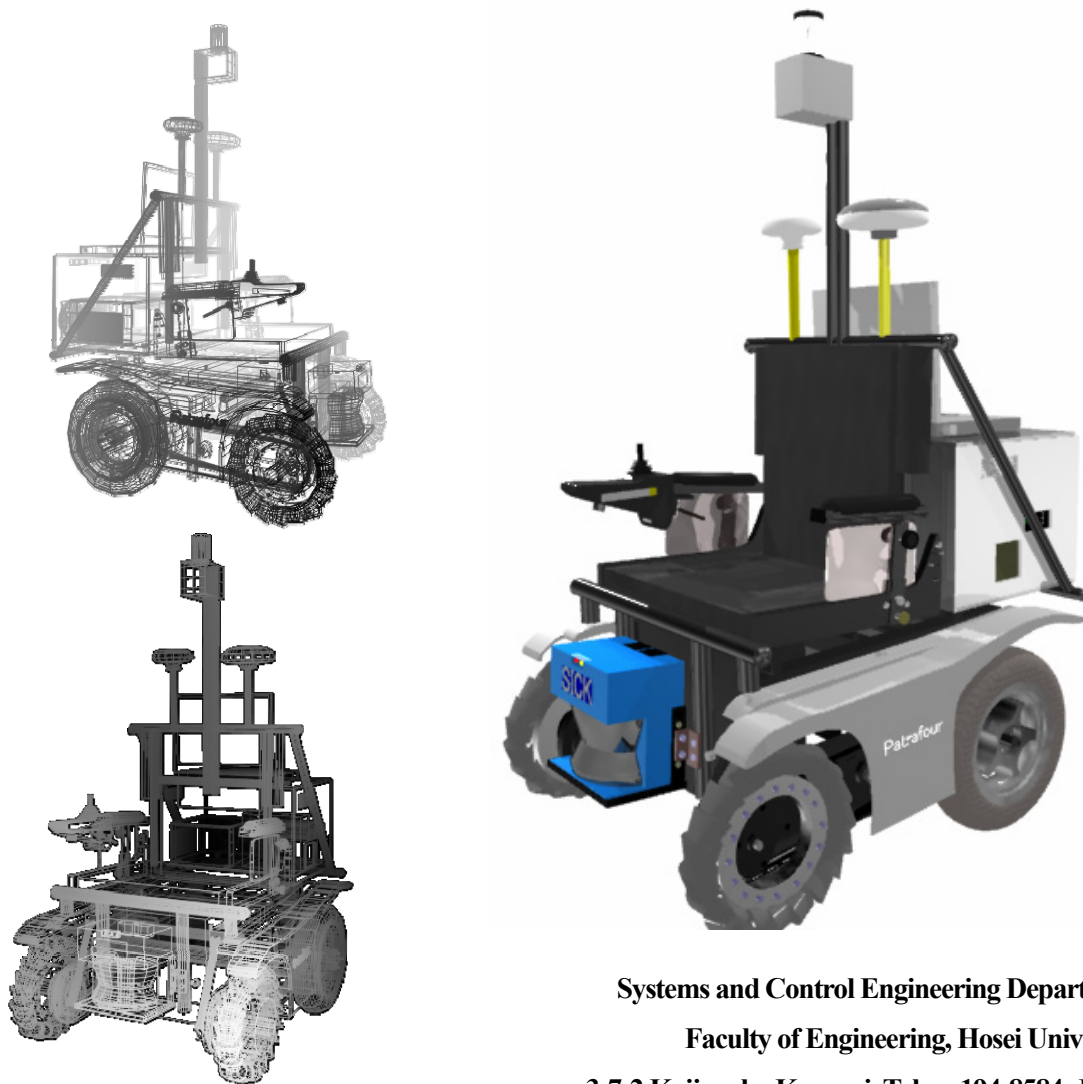


Omnix2007

HOSEI UNIVERSITY



Systems and Control Engineering Department
Faculty of Engineering, Hosei University
3-7-2 Kajinocho Koganei, Tokyo 194-8584, Japan

E-mail; ikko@hosei.ac.jp

Faculty Advisor Statement

I hereby certify that the engineering design on Omnix2007 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/15/2007
Associate Prof. Kazuyuki Kobayashi May 15, 2007.

1. Introduction

The Autonomous Robotics Lab (ARL) team of Hosei University is proud to present an innovative, improved version of the Omnix2007 to the 15th annual Intelligent Ground Vehicle Competition (IGVC). Building upon previous successes, the Omnix2007 has been updated to meet the demands of the IGVC with more intelligence and innovative features.

The newly-developed Omnix2007 is based on the Omnix2006 chassis. The concept of the Omnix2007 is a personal transportation vehicle for the coming aging society such as in Japan. As society rapidly grays, demands for safe and helpful wheelchairs are increasing. To maintain quality of life for the elderly such as by providing mobility to participate in society, we must reduce the physical and psychological burden that walking imposes and provide pedestrian environments where the elderly and physically impaired people can walk or drive safely and comfortably. To achieve this, the Omnix2007 employs the following sensing devices to control the wheelchair safely and intelligently:

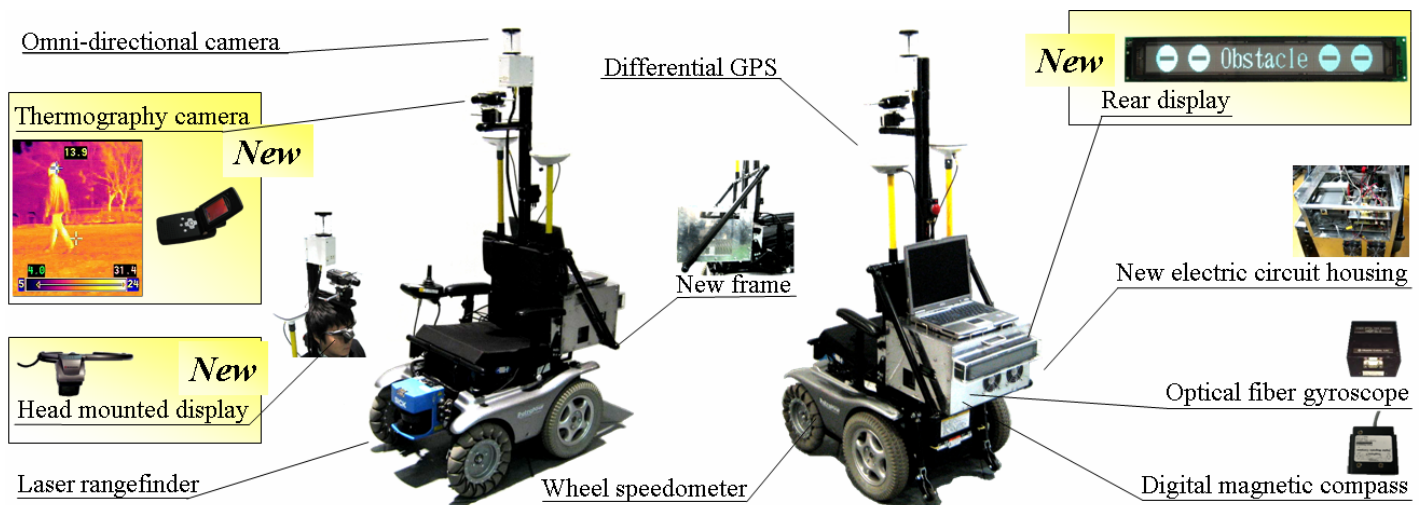


Figure 1 Omnix2007

The innovative features of the Omnix2007 can be summarized as follows:

Software innovations:	GPS free laser rangefinder based on short-term map-building algorithm (SLAM) HMD GUI interface (new)
Hardware innovations:	Thermography camera (new) Rear information display (new) Electrical circuit housing (Built from scratch) JAUS box (Built from scratch)

We installed a high-contrast vacuum fluorescent display (VFD) board to ensure the safety of people behind the vehicle; this display shows the vehicle's actions so that people behind can take avoidance action in case of turning and emergency stop.

A thermography camera is also newly employed. The combination of thermography camera and laser rangefinder can detect obstacles in the dark where common vision-based vehicles cannot drive safely.

We developed an intelligent and safe electric wheelchair by applying the latest technologies to the new chassis. The autonomous wheelchair offers promising potential for next-generation personal transportation vehicles.

2. Innovation

The key issues in developing a vision-based lane-following autonomous ground vehicle (AGV) are safety, accuracy and robustness of navigation. Obstacles may be randomly arranged, and the vehicle has to navigate without collision. To avoid obstacle collisions, environment recognition is important. Conventionally, for both autonomous challenges and navigation challenges in the IGVC, we applied only a reaction-based obstacle-avoiding algorithm. However, by using a wide range of laser rangefinder information, real-time map-building based on detected obstacle positions is possible. This year, we totally rewrote the autonomous algorithm developed based on the SLAM technique by using detected obstacle positions. SLAM stands for Simultaneous Localization And Map-building, and a laser rangefinder and inertial navigation sensors are used as self-localization sensing devices.

GPS is a useful absolute positioning system which can be used for vehicle navigation. However, with GPS it is sometimes difficult to estimate self-location for outdoor vehicle navigation. Since the spatial availability of signals depends on satellite locations, the accuracy of measuring vehicle location using GPS may vary.

SLAM can identify self-position as GPS information. To improve the accuracy of vehicle location, we developed a new SLAM algorithm suitable for autonomous navigation. The proposed SLAM algorithm is a landmark-based terrain-aided navigation system that has capabilities for online map-building and simultaneously utilizing the generated global map.

2.1 Navigation System-based SLAM

The vehicle which is shown in Figure 2 is mounted with a laser rangefinder and local sensor as speedometer and optical fiber gyroscope. The data from the local sensor is used to estimate the relative vehicle location by applying a dead-reckoning algorithm. The data from the laser rangefinder is used to acquire environment distance profile information that can be used to identify obstacles as landmarks.

These data can be fused by applying the Kalman filter to build an online map, and simultaneously using the waypoints global map.

Figure 3 compares simulations between the SLAM method and the dead-reckoning navigation. This simulation shows vehicle travel apexes of 20 meters square as waypoints for 5 laps.

In the SLAM method, the vehicle travels more precisely than with the conventional method of dead-reckoning. The SLAM method allows the vehicle to navigate waypoints correctly without GPS. In the navigation challenge, we will apply the SLAM method which uses a laser rangefinder, speedometer, optical fiber gyroscope, and GPS data. The specific system of the SLAM method is described in Section 7.2, “Navigation Challenge.”

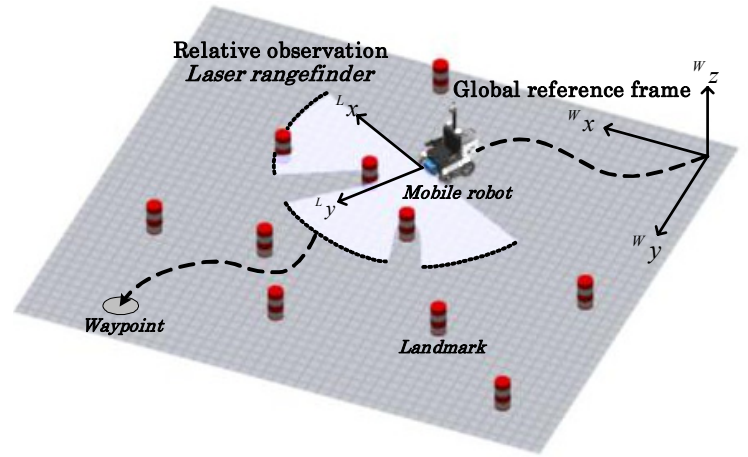


Figure 2 Basic configuration of proposed SLAM system

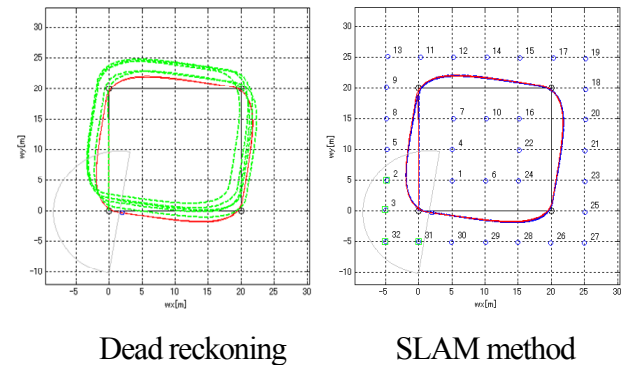


Figure 3 Comparison of simulation SLAM method with dead-reckoning

3. Design Process

3.1 Team Organization

The ARL2007 team now has a total of 12 members including 5 new members. Since ARL2006, a total of 17 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 ARL2007 team was split into three sub-teams to 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, and Software sub-teams, is shown in Figure 4.

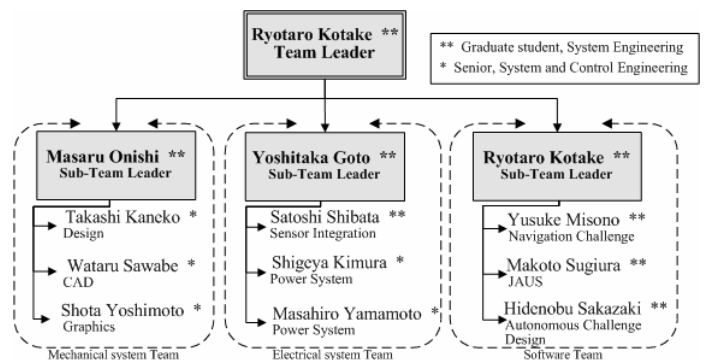


Figure 4 Team organization

3.2 RUP, UML

Last year, we adopted the Rational Unified Process (RUP) for the design process and attained successful results. This year, due to the change in team size, we reorganized the team and applied a

new design approach to suit the advantages of the waterfall method and iterative method with RUP and Unified Modeling Language (UML).

The overall design process was executed by applying the RUP method by using UML. UML is the optimal notation system for ensuring smooth communication among team members.

The main difference between the design process last year is the mechanical design process, which is costly and time-consuming, so we employed the waterfall method in the mechanical design process instead of applying the RUP method.

This waterfall model provides a specific cost and

time for the entire project. Figure 5 shows our RUP for the modified IGVC project. Each iteration follows a waterfall pattern containing requirements for gathering, analysis, design, implementation, testing, deployment, and the final product, which grows incrementally from iteration to iteration. To iterate the design process appropriately, team members from other design groups confirm whether the developed system satisfies the requirements. The estimated total human-hours spent on this project was 3600hr. All works were carried out under the RUP for the IGVC project.

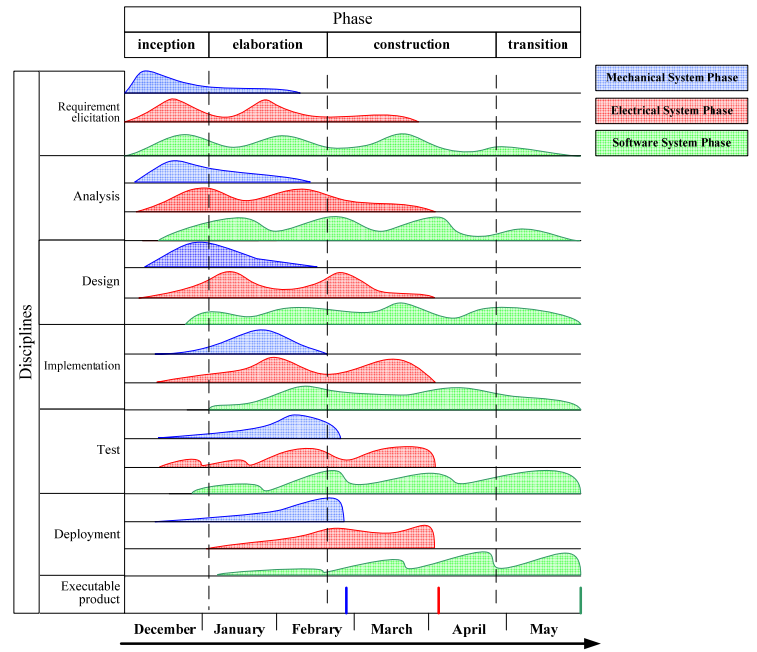


Figure 5 RUP for IGVC

4. Mechanical Design

Because the assigned development time and cost are limited, we employed the waterfall model development process for the mechanical design, with the “requirement gathering” and “analysis” part of RUP as the principal processes. We analyzed the problem of Omnix2006 and decided on the concept of mechanical design: **safe and vibration-isolation vehicle.**

4.1 Base Vehicle

The base vehicle is shown in Figure 6. It is the Patrafour (Kanto Auto Works, Ltd.), which can turn with zero radius. Employing this commercially-available electric wheelchair as the base guaranteed chassis reliability and considerably reduced the mechanical manufacturing time.



Figure 6 Base vehicle

The Omnix2007 is based on this unique mechanism. The enhanced performance of the zero-radius turning is achieved by the AWD system and the front omni-wheels.

4.1.1 Actuators

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

4.1.2 Omni-wheels

Figure 7 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 drive 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 directed to turn, the cups rotate laterally and the wheelchair turns smoothly.

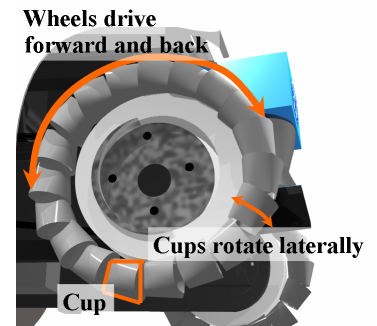


Figure 7 Omni wheels

4.2 Chassis Modification

Based on discussions among team members, we identified the following three main problems of Omnix2006:

- 1) Speed problem due to maximum speed of the vehicle
- 2) Vibration problem in electrical circuit housing
- 3) Stiffness problem caused by frame

As illustrated in Figure 8, the three problems are interdependent. To solve them, we did the following:

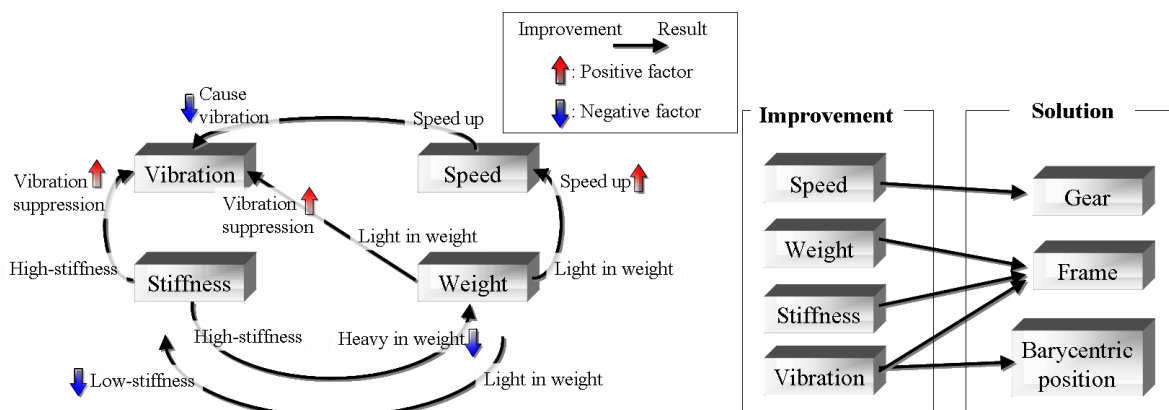


Figure 8 Problems of Omnix2006 chassis

- 1) Replaced the reduction gear.
- 2) Replaced the frame material.
- 3) Improved the barycentric position of the electrical circuit housing.

Due to the limitation maximum speed of the Omnix2006 (6.2 km/h), we decide to change the reduction gear from 11:37 to 13:35, resulting in a theoretical speed increase of around 25%.

To solve the problem of the stiff frame, we changed the frame material from steel angle bar to aluminum pipe to reduce weight. This also enabled the frame to be used for multiple purposes by using adjustable joints. Because of the flexibility of the new joint and pipe, the pipe is used not only for the frame but also to support the electrical circuit housing as shown in Figure 9.



Photo 1 Exchanged gear



Photo 2 Vehicle frame

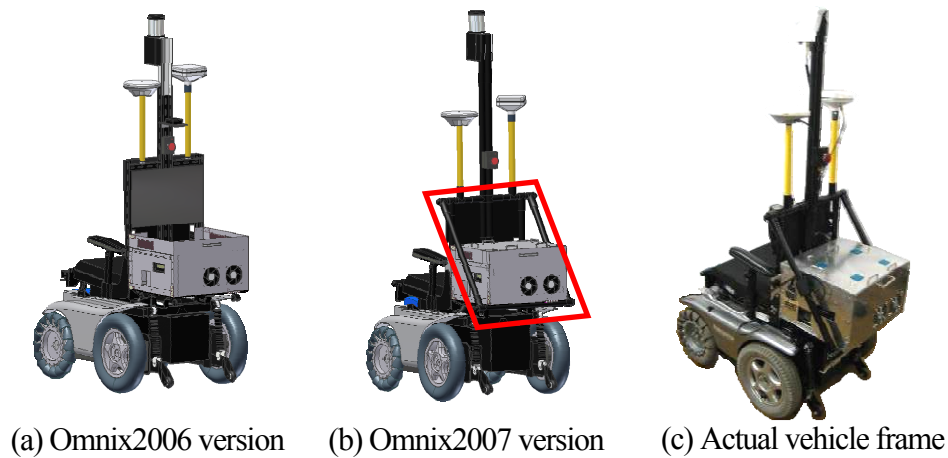


Figure 9 Vehicle frame

The problem of vibration was caused by the asymmetric center of gravity due to the distribution of weight in the electrical circuit housing. To solve the weight distribution, we rearranged the layouts of the circuits and sensors to move the barycentric point near to the center of the vehicle. Figure 10 shows the revamped electrical circuit housing.

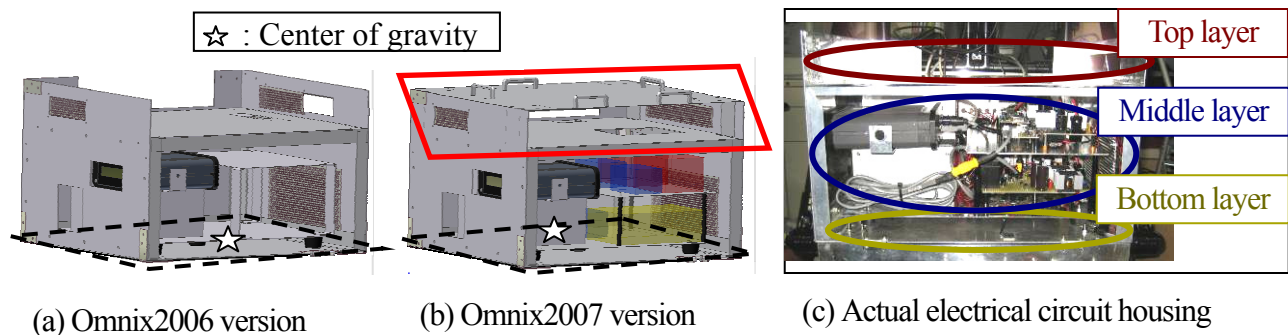


Figure 10 Electrical circuit housing

The electrical circuit structure, which used to be two layers, was redesigned to be three layers, resulting in 7 liters ($35 \times 40 \times 5$ cm) more space in the housing.

The bottom layer is the vibration isolation block. There are rubber stop blocks to isolate the second and third layers from vibration. The third layer is for sensor cables to install the electrical wiring internally, to reduce troubles in assembly and for fault identification. The notebook computer is placed on top of the electrical circuit housing and isolated from shock and vibration by gel shock absorbers.

5. Electrical Design

We gathered the requirements for the vehicle in the requirement gathering process, and gathered and analyzed the problems in last year's IGVC. Last year, we used a DC/AC inverter for the power supply from the battery to the laptop PC, but this quickly drained the battery so we installed a DC/DC converter to solve the problem. However, this introduced another problem. Because the number of electrical components rose, there was a higher possibility of human errors while connecting the electrical components. To prevent human errors, we used a different type of jack for each voltage so that the jacks could not be connected with the wrong voltage supply. Also, to make it easy to add new sensors to extend functions, we made an electrical circuit using a variable voltage controller that can supply a variable voltage. The layout inside the electrical circuit housing was redesigned so as to put the center of gravity at the center.

5.1 Sensors

The sensors incorporated with the Omnix2007 are an omni-directional camera (Sony CCD EVI-370 with hyperbolic mirror), a laser rangefinder (LRF) (SICK LMS-200), two rotary encoders set to control the two motors, an optical fiber gyro (Hitachi HOFG-3) to detect the angle of the vehicle, a digital magnetic compass (Honeywell True Point) to accurately estimate the self-position and self-orientation of the vehicle, and a differential global positioning system (Trimble BD950) to locate the position of the vehicle with respect to the latitude and longitude coordinates of the earth. The video frame images are grabbed using a video capture USB card (IODATA USB-CAP2), converted into a digital format using VCAPG2, and sent to the software programmed by MATLAB for image recognition. The average sampling interval of the laser rangefinder is about 20 ms. Again, this information is sent to MATLAB through an RS422 interface for range profile recognition. The vehicle velocity measured by rotary encoders and the optical fiber gyro provides accurate dead-reckoning. The differential global positioning system (Trimble BD950) is based on the dual-frequency GPS, and provides latitude and longitude information of the vehicle's position.

5.2 Power System and System Integration

Figure 11 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 serial RS-422 at 500 kbps. A DGPS signal is transmitted to the PC via a serial RS-232C to a USB converter; the optical fiber gyroscope is also connected to the PC via a serial RS-232C to USB converter while the speedometer and digital magnetic compass are connected to the PC via USBs.

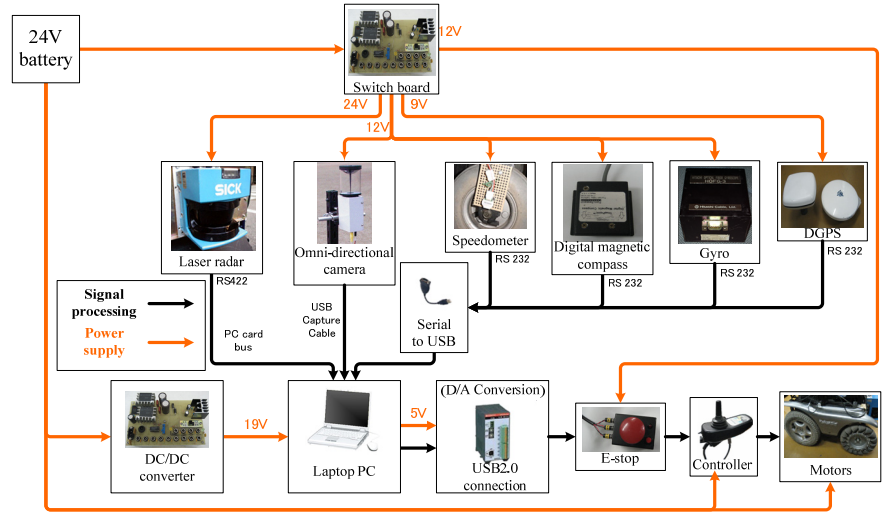


Figure 11 Power supply and sensor integration

5.3 Computers

Software in the laptop computer determines the navigation route in an off-line manner and generates on-line control signals from data by the sensors above. The laptop computer is driven by a 1.73-GHz Pentium M processor with 512 MB of memory, running Microsoft Windows XP Professional.

6. Joint Architecture for Unmanned System

Last year, we succeeded in the vehicle mount JAUS challenging level 1 and won the JAUS First Qualify prize and the JAUS requirements prize in the JAUS Challenge. This year, we are challenging level 2. We analyzed and researched the header of the JAUS message which we used in last year's competition practice. In the level 1 JAUS system, we distributed

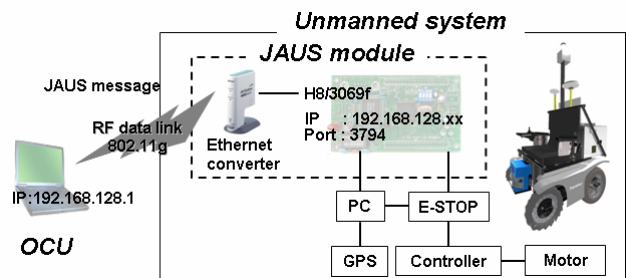


Figure 12 JAUS in the electrical system

the function to decrease the load on the laptop PC to gain advantages in fusing other sensors in the future. The JAUS message commands from the IGVC developed by the operator control unit (OCU) via an RF data link are received by the wireless Ethernet converter (BUFFALO WLI-TX1-G54) and the data is processed by the microcontroller board (RENESAS H8/3069) with Ethernet. To implement the level 2 JAUS, GPS is used to recognize the self-position. We tried to process the GPS data with the microcontroller, but troubles occurred during data reception: the processing of the microcontroller became unstable because the amount of data output from the GPS was too much. For this reason, we processed the data from the GPS with the laptop PC.

7. Software Strategy

7.1 Autonomous Challenge

Omnix2006 won second prize in the 2006 IGVC Autonomous Challenge, but it could not complete the obstacle area of the course. In order to complete the course, we carefully analyzed the obstacle avoidance processing algorithm.

7.1.1 Vision-based two-phase strategy

A vehicle that navigates undefined and/or unstructured and dynamically changing environments must react quickly and correctly to all situations to avoid danger. To complete any situation in the autonomous challenge course, we developed a navigation strategy combining an open-loop and closed-loop system, which we call “vision-based two-phase strategy”. The vision-based two-phase strategy shown in Figure 13 consists of two phases. The first phase consists of an off-line sensing process by external sensors, an environment-recognition process and a path-planning and path-calculation process. The second phase consists of on-line motor control and position-correction processes by internal sensors. In the first phase, the vehicle acquires a time-series of images and completes the image-processing iterations until it has sufficient confidence of successfully generating the appropriate path. During image acquisition and calculation, the vehicle does not move. Subsequently, the vehicle navigates based on the appropriate path provided by the processing in the first phase. The key strategy in controlling the new vehicle is the separation of off-line route scheduling and on-line navigation control given by the

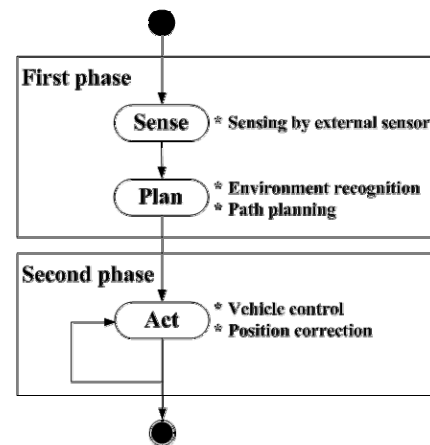


Figure 13 Vision-based two-phase strategy

two phases. This separation yields efficient use of sensor signals, some of which are measured slowly, and quick vehicle control, which leads to safe navigation in a variety of outdoor environments.

7.1.2 Lane detection

Problems in lane detection are often caused by sunshine and/or shadow effects in an outdoor environment. The shadows of trees or other obstacles can create false lanes and/or false obstacles. 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 14 shows the lane detection activity diagram and images grabbed by the omni-directional camera.

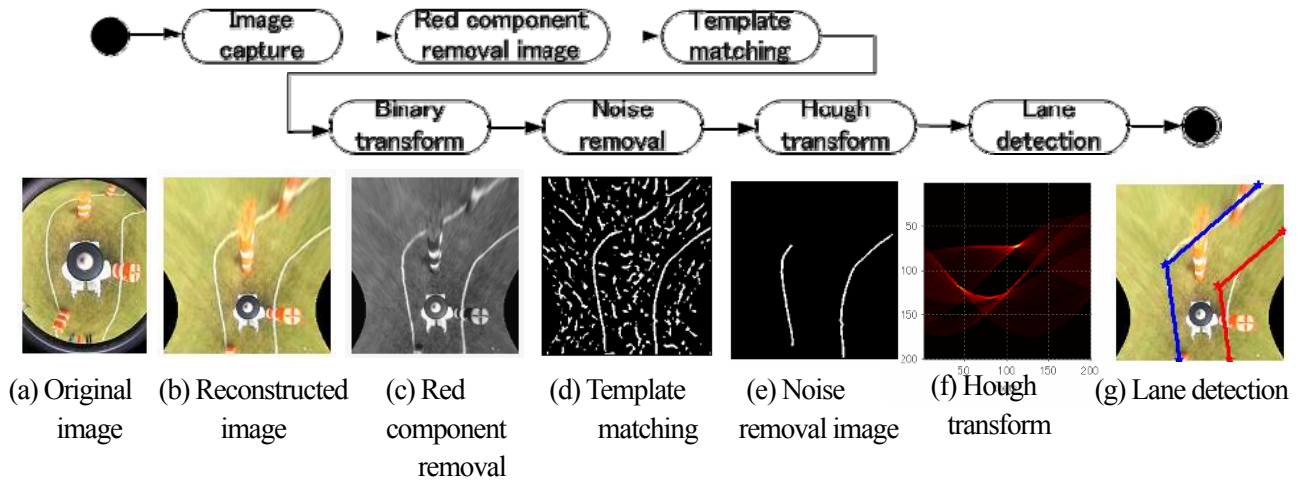


Figure 14 Lane detection

Figure 14(b) shows the reconstructed ground image. After the reconstruction, we convert a RGB color image to a grayscale image using only the B component. Figure 14(c) shows the grayscale image. By using a referenced lane template image prepared ahead of time, 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 14(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 14(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 steep 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, the Omnix2007 proved reliable at detecting lanes even in cases when the lines were hidden

by obstacles or drawn only by dashed lines. Figure 14(f) shows the plots in the Hough domain and Figure 14(g) shows the lane detected. The lane lines detected can be stored as sets of starting points and end points and line-crossing points.

7.1.3 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 15(a). After the path point generation, cubic-spline interpolation is applied to paths given by the sequence of path points. Figure 15(b) shows a path generated by the proposed method.

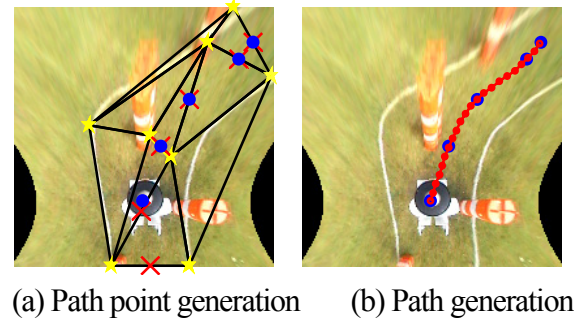


Figure 15 Result of path generation

7.1.4 Obstacle area

In the obstacle area, lanes are often hidden by the obstacles and it is difficult for the vehicle to generate the desired appropriate path. With our Delaunay triangulation method, a faulty path could be generated when the vehicle is surrounded by obstacles. To complete a crowded obstacle course, the obstacle avoidance algorithm is automatically switched from the range profile algorithm to the image-based algorithm.

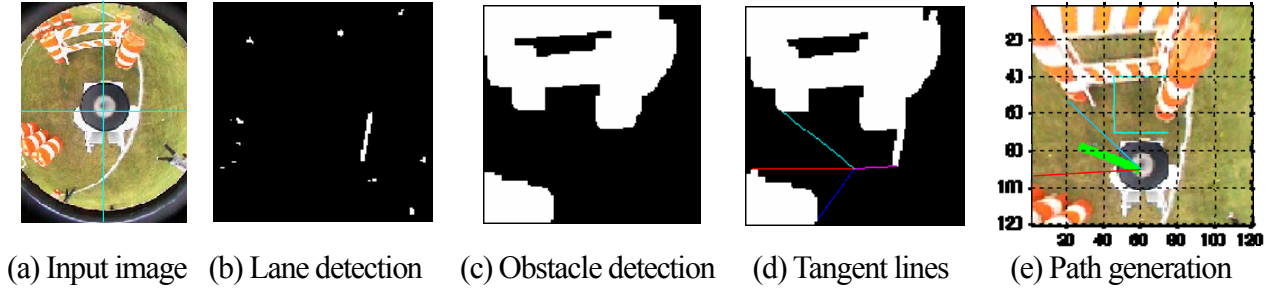


Figure 16 Path generation in obstacle area

Figure 16 shows the path generation flow in the obstacle area. Using logical OR operation of binary lanes (b) and obstacles (c), tangent lines are drawn from the vehicle center to lanes and obstacles (d). The algorithm generates the path which bisects the angle made by the tangent lines (e).

7.2 Navigation Challenge

To complete waypoint navigation, we introduce a new navigation algorithm by using SLAM. By using the SLAM method, our vehicle can estimate its own location more accurately and robustly even if GPS signals are not available. Figure 17 shows the activity diagram of the SLAM method.

The important sensor for the proposed SLAM method is the laser rangefinder. In SLAM, we use the laser rangefinder not only for obstacle detection but also to detect landmarks to generate a global waypoint map. The location data for specified landmarks are fused with the data from the optical fiber gyroscope and the speedometer by the extended Kalman filter to estimate its own location and the global map of the landmarks at the same time. The vehicle follows the path planned using the estimated location data. The new

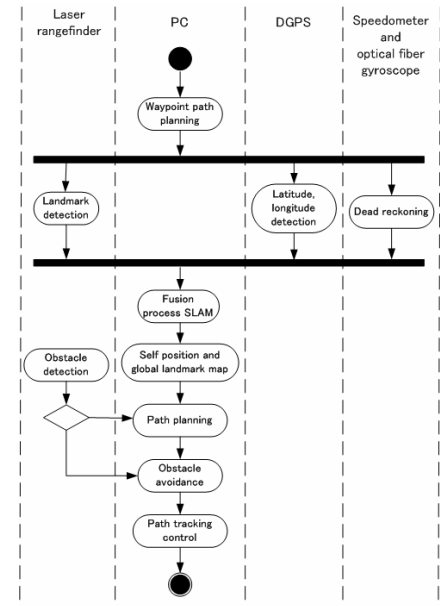


Figure 17 Activity diagram of proposed SLAM method

algorithm was extensively tested in both simulations and real field experiments. The results of the field experiments showed that the algorithm is robust. We believe that the Omnix2007 will offer more reliable and stable performance in the navigation challenge than last year's Omnix2006.

8. Analysis of Predicted Performance and Results

Most performance and quality aspects of the Omnix2007 were much higher than those of the Omnix2006. Comparisons of field test results with predicted parameters and the Omnix2006 are shown in Table 1.

Table 1 Comparison of test results and predicted parameters

Performance Measure	Competition	Omnix2006	Prediction	Results
Maximum speed		4.25 mph (6.8 km/h)	5.0 mph (8km/h)	4.7 mph (7.5 km/h)
Maximum swing speed		120 deg/sec	140 deg/sec	130 deg/sec
Ramp climbing ability		10 degree incline	9.5 degree incline	9.1 degree incline
Reaction times	Autonomous	0.10 to 0.28 seconds	0.12 seconds	0.12 to 0.28 seconds
	Navigation	0.15 to 0.20 seconds	0.18 seconds	0.18 to 0.22 seconds
Battery life		4.25 hours	2.92 hours(at maximum power)	4.25 hours
Obstacle detection distance	Autonomous	4.5 meters (Omni-directional camera and LRF) [maximum]		
	Navigation	10 meters (Omni-directional camera and LRF) [maximum]		
Traps, and potholes	Autonomous	Detection of obstacles: (LRF)		
	Navigation	Detection of potholes: template matching (Omni-directional camera)		
Dead ends		The vehicle performs a near-zero radius turn until a suitable path is found		
Waypoint accuracy		0.25 to 1.00 meters	±0.2 meters (DGPS in use)	±0.3 meters (DGPS in use)
			±0.6 meters (DGPS not in use)	±0.8 meters (DGPS not in use)
Remote emergency stop capability		100 meters [maximum]	250 meters [maximum]	100 meters [maximum]

To improve the maximum speed of the vehicle, we newly developed and replaced the speed gear. By using the new speed gear, the maximum speed was raised but the torque was decreased, thus degrading the climbing ability. However, the vehicle is still able to climb the regulation lawn ramp of 15%.

8.1 Reaction Time

In the navigation challenge, by using the SLAM method, the reaction time improved from 0.15 s to 0.18 s, and the reaction distance also improved to 0.38 m. However, since the laser rangefinder is able to search within a 10-m area, there are 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 0-radius turn.

8.2 Run Time

Table 2 details the power requirements for all the components on the vehicle.

Table 2 Estimates of power consumption

Component	Nominal Operating Voltage (VDC)	Maximum Current (Amps)	Power (watts)
DC motors mounted on the electric wheelcha	24.00	7.500	180.00
Wireless ethernet converter	5.00	0.820	4.10
Laptop computer	19.50	3.340	65.13
CCD camera	12.00	0.308	3.70
Laser rangefinder	24.00	1.458	35.00
GPS receiver	9.00	0.111	1.00
DGPS beacon antenna	12.00	0.065	0.78
Digital magnetic compass	5.00	0.054	0.27
E-stop	12.00	0.030	0.36
Speedometer	5.00	0.050	0.25
Optical fiber gyroscope	12.00	0.500	6.00
Vacuum fluorescent display	5.00	3.080	15.40
Total			311.99

From the calculated maximum power, a conservative estimate of the Omnix2007's driving time is approximately 3 hours. In addition, the results of experiments suggest that the Omnix2007 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, turns with a 0-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 0-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 ± 20 cm. In case the vehicle cannot use GPS data, the error is within ± 60 cm.

9. Safety, Reliability, Durability

9.1 Safety

For safety, we designed the Omnix2007 from the two perspectives of mechanical and electrical designs.

In the mechanical design, we examined the safety of operators and spectators at the competition and decided to reduce the sharp edges and corners of the vehicle by changing the frame material from sharp steel angle bar to round aluminum pipe.

In the electrical design, we designed two different types of emergency stop (E-stop) to follow the rules of IGVC. The Omnix2007 has a remote controlled E-stop and a vehicle-mounted E-stop push-button. The signal of the remote-controlled E-stop is transmitted by an automobile wireless engine starter, which can transmit signals over 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 Reliability

The reliability of the Omnix2007 has been improved by totally redesigning the electrical circuit housing and using new stiff frames. In the electrical design, the power supply jack is designed to prevent connection to wrong voltages to prevent human errors.

9.3 Durability

We changed the frame material from steel angle bar to aluminum pipe. The new frame is significantly stronger and more rigid than last year's frame. The frame also supports the electrical circuit housing to prevent vibration caused by running. In order to extend battery life, we changed the power supply circuits from DC/AC inverter to DC/DC converter.

10. Cost

The costs involved in developing the Omnix2007 are summarized in Table 3.

Table 3 Estimated costs for development of Omnix2007

Components	Remarks	Retail Cost	Team Cost
Laptop personal computer	DELL (Intel Mobile Pentium M 1.6GH	\$2,000	\$2,000
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
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
Head mount display *	SHIMADZU (Data Glass2/A)	\$1,620	\$0
Mechanical parts		\$242	\$242
Brushless DC motor and gearhead		\$1,704	\$1,704
Electrical system components		\$305	\$305
Vacuum fluorescent display		\$50	\$50
Infrared thermography camera		\$6,815	\$6,815
Total		\$50,053	\$11,116

* reused from Omnix2006

11. Conclusion

This report has described the design process, development, and construction of the Omnix2007. The Omnix2007 offers improvements in: (1) chassis stiffness, (2) maximum speed, (3) lighter weight, and (4) barycentric position to the center of the vehicle. The GPS free SLAM algorithm is newly employed for both the autonomous challenge and navigation challenge.

Despite the limited period for development, the RUP and UML design approach facilitated smooth communications between team members. The new design process facilitated both hardware development and software integration. The Omnix2007 has outstanding potential.