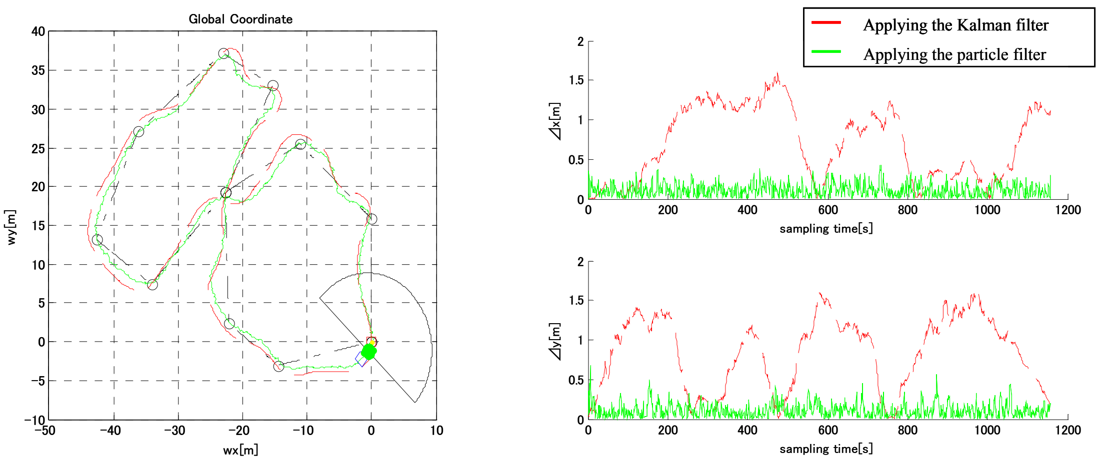


Figure 21 Comparison of running results

8. Analysis of Predicted Performance and Results

Most performance and quality aspects of Omnix2008 are much higher than those of Omnix2007. Comparisons of field test results with predicted parameters and Omnix2007 are shown in Table 2. The weight distribution of Omnix2008 has been improved, and consequently acceleration and maximum speed performance were raised.

Table 2 Comparison of test results and predicted parameters

Performance Measure	Competition	Omnix2007	Prediction	Results
Maximum speed		4.7 mph (7.5 km/h)	5.0 mph (8 km/h)	**4.8 mph (7.7 km/h)**
Maximum swing speed		130 deg/sec	140 deg/sec	134 deg/sec
Ramp climbing ability		9.1 degree incline	9.5 degree incline	9.1 degree incline
Reaction times	Autonomous	0.12 to 028 seconds	0.15 seconds	0.15 to 029 seconds
	Navigation	0.18 to 0.22 seconds	0.20 seconds	0.20 to 0.25 seconds
Battery life		4.25 hours	2.92 hours(at maximum power)	**4.31 hours**
Obstacle detection distance	Autonomous	4.5 meters (Omni-directional camera and LRF) [maximam]		
	Navigation	10 meters (Omni-directional camera and LRF) [maximum]		
Traps and potholes	Autonomous	Detection of obstacles: (LRF) Detection of potholes: template matching (Omni-directional camera)		
	Navigation	Detection of obstacles: (LRF)		
Dead ends		The vehicle performs a near zero radius turn until a suitable path is found		
Waypoint accuracy		±0.30 m (DGPS in use)	±0.12 m (DGPS in use)	**±0.15 m (DGPS in use)**
		±0.80 m (DGPS not in use)	±0.50 m (DGPS not in use)	**±0.62 m (DGPS not in use)**
Remote emergency stop capability		100 meters [maximum]	250 meters [maximum]	100 meters [maximum]

8.1 Reaction Time

In the navigation challenge, by using the new SLAM method, the reaction time slowed from 0.18 s to 0.20 s, and the reaction distance also improved to 0.43 m. However, since the laser rangefinder is able to search within a 10-m area, there will be no problems for safe navigation.

In the emergency avoidance mode, the reaction time will drop to 0.06 s and will stop within 0.11 m to make a zero-radius turn.

8.2 Run Time

Table 3 details the power requirements for all the components on the vehicle.

Table 3 Estimates of power consumption

Component	Nominal Operating Voltage (VDC)	Maximum Current (Amps)	Power (watts)
DC motors mounted on the electric wheelchair	24.00	7.50	180.00
Wireless Ethernet converter	5.00	0.82	4.10
Laptop computer	19.50	3.34	65.13
CCD camera	12.00	0.31	3.70
Laser rangefinder	24.00	1.46	34.99
GPS receiver	9.00	0.11	1.00
DGPS beacon antenna	12.00	0.07	0.78
Digital magnetic compass	5.00	0.05	0.27
E-stop	12.00	0.03	0.36
Speedometer	5.00	0.05	0.25
Optical fiber gyroscope	12.00	0.50	6.00
		Total	**296.58**

From the calculated maximum power, a conservative estimate of Omnix2008's driving time is approximately 3 hours. In addition, the results of experiments suggest that Omnix2008 can be operated in manual mode for over 4 hours.

8.3 Obstacle Detection Distance

The omni-directional image (4.5 m front, 1.5 m behind and 3 m to the side) is grabbed by the omni-directional camera and the data is used to detect lanes and obstacles. In the autonomous challenge, the vehicle detects obstacles in 180 degrees within 4.5 m in front by using the laser rangefinder. In the navigation challenge, the vehicle detects obstacles within 10 m. Obstacles found further than 3 m are avoided smoothly. If it detects an obstacle within 3 m, the vehicle stops immediately, makes a zero-radius turn and finds a safe route.

8.4 Dead Ends, Traps, and Potholes

The vehicle detects potholes using shape data. If the vehicle faces a dead end, it will find a suitable route by making a zero-radius turn.

8.5 Accuracy of Arrival at Navigation Waypoints

With the new SLAM method, the vehicle can navigate with an error of less than ±15 cm. In case the vehicle cannot use GPS data, the error is within ±62 cm.

9. Safety, Durability and Reliability

9.1 Safety

For safety, we redesigned Omnix2008 from the two perspectives of mechanical and electrical designs.

In the mechanical design, to protect the fragile electrical circuit housing box, we introduced a new vibration damping system. In addition, we rearranged the electrical circuit housing to the vehicle's center of gravity to stabilize the vehicle.

In the electrical design, we designed two different types of emergency stop (E-stop) to follow the rules of IGVC. Omnix2008 has a remote controlled E-stop and vehicle mounted E-stop push-button. The signal of the remote controlled E-stop is transmitted by an automobile wireless engine starter. It can transmit signals in a wide range with a maximum distance of about 100 m (330 feet). In addition, the E-stop push-button is located on the mast of the vehicle so that it can be found and accessed easily.

9.2 Durability

The vibration damping system is useful for not only the safety but also the durability of the developed system. This improvement reduces severe vibration of the electrical circuit housing and prevents the internal electrical circuit from breaking down. In addition, the electrical energy was increased by improving the DC/DC converter. The load on the motor was reduced by these two improvements, and hence the load on the battery was reduced and the life of the battery increased by 10%. We thus succeeded in improving vehicle operation time.

9.3 Reliability

To improve the reliability of the vehicle, we developed a new algorithm called "route-map navigation strategy". The new algorithm generates the route map in real time by integrating the sensor information of the time series efficiency. As a result, Omnix2008 can run smoothly in irregular environmental situations.

10 Cost

The costs involved in developing Omnix2008 are summarized in Table 4.

Table 4 Estimated costs for development of Omnix2008

Components	Remarks	Retail Cost	Team Cost
GPS receiver *	TRIMBLE (BD950)	$10,000	$0
Laser rangefinder *	SICK (LMS-200)	$8,500	$0
Optical fiber gyroscope *	HITACHI (HOFG-3)	$5,800	$0
Electric powered wheelchair *	KANTO AUTO WORKS (Patrafour)	$5,310	$0
Hyperbolic mirror *		$4,600	$0
Laptop personal computer	HP (Intel Core2duo 1.8GHz)	$2,000	$2,000
Head mount display *	SHIMADZU (Data Glass 2/A)	$1,620	$0
Digital magnetic compass *	HONEYWELL (True Point)	$1,575	$0
Isolated analog output module for USB *	CONTEC (DAI12-4(USB)GY)	$660	$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 (WLI-TX1-G54)	$100	$0
Microcontroller *	H8, PIC and PSoC	$60	$0
Power inverter (DC 24V to AC 100V) *	CELLSTAR (HG-150/24V)	$35	$0
Rotary encoders *	IWATSU	$34	$0
Infrared thermography camera *		$6,815	$0
Brushless DC motor and gearhead *		$1,704	$0
Mechanical parts		$776	$776
Electronics parts		$305	$305
Totals		**$50,537**	**$3,081**

11 Conclusion

This report has described the design process, development, and construction of Omnix2008. With improved software and hardware, Omnix2008 has the most intelligence and innovative features ever. Despite the limited period for development, the model-based method approach facilitated smooth communications between team members. The new design process also facilitated the software development as well as hardware integration. We believe that Omnix2008 will perform well in IGVC2008.