7th Annual International Autonomous Ground Robotics Competition

Design Competition Written Report

NECTAR

Actually, we would like to taste NECTAR after winning the first prize

Watanabe Laboratory Team
System Control Engineering
Department
Hosei University
3-7-2 Kajinocho Koganei Tokyo
184-8584, Japan
e-mail : bob@k.hosei.ac.jp
Fax 81-42-387-6123

June 5th, 1999

1. Introduction

The autonomous navigation vehicle named NEw CompacT Autonomous gRound vehicle, shortly nicknamed NECTAR was designed by eight undergraduate and four graduate students from HOSEI university under the advice of Professor Kajiro Watanabe and Lecture Kazuyuki Kobayashhi of HOSEI university. The team was organized in the early of March 1999. At fall of the last year 1998, four graduate students tentatively set out to design a new vehicle, later to be nicknamed NECTAR. **Figure 1** shows the team organizational chart. And all team members in this chart are cross-listed in the team roster shown in **Table 1**.

The NECTAR is a four wheeled and differentially driven autonomous vehicle powered entirely by a 24 volt DC power source. “**Simplicity**” and “**compactness**” are the key words that expresses the design concept of the vehicle NECTAR. The simplicity yields the high reliability of hardware and software and shortens man-hour required for the development. The compactness helps transportation of the vehicle from Japan to Michigan.

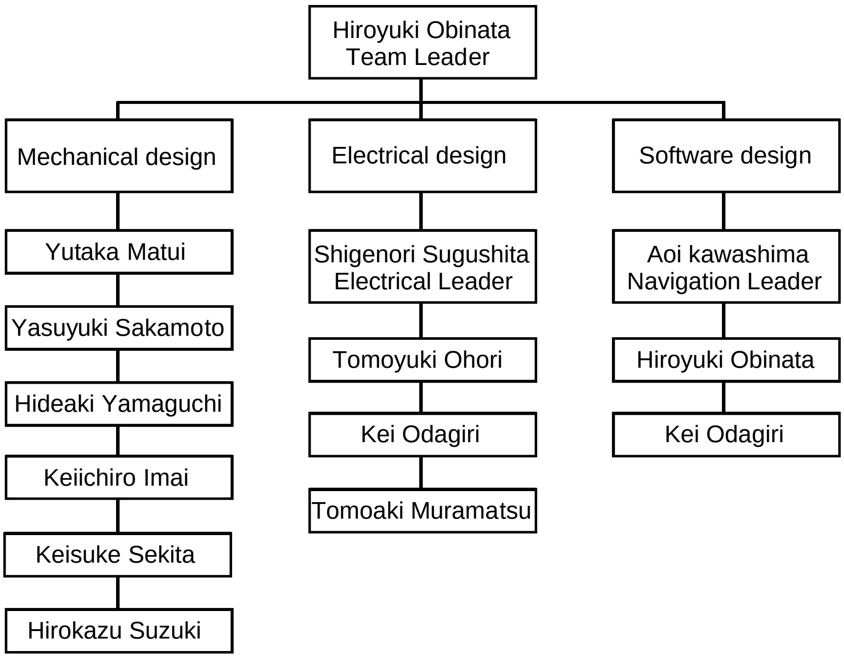

Figure 1 The team organizational chart

Table 1. Team roster

Function	Name	Major	Academic Level
Team Leader	Hiroyuki Obinata	System Control engineering	graduate
Navigation Leader	Aoi kawashima	System Control engineering	graduate
Electrical Leader	Shigenori Sugushita	System Control engineering	graduate
	Tomoyuki Ohori	System Control engineering	graduate
	Hideaki Yamaguchi	System Control engineering	undergraduate
	Hirokazu Suzuki	System Control engineering	undergraduate
	Kei Odagiri	System Control engineering	undergraduate
	Keiichiro Imai	System Control engineering	undergraduate
	Keisuke Sekita	System Control engineering	undergraduate
	Tomoaki Muramatsu	System Control engineering	undergraduate
	Yasuyuki Sakamoto	System Control engineering	undergraduate
	Yutaka Matui	System Control engineering	undergraduate

2. Design Process

Figure 2 shows the scheme of the design process. The base vehicle is an electric powered four wheel-chair with a controller for manual operation. The design process can be categorized into five stages.

[Stage Ⅰ] Investigation of I/O Specifications of the Manual Controller

The base vehicle is manually operated and/or driven by human through a joystick. We first, investigated the interface of the joystick, i.e., relation between the joystick motion and the voltage of control signal from the controller. Information about the voltage inputs, i.e., one for speed control and the other for steering control are all we need. Through experimental investigation, we found the upper and lower limitation of the voltages and corresponding speed and steering limitations. The speed and steering angle are independently controllable and they are linearly proportional to the two input

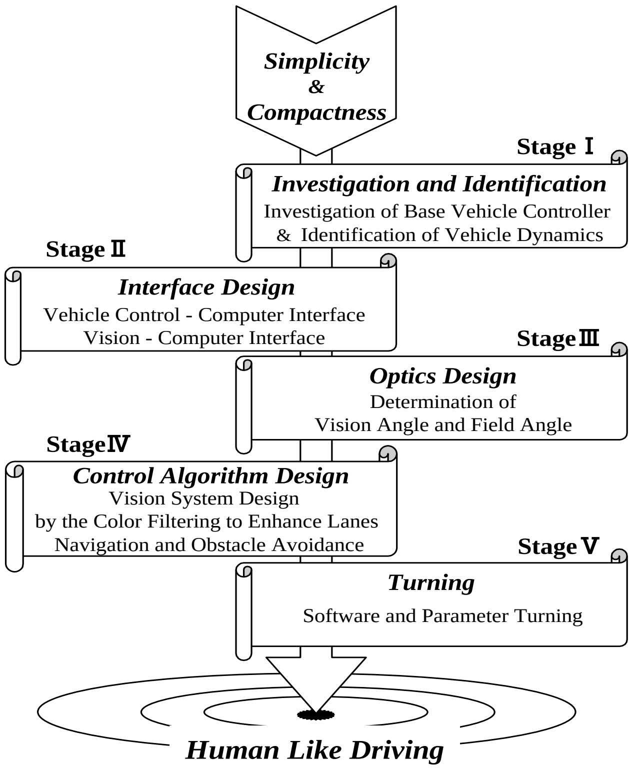

Figure 2 The scheme of the design process

voltages within the limitation range. And when both input voltages are 0, the vehicle is mechanically braked and locked.

[Stage Ⅱ]　Interface Design

Two major interfaces, i.e., (1) vehicle control interface and (2) environmental information acquiring interface was designed.

(1) Vehicle control interface: Basing on the results of the investigation of the controller for manual operation in [stage Ⅰ] , we designed the interface (signal conditioning) circuits from a PC to the controller through DAC. The circuit includes the interface from the E-stop switch and/or the E-stop wireless transmitter to the PC and to the mechanical braking system.

(2) Environmental information acquiring interface: Interfaces from a 2-D color CCD camera and three ultrasonic obstacle detection sensors to the PC were designed.

[Stage Ⅲ]　Optics Design

Selection and attachment of optional lens with proper field angle to the CCD camera makes the acquisition of the environmental information easy. Especially it is effective to acquire the lane information. We found the optimal field angle of the lens.

[Stage Ⅳ]　Software Design for Navigation and Obstacle Avoidance

The basic software was designed under the MATLAB circumstance. The software directly concerned with the hardware was coded by C-compiler. The most effort was paid to develop the following software (1) lane-image enhancement and detection and (2) navigation and obstacle avoidance:

(1) Lane-image enhancement and detection: New color filtering technology was introduced to enhance and discriminate the lane and obstacle from the noisy circumstance (lawn). The software has the learning function. Thus it can adapt to any conditions.

(2) Navigation and obstacle avoidance: From the detected lane information, the vehicle control signal is calculated basing on the minimum energy control theory. If the vision information is noise free, the algorithm is very simple and simple (optimal) gain control is enough. In practice however, the lane information includes erroneous noise, thus we add the artificial intelligent technology to avoid the ill effect by the noise.

[Stage∨] Parameter Turing

Software and parameters for the lane detection and steering control were turned under the real circumstances.

3. Mechanical Design

3.1 Base vehicle

Figure 3 shows the scheme of the vehicle NECTAR. The vehicle was developed on the basis of the electric wheel-chair (Co. Ltd. Cerio) for foot handicap persons. The body size of the vehicle is 92cm long and 180cm tall, with a wheel-base of 46cm and the weight is 25kg.

The vehicle NECTAR has the upper and lower cabins. The lower cabin contains a driver, two 350W DC motors, two 12V deep-cycle batteries and an electromagnetic recharge type brake. The upper cabin contains a PC, terminal boxes, ultrasonic sensors for obstacle detection, E-stops (by radio wave and manual operation) and a controller for manipulating the vehicle. Around the center of the upper cabin, a tall pillar is set and fixed. At the top of the pillar, a 2-D color CCD camera attached with the super wide angle lens is set for monitoring the environment. These components are removable and changeable, and independent as the component. Further a space to put on a payload is prepared on the upper cabin.

3.2 Component packaging and placement

Figure 4 shows how the components were packed and placed on the vehicle. The deck of the vehicle is arranged compactly to satisfy the design concept of "compactness".

4. Electrical Design

4.1 Power System

The two 12volt 33AH deep cycle batteries are mounted on the vehicle. The cascade connection of these batteries provides 24volt power source from which four DC power sources with different voltages are regenerated by DC-DC converters. These are (1) 24V power source for motor driving, (2) 13.5V power source for PC, (3) 12V power source for vision sensor, control circuit and another (4) 12V power source for ultrasonic obstacle detector and E-stop wireless receiver. For power sources with different voltages from above, proper 3-terminal voltage regulator elements with proper voltages are used. The power is supplied to each circuit via DC connectors that satisfy the quality standard of Japan Industry Standard. As the each component is independent, each circuit has the independent power switch.

4.2 Vision sensing

The vision sensor is a substantial sensor to acquire environmental information by which vehicle is navigated. A color CCD camera for home TV with the automatic focus and automatic iris functions was employed as the vision sensor. The super wide angle lens with the angle of field of 115° was mounted on the camera by which 9 meter wide field is covered when the focusing target distance is 3 meter. The image acquired by the camera was transmitted to the PC via the image capture board whose transmission speed is 30-full frame images per second.

Obstacle sensing

The obstacle is monitored by the vision information acquired by the CCD camera and the ultrasonic obstacle detection sensor. The color of the obstacle is given as the prior information. Thus existence of the obstacle can be detected by color filtering that extracts the specified color, i.e., obstacle in the image.

The ultrasonic sensor plays the assistant role of the obstacle detection for the image. Three ultrasonic sensors whose directionality ranges from 30 to 40 degree were installed in the front of the vehicle, and the distance to the obstacle of right and left and front is measured. Each sensor measures the distance ranging from 0.1meter to 3 meter with the accuracy of 1cm. The accuracy is sufficient to recognize obstacles. Each sensor was placed with the sufficient angle in order to prevent the interference of each sensor. Measurement period is 30 times per second, it is quick enough to catch the obstacle.

4.4 Controller hardware

The vehicle can be operated either manually or autonomously. Both modes of operation are essentially the same. The only difference is that in manual mode, the operator specifies velocity and steering angle by means of a joystick, while in autonomous mode the computer calculates velocity and steering angle based on vision sensor information.

The controller circuit has three functions, and three modules depending on the functions were prepared.

The first one is the power supply module that generates various necessary voltages via DC-DC converters as described above. The second one is the E-stop module that sends E-stop signal to the vehicle when the E-stop bottom is pushed or E-stop wireless signal is transmitted. The third module conditions the signal from the DAC. The module adjusts the DAC signals so that the vehicle speed and steering controller accurately works in the normal operation range.

The manual mode and the autonomous mode are switched by the relay in the controller. Among those, the manual mode has the priority.

4 Software Design

5.1 Control rules for driving

The key concept to develop the vehicle control algorithm is "**human like driving**".

Figure 5 shows a situation of human driving. We can extract the following driving control rules form the careful observations of human driving manners as shown in Figure 5;

(R1) Drivers look around the wide front view to check the environmental change, as well as look at the focussed front area to perceive the center of two lanes.

(R2) They steer the handle so that vehicle goes forward to the front focussed target like as the center of the lanes.

(R3) When they find the curvy front road, they slow down the vehicle and look around near the front.

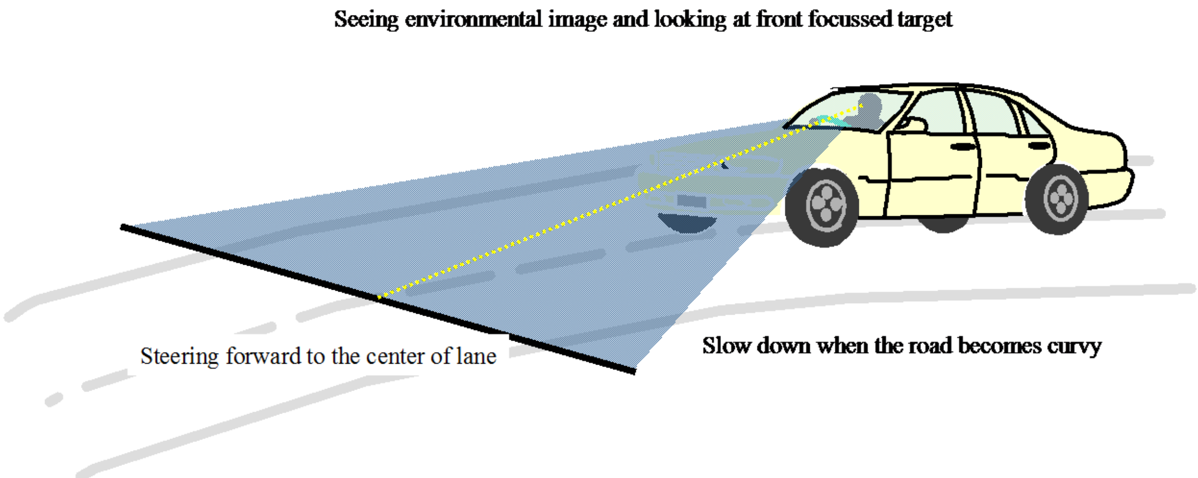

Figure 5 A situation of human driving

5.2 Computer vision

(1) Software developing

We made full use of the functions of the graphical user interface and multitasking capabilities of the Microsoft Windows operating system to realize the vision function of the vehicle. The 2-D image processing for vision function requires the heavy computational task, thus we employed distributed computing approach. Employment of MATLAB script as the main programming is one of the best and lightest approach to manage such the complicated distributed computing, signal processing from various sensors and controlling actuators. The MATLAB script-programming environment makes rapid prototyping as well as easy implementing and testing the control algorithm. As a result we can implement human like driving manner with the short developing time.

(2) Lane and obstacle enhancement and detection

Figure 6 shows the scheme of how the lane and obstacle are detected. Each pixel taken into PC is categorized into the white line (lane), the lawn and the obstacle by the color filtering technique. The color filtered image finally divides a frame of image into three zones, each of them corresponds to the zone of lane, the zone of lawn and the zone of obstacle. The processing provides the information of where is the lane, where is the obstacle and where is the lawn in the image. **Figure 7** shows a sequence of process of the image processing above.

5.3 Navigation

The navigation strategy is just following the human driving manners as described in Rules (R1), (R2) and (R3). Basic strategies are as follows;

(S1) Full utilization of the 2-D color image

To realize (R1), a 2-D color image sensor that acquires environmental information was employed and 2-D information and color information are fully used.

(S2) Preview control strategy

Following to (R2), the vehicle steers the handle to fit the center of two lanes at the certain front focussed target distance L and the canter of camera field. The error between two centers is used as the proportional control signal, i.e., (k = constant)×{(center of lanes) (center of frame of image)} is used as the feedback control signal. Note this simple preview control scheme is nothing more than the optimal control in the sense of the minimum energy and the parameter L and k are determined from the weighting coefficients of the energy objective function.

(S3) Human like speed control

Following (R3), the speed of vehicle is slow down, when the vision sensor detect the curve. The speed is qualitatively given following to the human driving manner and the value of the speed is quantitatively determined by using Fuzzy logic.

(S4) Exceptional processing

When the vision system acquires irregular image due to sudden appearance of obstacles or noise by sunshine reflection, from which the above control cannot be conducted, the exceptional processing is carried out. Algorithm following to the artificial intelligence technology based on the knowledge of the presumable evens was prepared.

6 Other Design Issues

6.1 Safety

(1) Mechanical braking system

The original base vehicle (electric four wheel chair) itself includes the mechanical braking system for safety purpose. When the both speed control and steering control signals are all 0, the vehicle is mechanically braked. Further if the all of the batteries of the vehicle are off, again the vehicle is mechanically braked and locked.

(2) E-Stop

Two different types of emergency stop mechanisms were prepared. One is the contact switch at the back of the pillar where operator can easily touch. The other is the stop via the wireless. The employed wireless transmitter is used as a real automobile remote starter. Because it is used to start engine, it works after very complicated sequence of switching operations to avoid the miss-starting by noises. The sequence circuit was designed to not start up engine but to stop the vehicle. The wireless E-stop works at the far place over 100 meters.

6.2 Reliability and durability

The key words "**simplicity** " and "**compactness**" expressing the key concept of the vehicle are deeply related with the reliability. The simplicity yields the high reliability of not only the software development but also the hardware implementation. Further to keep high reliability, we use the devices that satisfied the quality standard of Japan Industrial Standard. Double components were prepared as the backup.

The compactness is related with durability. The mass of vehicle is light as well as the mass of each component is light because of their compactness. Lighter mass leads to less acting force to each component, which increase the durability.

6.3 Innovations

The substantial innovations of the vehicle NECTAR can be found in the lane detection and navigation controller design.

(1) Color filtering

In the lane detection algorithm, we newly develop a color filtering with the function of learning. At the initial stage, we men teach what is the lane, what is the obstacle and what is the lawn in the image captured. Then the software decomposes the lane color information into three color components R, G and B. The lane is recognized by the vector $[\ R\ G\ B\ ]_{lane}$. Similarly vectors $[\ R\ G\ B\ ]_{lawn}$ and $[\ R\ G\ B\ ]_{obstacle}$ are generated. The three items lane, lawn, obstacle are discriminated by the above three vectors using them as their template. Once recognized, the template vectors can be updated if necessary. The necessary condition of updating is the circumstance change. For example, when vehicle begins to move forward to sun shining from other direction, the characteristics of image change. In such the situation updating will start.

(2) Preview control as an optimal control

In the navigation, we employed the preview control scheme, which is nothing more than the optimal control in the sense of minimization of energy. We found that the distance (L) from camera position to front focusing target and proportional gain (k) of preview control are related with the weighting coefficients in the energy objective function. This knowledge helps when turning the parameters L and k.

(3) Human like driving by using the fuzzy logic

Employment of the fuzzy logic to control the vehicle speed is also innovative. From the human driving manner, we extracted feature of human driving and determined several rules of speed and steering control. These rules are somewhat qualitative. Thus we employed the fuzzy logic to produce the quantitative control signal by which human like steering can be achieved.

(4) Artificial intelligence to avoid irregular situation

Further for the exceptional and irregular events occurring in our environment, we made use of the artificial intelligence technology. We made data base for the exceptional events presumed and we let vehicle automatically carry out reasoning to know what happens and generate steering signal to avoid such the exceptional events.

6.4 Cost

Cost to develop the vehicle is summarized in **Table 2**. Most expensive one is the labor cost. Actually, this project has been carried out as the theme of graduation thesis, the fee was not paid. The most expensive item was the base vehicle (electric four wheeled chair). The second expensive item was PC and the third item was CCD camera with super wide angle lens.

Table 2 Cost

Items	Cost		Remark
	¥	$	
Electoric Wheels Chare	330,000	2538.4615	
Libbret70 (Personal Computer)			
CCD Camera(SONY)			
CCD Camera			
Camera Lense			
Wire Less E-stop			
Electronic parts			
Mecanical			
Shell			
Lobor Cost			
TOTALS			