8th Intelligent Ground Vehicle Competition

Vehicle Design Competition

Written Report

NECTAR 2000

Actually, we would like to taste the NECTAR after winning the first prize in 2000.

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1. Introduction

The autonomous ground vehicle named NEw CompacT Autonomous gRound vehicle in 2000, nicknamed **NECTAR 2000** is introduced in this report. It was designed by two undergraduate and three graduate students under the advice of Professor Kajiro Watanabe and Assistant Professor Kazuyuki Kobayashi of the Systems and Control Engineering Department, Hosei University (see Section 6.4 for a complete team roster). In the fall 1999, three graduate students set out to design the NECTAR 2000 vehicle, and the formal team was organized in early March 2000. The NECTAR 2000 vehicle was realized by two years of experience and over two thousand person-hours of design, fabrication, and testing. The overall structure of the team is presented in Section 6.4 in the form of a team organizational chart.

The NECTAR 2000 vehicle is a four-wheeled, differentially driven autonomous vehicle powered entirely by a DC 24-volt power source. "**Simplicity**" and "**Compactness**" are the key words that express the design concept of the vehicle. The simplicity yields the high reliability of the vehicle's hardware and software as well as shortens the man-hours required for its development. The compactness yields the high durability of the vehicle and also makes transporting the vehicle from Japan to Florida much easier.

2. Design Process

. The base vehicle is an electric-powered four-wheeled wheelchair with a controller for manual operation. The design process can be categorized into five stages.

Stage 1 Investigation of the I/O specifications of the manual controller

The base vehicle is manually operated and/or driven via a joystick. We first investigated the interface of the joystick and the controller, i.e., the relation between the joystick motion and the voltage of controller signal. The only information we needed was two voltage inputs, that is, the voltage for speed control and the voltage for steering control.

Through experiments, we found the upper and lower limitations of the voltages and the corresponding speed and steering limitations. The speed and the steering angle are independently controllable, and they are linearly proportional to the two input voltages within the limitation ranges. When both input voltages are 0, an electromagnetic recharge-type brake works and the vehicle is locked.

Stage 2 Interface design

We designed the vehicle's two major interfaces as follows.

(1) Vehicle control interface: Based on the results of the experiments in (stage 1), we designed the interface (signal conditioning) circuits from a personal computer (PC) to the controller through a D to A converter. The interface circuits include the interfaces from the emergency stop (hereafter known as "E-stop") switch and/or the E-stop wireless transmitter to the PC and to the electromagnetic recharge-type brake system.

(2) Environmental information acquiring interface: We designed the interfaces from a 2-D color CCD camera and the laser radar to the PC.

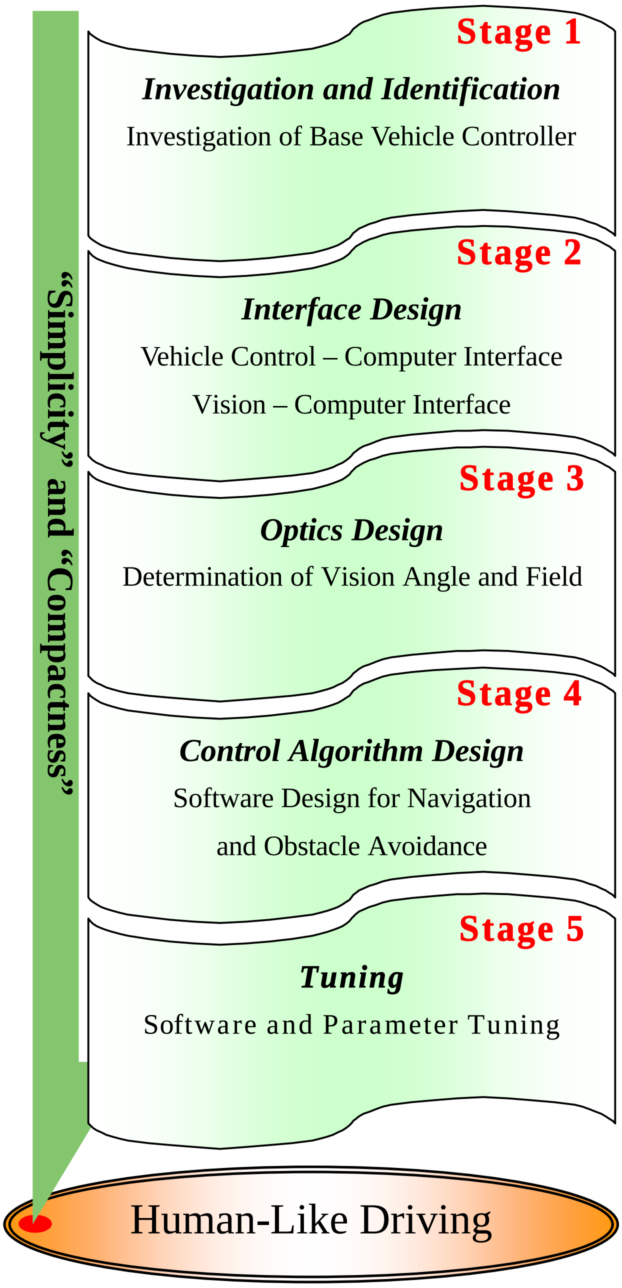

Figure 1 Scheme of the Design Process

Stage 3 Optics design

Selection of an optical lens with the proper scope angle and attachment to the CCD camera makes the acquisition of environmental information quiet easy. A sufficiently wide-scoped lens is effective for acquiring the lane information in a wide region. However, if the scope is too wide, it can induce undesirable causes. We determined the optimal scope angle needed for the lens.

Stage 4 Software design for navigation and obstacle avoidance

Most of the basic software was designed using MATLAB, with some of the exceptional sets of software directly concerned with the hardware coded in the C-language. The most effort was used to develop software for lane-image enhancement and detection and for navigation and obstacle avoidance:

(1) Lane-image enhancement and detection: A new color filtering technology was introduced to enhance the images of and discriminate between lanes, obstacles, and what we termed "noisy circumstances" such as lawns. The software has a learning function, so it can adapt to any conditions.

(2) Navigation and obstacle avoidance: From the detected lane information, the vehicle control signal is calculated based on the minimum energy optimal control theory. If the vision information is noise free, the algorithm is very simple and simple (optimal) gain control is sufficient. In practice, however, the lane information includes erroneous noises, so we added the artificial intelligence technology to avoid the ill effects caused by noise.

Stage 5 Parameter tuning

The software to detect the lanes and the parameters to control speed and to steer were tuned under the real circumstances.

3. Mechanical Design

3.1 Base Vehicle

Figure 2 shows the base vehicle. The base vehicle is an electric-powered wheelchair (Cerio Co. Ltd.) normally used by persons with foot and/or leg handicaps. It is 66 cm long and 40 cm tall, with a wheelbase of 46 cm. It weighs 35 kg. The 9-degree of ramp climbing ability is guaranteed by the original

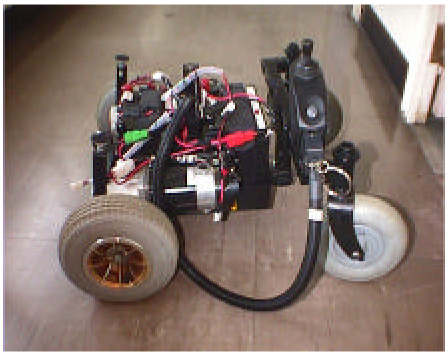

Figure 2 Base Vehicle

specifications. The maximum speed is 4 km/hr. The battery life is 6 hours.

3.2 Body Design and Placement

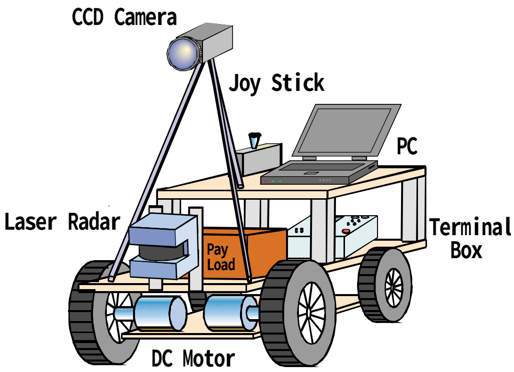

Figure 3 Scheme of the NECTAR 2000 vehicle

Figure 3 shows the scheme of the NECTAR 2000 vehicle. The NECTAR 2000 vehicle is 95 cm long and 180 cm tall. The 9-degree of ramp climbing ability is guaranteed. The maximum speed is 4 km/hr. The battery life is almost 3 hours because of the electricity consumption by additional PC and CCD camera and the laser radar. It has two upper and lower rooms. The lower room contains a driver, two 350-W DC motors, two 12-V deep-cycle batteries and an electromagnetic recharge-type brake. The upper room contains a PC, terminal boxes, laser radar for obstacle detection, E-stops (controlled by manual operation and whistle and/or radio wave) and a controller for manipulating the vehicle. Around the center of the upper cabin, a tall pillar 180 cm in height is set and fixed. At the top of the pillar, a 2-D color CCD camera with a super-wide-scope lens is set for monitoring the environment. These independent components are removable and changeable. There is also space in the upper room to add a payload. The deck of the vehicle is arranged compactly to satisfy the design concept of compactness.

4. Electrical Design

4.1 Power System

Figure 4 shows the electrical system. Two deep-cycle 12-V, 33-AH batteries are mounted on the vehicle. The cascade connection of these batteries provides a 24-V power source from which three DC power sources with different voltages are regenerated by DC-DC converters. These are (1) the 24-V power source for the motor and the laser radar, (2) the 12-V power source for the vision sensor and the control circuit, and (3) the 12-V power source for the E-stop wireless receiver. Because the power sources have different voltages, our design includes the use of a 3-terminal voltage regulator. The power is supplied to each circuit via DC connectors that satisfy the quality standard of the Japan Industry Standard (JIS). Since each component is independent, each circuit has an independent power switch.

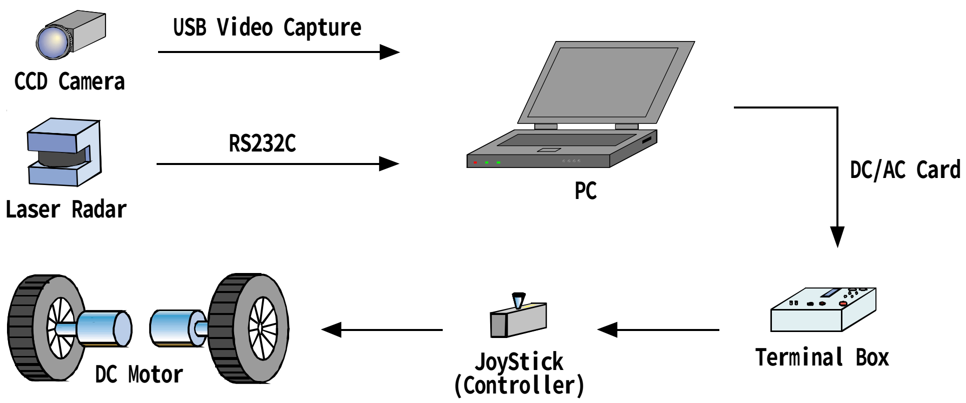

Figure 4 Electrical System Overview

4.2 Sensing

The NECTAR 2000 vehicle's two primary sensing techniques are computer vision by means of a CCD camera and the laser radar.

The vision sensor acquires most of the environmental information by which the vehicle is navigated. A 2-D color CCD camera for home TV use with automatic focus and automatic iris functions was employed as the vision sensor. The super-wide-scope lens with 110-degree field angle was mounted on the camera, which means that a 9-meter-wide scope can be covered when the focusing target distance is 3 m. Figure 5 shows the color CCD camera with its wide-scope lens. The image acquired by the camera is transmitted to the PC via an image capture board whose transmission speed is 30-full-frame images per second.

Figure 5 CCD Camera with Wide-Scope Lens

Obstacles are monitored by the vision sensor described above as well as by the laser radar. An obstacle color can be known as the prior information in the competition field. Thus existence of an obstacle can be detected by color information processing, i.e., by the color filtering that discriminates the color of the obstacle in the image.

The laser radar assists the vision sensor in detecting obstacles. When the vision sensor fails to detect an obstacle, the laser radar prevents sensory failure by supplementing to search. Figure 6 shows the laser radar. The laser radar system has capability to ±90 degrees of angle at 0.5-degree resolutions. The longest measurable distance is 80m and range resolution is 0.05m. The developed measurement system can capture the laser radar data one scan (361 point's data) at 0.1 seconds interval.

Figure 6 Laser Radar

4.3 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 the velocity and steering angle by means of a joystick, while in autonomous mode the computer calculates the velocity and steering angle based on vision and/or radar information.

The controller circuit has three basic functions, and we prepared three modules depending on the functions to be tested. 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 an E-stop signal to the vehicle when the E-stop button is pushed or when an E-stop wireless signal is transmitted. The third module conditions the signal from the D to A converter. The module adjusts the D to A converter so that the vehicle speed and steering controller work accurately in the normal operation range. Switching between the manual mode and the autonomous mode is done by a relay in the controller. The manual mode has priority.

5. Software Design

5.1 Control Rules for Human-Like Driving

The key concept for developing the vehicle control algorithm was to achieve "Human-Like Driving". Figure 7 shows how human beings drive a car. We can extract the driving control rules from the careful observations of human driving manners as follows:

(R1) Drivers see around the wide front view to check for changes in the environment, as well as to look at the focussed front area to perceive the center of two lanes.

(R2) They steer the handle so that the vehicle goes forward toward the front focussed target, in the center of the lanes.

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

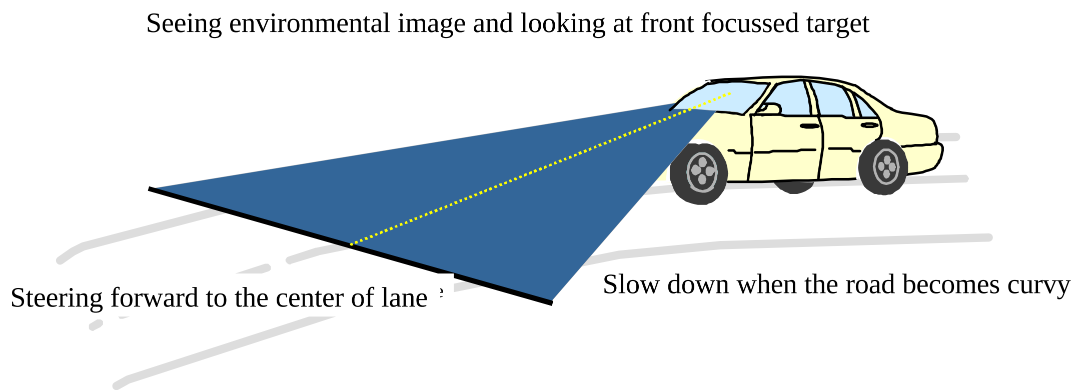

Figure 7 How Human Beings Drive a Car

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 functions of the vehicle. Because the 2-D image processing for the vision functions results in a very heavy computational load, we employed a distributed computing approach to reduce the load. We used MATLAB script as the main programming tools, as it is the best approach for managing such complicated distributed computing, signal processing from various sensors and actuator manipulation. The MATLAB script-programming environment allows the rapid prototyping as well as easy implementing and testing of the overall control algorithm. As a result we can implement a humanlike driving manner within a short development period.

(2) Lane and obstacle enhancement and detection

Figure 8 shows the scheme of how the lane and obstacles are detected. Each pixel taken into the PC is categorized as being part of the lane (colored something like white), the lawn (colored something like green) or the obstacle (colored something like orange) by the color filtering technique. Notice that this algorithm may detect a white pail as white lane, however it is not so important for the vehicle navigation, since the vehicle have to avoid white lane as well as white pails. The color- filtered image finally divides a frame of image into three zones, corresponding to the lane, lawn and obstacle zones. The processing determines where inside the image the lane, lawn or obstacle lies.

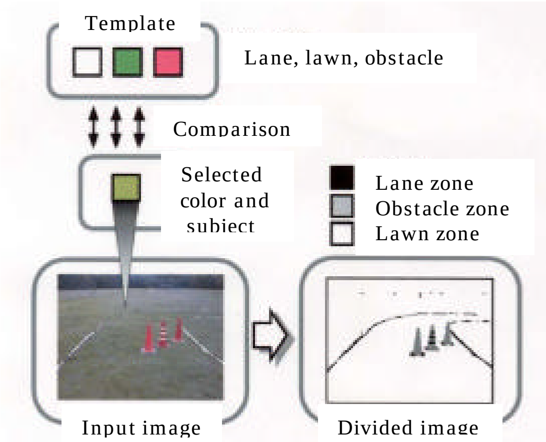

Figure 8 Lane and Obstacle Image Enhancement and Detection

5.3 Navigation

The navigation strategy is to follow the human driving manners described in Rules (R1), (R2) and (R3). The basic strategies are as follows:

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

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

(S2) Preview control strategy

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

(S3) Human-like speed control

Following (R3), when the vision sensor detects a curve, the vehicle's speed is decreased. The speed is qualitatively given in the manner of human driving from which the value of the speed is quantitatively determined by using fuzzy logic.

(S4) Exceptional processing

When the vision system acquires irregular images due to the sudden appearances of obstacles or noise by sunshine reflection, from which the above control cannot be conducted, exceptional processing is carried out. We prepared an algorithm from the knowledge of presumable irregular events.

5.4 Follow the Leader Event

(1) Detection of lead vehicle

Because of the accuracy as well as robustness, we use the laser radar to detect the lead vehicle. The laser radar can get 180 degrees of profile of distance of 25 m. In order to distinguish the target lead vehicle from the outside profile, we apply the range distance limited filter to track the lead vehicle.

(2) Control algorithm

Steering angle is determined by the relative angle between the lead vehicle and the NECTAR 2000 vehicle. And the reference distance according to the leader vehicle determines control speed. In case, the white lane is detected by using a CCD camera, the steering angle is determined by using information according to image sensor.

6. Other Design Issues

6.1 Safety

(1) Electromagnetic recharge-type braking system

The original base vehicle (electric-powered four-wheeled wheelchair) itself has an electromagnetic recharge-type braking system for safety purposes. When both the speed control and steering control signals are 0, an electromagnetic recharge-type brake works and the vehicle is locked. Furthermore, if the all of the batteries of the vehicle are off or gone, again the vehicle is an electromagnetic recharge-type brake works and locked.

(2) E-Stop

We designed three different types of emergency stop mechanisms to prevent the fail-safe purpose. The first one is a contact switch at the back of the pillar where the operator can easily touch it. The second one is stopping via wireless transmission. As the wireless transmitter we chose the whistle. The vehicle stops, only when the whistle rang. The third one is stopping via wireless electro-magnefic transmission, for the fail-safe capability. The wireless transmitter we chose was used as a real automobile remote starter. Because it is normally used to start engines, it works by a very complicated sequence of switching operations to avoid miss starting due to noises. We designed a sequence circuit that would stop the vehicle rather than start up the engine. The wireless E-stop works at the far place over 100 m. Figure 9 shows two different types of the wireless transmission system used for E-stops.

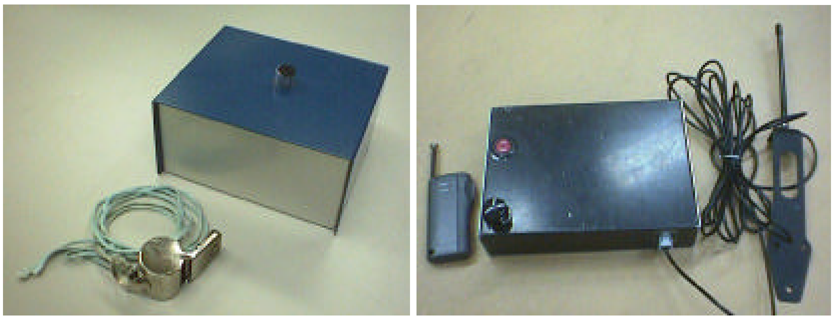

Figure 9 Whistle and Radio Wave E-STOP

6.2 Reliability and Durability

The key words "**Simplicity** " and "**Compactness**" are closely related to reliability and durability in our vehicle design. The simplicity yields the high reliability of not only the software development but also the hardware implementation. To maintain that high reliability, we used devices that satisfied the quality standard of the Japan Industrial Standard. Double components were prepared as backups.

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

6.3 Innovations

The substantial innovations of the NECTAR 2000 vehicle can be found in the lane detection and navigation controller designs, and thus we have included more details about these designs in the following paragraphs.

(1) Color filtering during lane detection

For lane detection, we developed a new color-filtering algorithm with a learning function. At the beginning, we human beings learn what comprises lanes, obstacles and lawns by recognizing these things in a mental image. Likewise, our system learns what comprises lanes, obstacles and lawns by examining captured images. First, the software decomposes the lane color into the trichromaticity R, G and B. Then the lane color is characterized by the vector $[\ R\ G\ B\ ]_{lane}$. Similarly the vectors $[\ R\ G\ B\ ]_{lawn}$ and $[\ R\ G\ B\ ]_{obstacle}$ are generated for lawns and obstacles, respectively. The system discriminates among those three items lane, lawn and obstacle by using the three vectors just described as templates. The colors of pixels taken in are compared with the templates and recognized. Once recognized, the template vectors can be updated as needed when circumstances change. For example, when the vehicle begins to move forward with the sun shining from another direction, the characteristics of the received images change, and in such a situation the vectors would be updated.

(2) Preview navigation control as an optimal control

In designing navigation system, we employed a preview control scheme, which is nothing more than the exerting the optimal control while minimizing the use of energy. We found that the distance (L) from the camera to the front focusing target and the proportional gain (k) of preview control are related with the weighting coefficients in the energy objective function. This knowledge helps when tuning the parameters L and k. We tuned these two parameters by employing our knowledge of the optimal control theory.

(3) Human-like driving by using fuzzy logic

Our use of fuzzy logic to control the vehicle speed is also innovative. After studying human driving, we extracted its basic features and determined several rules of speed and steering control. These rules are somewhat qualitative. Thus we employed fuzzy logic to produce the quantitative control signal, by which humanlike steering can be achieved.

(4) Artificial intelligence to avoid irregular situations

To handle the exceptional and irregular events that occur in our environment, we made use of artificial intelligence technology. We made a database for the presumed exceptional events, and we let the vehicle automatically carry out reasoning to estimate what will happen and to generate the appropriate steering signals to avoid such exceptional events.

6.4 Team Organization

Figure 10 shows the team organizational chart. And all team members in this chart are cross-listed in the team roster shown in Table 1.

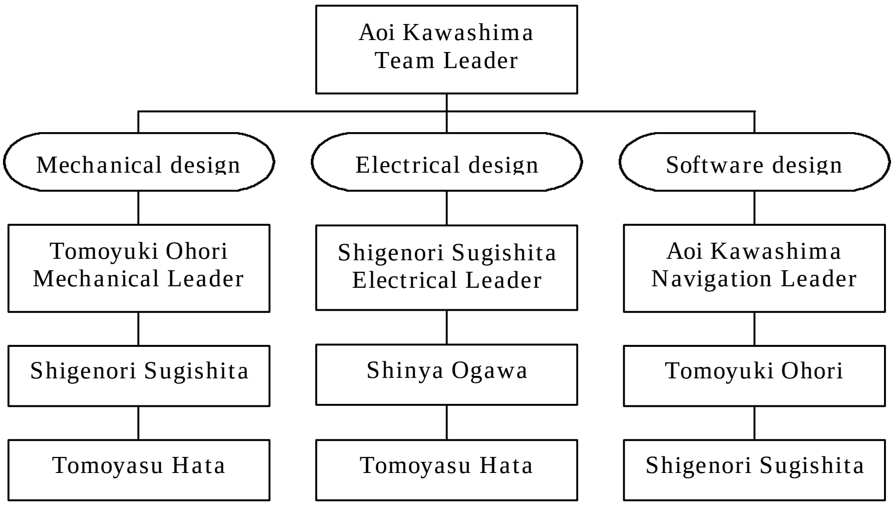

Figure 10 Team Organizational Chart

Table 1 Team Roster

Function	Name	Major	Academic Level
Team Leader	Aoi Kawashima	Systems Engineering	Graduate
Mechanical Leader	Tomoyuki Ohori	Systems Engineering	Graduate
Electrical Leader	Shigenori Sugishita	Systems Engineering	Graduate
	Shinya Ogawa	Systems and Control Engineering	Undergraduate
	Tomoyasu Hata	Systems and Control Engineering	Undergraduate

6.5 Cost

The costs of developing the NECTER 2000 vehicle are summarized in Table 2. The most expensive item was the Laser Radar. Maekawa Co. donates the Laser Radar for the academic research. The second-most expensive item was an electric-powered four-wheeled chair (Base Vehicle), and the third-most expensive item was the PC.

Table 2 Cost

Item	Cost		Remarks
	Yen (\)	Dollars ($)	
Electric-Powered Wheel chair (Cerio Co. Ltd.)	330,000	3,113	Base Vehicle
Personal Computer (IBM)	320,000	3,019	Celeron 333MHz
CCD Camera (Sony)	120,000	1,132	
Wide-Scope Lens (Sony)	10,000	94	
Laser Radar (SICK)	800,000	7,547	Donated by Maekawa Co.
Wireless E-stop	70,000	660	for Automobile Engine Starter
Electronics Parts	50,000	472	ICs, Electric parts
Mechanical Parts	30,000	283	Frame Steel
Body Cover	5,000	47	
Totals	**1,735,000**	**16,367**	