Simulation Study for Intelligent Wheelchair Vehicle with Ultrasonic and Infrared Sensors

Kouichi Kamimura*, Takahiro Kai*, Masahiro Yokomichi* and Tetsuro Kitazoe**
* Faculty of Engineering, University of Miyazaki **International University of Kagoshima
Gakuen Kibanadai Nishi 1-1, Miyazaki City, Japan, 889-2192
kai@cs.miyazaki-u.ac.jp

Abstract

In this paper, we propose wheelchair navigation system with infrared sensors and ultrasonic sensors to aid senior people and the handicapped to drive a wheelchair. We consider neural network to connect input sensor signals and output wheel speed. To get nice wheelchair controller, we constructed wheelchair simulator and applied G.A. for synaptic couplings in the neural networks. We investigated that a wheelchair controlled by this system ran safely and comfortably.

1 Introduction

Recently, many people have been researching autonomous mobile robots extensively. The purpose of these researches is to build the robots that are able to run safely in unknown or dynamically changing environments. In order to perceive the surrounding environments, robots mount many kinds of sensors, e.g., infrared sensors, ultrasonic range sensors and CCD cameras.

There is a growing demand for more safe and comfortable wheelchairs as mobile aids, as the population of senior people has been increasing. There are two research issues with these wheelchairs. One is autonomous (or semi-autonomous) and safe navigation, such as avoiding obstacles, wall following, going to a goal using various sensors [1,2]. The other is to develop human interfaces for easy operation [3,4].

In this paper, we aim to build an autonomous wheelchair robot so as to reduce navigation efforts of a handicapped person as far as possible. We use wide ranged ultrasonic sensors in front of wheelchair to detect obstacles and sharp ranged infrared sensors mounted on both sides of wheelchair to measure a distance to a wall.

The most major problem to construct the best robot is to make a realistic simulation of a robot. We use Webots by *Cyberbotics*[3] which is an excellent software to take account of noises in real world and to enable us to build any shape of mobile robot easily. We focus the task in the present paper to the navigation going along a right side wall by using front and right side sensors. If we are successful to get a task of going along a right side wall, then we can easily extend it to the task of going along a left side wall. If a robot can move along any side of a wall or can proceed straight, it will be possible to build a robot to go from one place to a destination, following an ordinary corridor in a building. We connected input sensors and output wheels by neural networks and developed G.A for the wheelchair simulator in a rather complicated test course to obtain the best robot. The simulation result was applied to the real wheelchair navigation in a corridor inside our building and eventually we had a smoothly moving nice wheelchair robot.

2 Outline of Wheelchair system

Fig. 1: *Wheelchair system*

The wheelchair system in our research is composed of a commercial electric wheelchair (Matsunaga MD-100), a desktop PC (CPU:PentiumIV 2.66GHz, OS:Linux), infrared sensors (GP2D12) and ultrasonic sensors (BTE054) as shown in Fig.1 The wheelchair has the maximum speed of 4.5 [km/h]. The infrared sensors are mounted on the side of the wheelchair and the ultrasonic sensors are mounted on the front. The PC processes infrared and ultrasonic sensor input values and controls wheel motors of the robot.

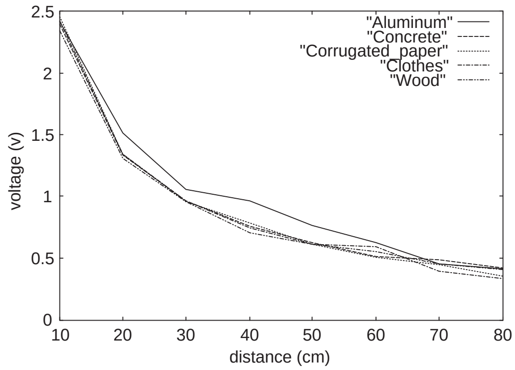

Fig. 2: *Distance-Voltage graph of an infrared sensor*

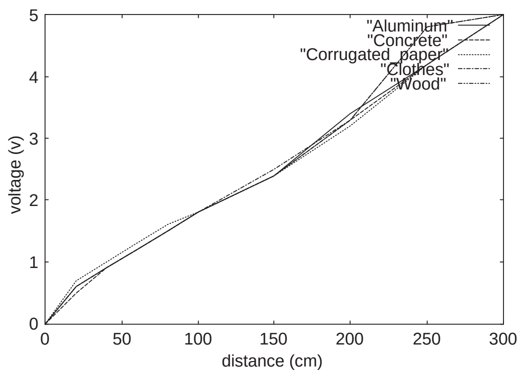

Fig. 3: *Distance-Voltage graph of an ultrasonic sensor*

The infrared and ultrasonic sensors output a distance to an object in voltage. Fig.2 shows distance - voltage graph for several kinds of objects. We find that the maximum detection ranges of the infrared and ultrasonic sensors are about 80 cm and 300cm, respectively. They have almost simulator response to the different objects as shown in Fig.2 and Fig.3.

3 Control methods

We consider control methods of a wheelchair so that a wheelchair runs along a right-hand side wall. We mount infrared and ultrasonic sensors on the wheelchair as shown in Fig.4. Since the ultrasonic sensors cover wide range of angle, three ultrasonic sensors($X01, X02, X03$) are installed on the front to detect front obstacles. Since the infrared sensors have narrow range sensing angle, four infrared sensors $X1, X2, X3, X4$ are installed on left and right sides to measure the distance to a wall. Since we do not use left side sensors $X3, X4$ for our present task of going along a right side wall, we can easily extend our task to go along a left side wall by using $X3, X4$. The ultrasonic sensors ($X01, X02, X03$) which detect an obstacle or a wall in the front direction are normalized in the range 0∼1.0 by defining

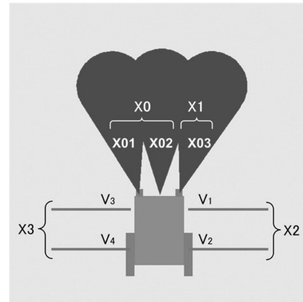

Fig. 4: *Sensor configurations for wheelchair robot*

$$X01 = \alpha_{ultra\_s}/V01, \quad X02 = \alpha_{ultra\_s}/V02 \qquad (1)$$
$$X03 = \alpha_{ultra\_s}/V03$$
$$\alpha_{ultra\_s} = 75.0 \qquad (2)$$

where $V01$ is the output voltage of the sensor and α_{ultra_s} is a normalization constant. To reduce variables, we take the mean value of $X01$, $X02$ as

$$X0 = (X01 + X02)/2.0 \qquad (3)$$
$$X1 = X03$$

Side infrared sensor values are denoted by

$$X2 = (V_1 + V_2)/2V_{infra\_s} \qquad (4)$$
$$X3 = (V_3 + V_4)/2V_{infra\_s}$$

To normalize Xi to take 0∼1.0, we choose

$$V_{infra\_s} = 2.78 \qquad (5)$$

The control system of the wheelchair consists of neural networks shown in Fig.5. To train the synaptic couplings by means of genetic algorithms, we investigated robot movement in a computer simulation model. A difficult problem in computer simulations is how to simulate the real world with respect to noises. *Webots ver.4.0.24 by Cyberbotics*[5], is an excellent software tool that takes account of uncertainties assumed to exist in the real world. Noises of ±10% and ±10% are randomly added to the amplitude of the sensor value, and the amplitude of the motor speed, respectively.

Another difficulty in computer simulation is how to build a simulator to imitate the real object as far as possible. The webots software package is composed of VRML coding and any parts of an object are easily replaced or modified. As a typical example, we take a rectangular area with concave spaces surrounded by a wall as shown in Fig.6, in which wheelchair webots is required to follow the wall counterclockwise. It must keep a safe and short distance from the wall on the right, and enters wide spaces and narrow spaces.

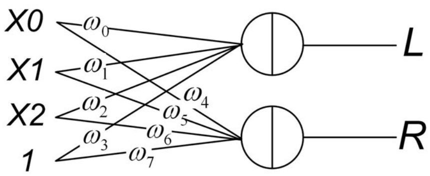

Fig. 5: *Neural Network to control left and right wheel*

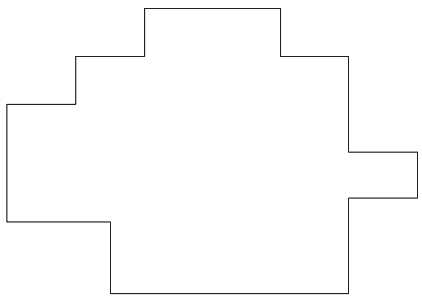

Fig. 6: *Test course for simulator wheelchair robot*

4 Evolutionary Adaptation

To train robot control systems, we perform adaptation under a computer simulation model of a robot and its environment. As shown in Fig.5, the data $X0, X1, X2$ output from the sensors are fed to the neural networks with self-training ability. The synaptic couplings are then revised by genetic algorithms. The control signals to the right wheel and left wheel, L and R are given by

$$L = F(\omega_0 X0 + \omega_1 X1 + \omega_2 X2 + \omega_3) \quad (6)$$

$$R = F(\omega_4 X0 + \omega_5 X1 + \omega_6 X2 + \omega_7) \quad (7)$$

$$F(x) = \tanh(x) \quad (8)$$

where L and R are normalized as $-1.0 \leq L, R \leq 1.0$. We define mean voltage V_m and differnce voltage V_d supplied to the wheel motors so as to control wheel speeds as

$$V_m = V_{max} \cdot (L + R)/2.0 \quad (9)$$

$$V_d = V'_{max} \cdot (L - R)/2.0 \quad (10)$$

where $V_{max} = 1.12volt$, $V'_{max} = 1.0volt$. A given voltage V_m, V_d determine left and right wheel speeds v_L, v_R. The functional relations between these variables are decided by moving our actual wheelchair. We obtained the best fit functions experimentally and denote them as

$$v_R = f_R(V_m, V_d) \quad (11)$$

$$v_L = f_L(V_m, V_d) \quad (12)$$

$\omega_0 \sim \omega_7$ are synaptic couplings, as shown in Fig.5, connecting data from sensors with the control of the right or left motors. We determine ω_i by using the genetic algorithms. The algorithms for obtaining the best genes are as follows:

1) Make N_1 robots with randomly generated synaptic couplings and left them run in the area shown in Fig.6 for certain period.

2) Make new N_2 robots from the old N_1 robots by using genetic algorithms in which the synaptic couplings of new robots are generated by real-coded genetic algorithms, in which α of $BLX - \alpha$[5] is set to 0.5. Then let them run for the same period as in step 1.

3) Make new N_3 robots from the old N_1 robots by using mutation.

4) Measure all the robots $N_1 + N_2 + N_3$ by using a given evaluation function, and choose N_1 robots with the highest scores. If the total score of the N_1 robots exceeds a given threshold, stop the loop; otherwise go to step 2.

5 Experimental results and conclusion

We performed simulation in the fairly complicated test course shown in Fig.6. The evaluation function in genetic algorithms is given as

$$g = \left(\frac{\sum^{STEP} speed}{STEP} \right) \cdot \left(\frac{\sum^{STEP} X2}{STEP} \right) \cdot \left(1 + \sum^{STEP} X3 \right)^{-1} \cdot \left(1 + \sum^{STEP} collision \right)^{-1} \quad (13)$$

Each term in Eq.(13) evaluates the robot performance from different points of view, ①measuring wheelchair robot's speed, ②going along a right side wall, ③movements without obstacles on the left side, and ④avoiding collision against a wall. The evaluation function g has a high value if a robot fallows a wall without colliding with anything and if it moves forward as far as possible. We take $N_1 = 10, N_2 = 4, N_3 = 11, speed = (v_R + v_L)/2v_{max}$, and $v_{max} = 0.88[m/s], STEP = 400$.

As a result of evolutionary adaptation after 400 generations, the coupling values of the best 10 robots became to have almost the same value which are shown in Table.1 together with the fitness value. Table.2 shows the behaviors of the best robot at the typical places shown in Fig.7. The trace of the robot in the test course is also shown in Fig.7.

Table 1: *The coupling values of the best robot after 400 generations.*

ω_0	ω_1	ω_2	ω_3	ω_4	ω_5	ω_6	ω_7	fitness
-5.24	-4.09	-0.23	1.59	1.77	1.05	0.73	0.05	9011.29

Table 2: *Typical behaviors of the best robot in Table.1*

	$X0$	$X1$	$X2$	L	R	v_L	v_R	
A	0.04	0.04	0.25	0.82	0.34	2.80	1.83	Turn right
B	0.24	0.21	0.25	-0.52	0.71	-0.13	1.18	Turn left
C	0.04	0.19	0.29	0.49	0.49	1.90	1.93	Go straight

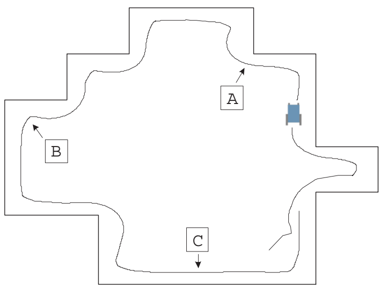

Fig. 7: *Result of test course simulation*

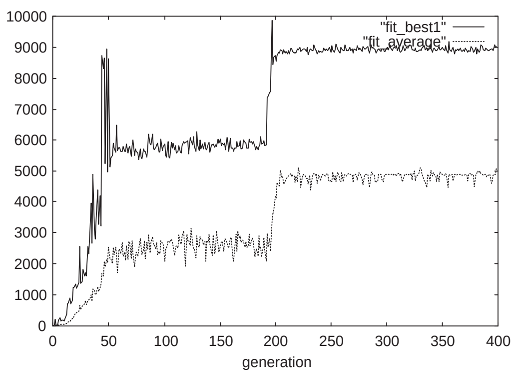

Fig. 8: *Evaluation function in GA*

The evaluation function for the best robot and their average value among robots are given in Fig.8 against generation development.

We made simulation experiments of wheelchair navigation on the second floor in the north building of the faculty of engineering, University of Miyazaki as shown in Fig.9. The robot moved smoothly as the trace is shown by a solid line in Fig.9. We conclude that our two step strategies, test course simulation and its application to real mapped course led to a successful result.

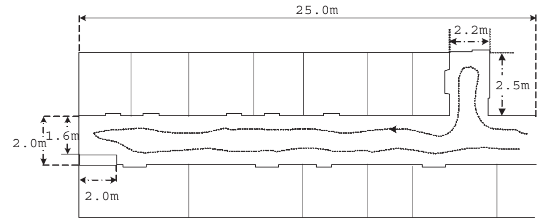

Fig. 9: *Course of the corridor inside our building and trace of the best robot*

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