# Development of Multi Purpose Small Electric Vehicle with Application of Automated Guiding Control System

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## Abstract
*A prototype of multi purpose electric vehicle (EV) is developed based on the concept toward future transportation. The EV is developed based on the concepts of smallness and multi-purpose of 'Structure' and 'control'. The size of the developed EV is 1m-width, 2m-length and 30cm-height. The EV has the flat floor on which a variety of upper structures are easily fixed. Moreover, traction, steering and braking are electrically controlled; so various control devices are used for controlling the vehicle. The developed prototype EV has potential to contribute will contribute not only to solving the problems of air pollution, energy consumption and congestions, but also to reducing cost of production, resulting in wider and faster prevalence. This study explains application of the developed EV and evaluates this application by experiments.*

## Keywords
*EV (electric vehicle), control system, intelligent, multi purpose, automated guiding control*

## 1. INTRODUCTION
There have been serious problems of air pollution, energy consumption, traffic accident and congestion caused by automotive traffic. An EV, of cause, contributes to solving the problems of air pollution, energy consumption. To solve the rest problems, the vehicle should be more intelligent. In addition, if the vehicle is very small and multi-purpose, it will contribute not only to solving the problems of air pollution, energy consumption and congestions, but also to reducing cost of production resulting in wider and faster prevalence.

This paper explains a prototype EV developed based on the above concept. Figure 1 shows the developed EV. The size of vehicle is 1m-width, 2m-length and 30cm-hight. The vehicle has multi-purpose features in two aspects. One aspect is that the vehicle accepts various upper structures according to use. All components are fixed in the floor frame structure. To obtain wider and flat-floor of 1m x 2m, the vehicle has eight small wheels instead of conventional four larger wheels. Various components can be fixed on the floor according to user's purposes. The other is that the vehicle accepts various kind of electric signal for control. Steering and braking are also controlled by electric motors as well as drive system. So, the vehicle has the drive-by-wire configuration. A traction force, brake force and steering angle are controlled by an electric signal input. Three kinds of signal input are accepted for controlling the vehicle, that is, serial data input (RS-232c), voltage input and pulse width input are acceptable. Various kinds of interface such as conventional steering wheel and pedals, joystick, game pad, radio receiver for remote operation and so on, can be used for control the vehicle. Moreover it is very easy to implement automatic operation of the vehicle by using computer and sensors.

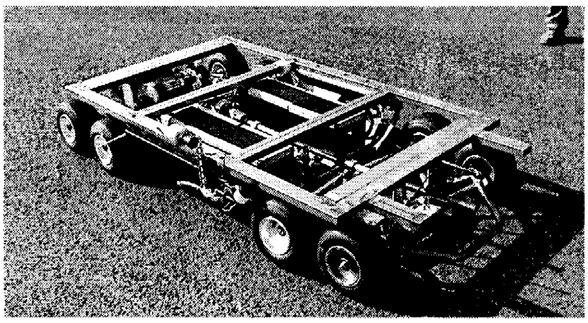

**Fig. 1** Developed prototype EV

In the following chapters, concept, structure and components, and application of the developed EV is described.

## 2. CONCEPT OF DEVELOPED EV
This chapter describes the concepts of the developed prototype EV. The main concepts are smallness and multi-purpose of 'structure' and 'control'.

Smallness of the vehicle contributes to low energy consumption and large traffic capacity. It is unreasonable and waste of energy that people use the vehicle whose weight more than 1ton for trivial transference. If vehicles are smaller, more vehicles can be driven on the road and parked in the parking lot. For example, if a vehicle is 1m-width and 2m-length, two vehicles can run in parallel on one lane for the current vehicles, and four vehicles can be parked in a parking space assigned for a current vehicle. Smaller sized vehicle can be made at lower cost and be sold at lower price. Of course, a lot of kinds of vehicles have been proposed based on the concept of smallness [Kakiuchi et al., 2001; Shimizu et al., 1998; Tsugawa, 1992].

In addition to the concept of smallness, the vehicle is developed based on the concept of structurally multi-purpose. To realize multi-purpose feature, the vehicle is designed to be used by combining upper structures for specific purpose and a platform of drive system. Constraints of upper body design should be as few as possible. So, the developed platform has flat border without wheelhouses or a steering shaft. Moreover, all components for driving the vehicle are fixed below the border. Small eight wheels are used instead of lager four wheels like the 8-wheeler EV, KAZ[Shimizu et al., 2001; Gogh et al., 2001]. Steering is conducted by an electric motor instead of a steering wheel. Traction and braking are also conducted by motors instead of pedals. So the upper structure is not constrained by wheelhouses, a steering wheel, and pedals. It should be noted that the vehicle also has a manual brake system attached a side of the platform for safety consideration.

The vehicle is so designed as to a variety of control devices are used for control it. This concept is called as multi-purpose of 'control' in this paper. As described above, traction, braking and steering are conducted by electric motors. Input devices are necessary for control the motors. In this vehicle, onboard computer is fixed for interfacing the input devices and motors. The computer accepts the three kinds of signal input, that is, serial data input (RS-232c), pulse width input, and voltage input are acceptable. The onboard computer receives the input signal and control the motors. So people can use, various kinds of input devices according to his purpose. For example, if people wants to drive the vehicle by themselves, steering wheel and pedals, joystick, game pad and so on can be used for control. If computer with sensors such as line sensors, laser radars are equipped, the vehicle can be used as an automated guided vehicle (AGV) in factories or institutes. If the wireless receiver is equipped, people or computer can control the vehicle from remote area.

## 3. STRUCTURE AND COMPONENTS

This chapter explains the structure and components of the developed EV. In the following subsections, frame structure and components of traction, braking, steering, power supply and computer are explained.

### *3.1 Frame structure*

A frame of a racing kart is used as a base frame of the developed EV. The developed EV has eight wheels, so additional frames for additional wheels are fixed front and rear sides of the base frame. The developed EV has no spring-damper suspension seen in the conventional vehicles. The base frame's bending absorbs a shock from the ground. Components of a traction motor, a steering motor, motor controllers, steering linkages, manual and electric brakes, batteries and an onboard computer are fixed on the base frame. Figure 2 and Table 1 show the layout and specifications of the components. An upper frame, the rectangle frame shown in Figure 1, is fixed on the base frame at six points, and is a flat border between this platform and the upper structure made according to various purposes.

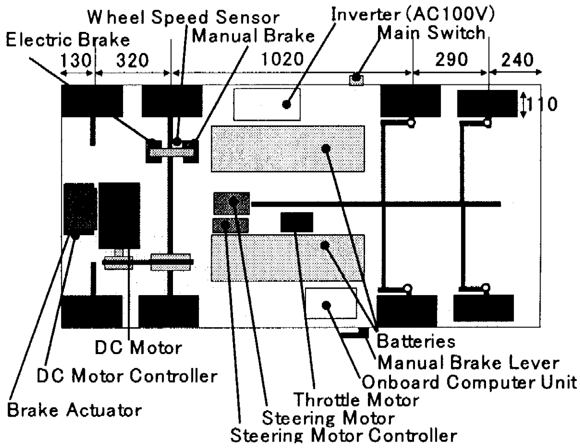


**Fig. 2** Layout of components

**Table 1** Specifications of components

| | |
|---|---|
| **Traction** | **Traction Motor:** ADVANCED DC MOTOR K91-4003 (DC series-wound motor, 8HP conterminous, 35HP at 400A)<br>Transmission: Chain drive (reduction 1:4)<br>**Motor Controller:** CURTIS PMC Model 1205-201 (maximum output 350A)<br>Servomotor for control POT box: FUTABA S3101(torque 2.5kgf cm) |
| **Brake** | **Type:** Hydraulic disk brake (2 series)<br>**Motor for Brake:** TUKASA TG47C-LA-100T (liner motion actuator) |
| **Steering** | **Motor for Steering:** ORIENTAL MOTOR RK596AW-P50 (Stepping motor, allowable torque 370kgf cm) |
| **Power Supply** | **Battery:** 12V Lead acid battery (26Ah x 8)<br>**DC-AC inverter:** AC100V, 600W |

### *3.2 Traction component*

A DC motor is used for generating a traction force. The DC motor drives the third axle of the vehicle. The left and right wheels are independently rotated at the first, second and forth axle. At third axles, however, a pair of wheels is rigidly connected to one axle. The DC motor drives the axle and the pair of wheels connected to the axle rotates. The motor is driven at 48V. The current supplied to motor is controlled by the motor controller. The controller has a control lever called as POT box, which is used to change output current. The POT box is usually connected to an acceleration pedal for a manual operated EV. In the developed EV, the POT box's lever is moved by a DC servomotor. So, the output current is controlled by position control of the servomotor and can be manually controlled if necessary.

### *3.3 Brake component*

Two series of hydraulic disk brake are fixed on the third axle. One is for manual brake, and the other is for electric control. As to electric controlled brake, the mechanism is the same as manual brake. A DC motor is used to pressurize a master cylinder. The DC motor's rotation is changed to liner motion by reduction gears and pushes the lever. The pushed lever bends and pressurizes the master cylinder.

### *3.4 Steering component*

The wheels on the first and second axles are steered. A stepping motor is fixed on the base frame and rotate steering linkage. A stepping motor controller is also fixed on the base frame. If the controller receives an electric pulse, it turns the stepping motor's rotor by one step clockwise or counterclockwise.

### *3.5 Power supply*

Lead acid batteries are used for main power supply. Two series of four 12V batteries (48V) are fixed in the left and right parts of battery boxes on the base frame, respectively. A DC-AC inverters (600W) is fixed to supply AC-DC converters for various components such as the onboard computer, DC-servomotor, stepping motor and motor for brake with AC100V.

### *3.6 Onboard computer*

An onboard computer is fixed on the base frame and plays a role of an interface between control device and traction, braking and steering components. Three kinds of signals from the control device are received by the onboard computer as shown in Figure 3. A person can select the type of received signal by setting dipswitches on the onboard computer. The following explains each signal input.

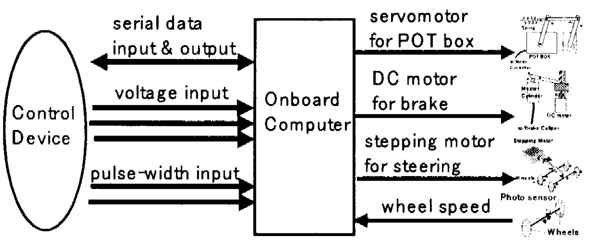


**Fig. 3** Control flow from control device to each component

## 4. APPLICATION

This chapter describes applications of the developed EV. The developed EV is multi-purpose in 'structure' and 'control'; so various applications are expected. In the following sections, the concept of application, developed applications of a commuting kart and a mobile shop, and developed automated guiding control are described.

### *4.1 Concept of application*

The developed EV's platform has a flat boarder and it accepts various upper structure according to use. Moreover, various control devices are accepted because traction, braking and steering are eclectically controlled. If people want to use the EV as a passenger vehicle, the upper structure will be composed of seat, control device of a handle and pedals, and components necessary for driving on the road such as lights, winkers, radio, wipers, door locks. If the EV is used as an automated guided vehicle (AGV), upper structure will be composed of a sensor for detecting a lane, a controller and necessary components such as obstacle detection sensors and wireless transmitter and receiver. The EV can be applied to various kinds of purposes, for example, loaders, a radio controlled vehicles, golf karts, amusement machines and so on. Figure 4 shows the simplified illustrations of application to a passenger vehicle, AGV, radio controlled car and loaders.

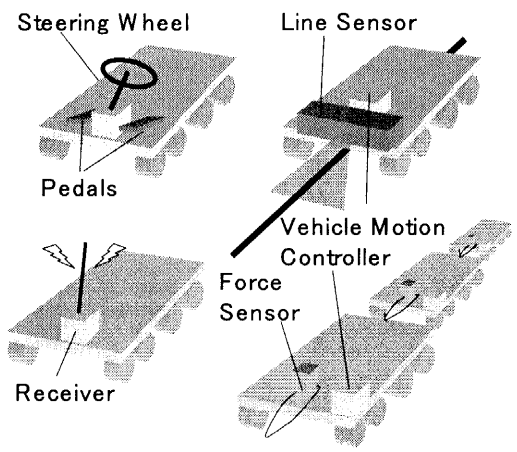


**Fig. 4** Simplified configuration of upper structure for various applications (upper-left: passenger vehicle, upper-right: automated guided vehicle, lower-left: radio controlled vehicle, lower-right: loader)

### *4.2 Application to commuting kart and mobile shop*

In this study, a prototype of a commuting kart and a mobile coffee shop are designed. Figures 5 and 6 show the design sketches for them. Figure 7 is the pictures of the developed commuting kart based on upper-left part of the design sketches shown in Figure 5. This kart is driven by radio control. So remote station as well as a passenger can control the vehicle. Wireless CCD camera is attached for remote station's control. Two people can be seated and four people can stand on the kart. Figure 8 shows the picture of the developed mobile coffee shop based on the design sketches shown in Figure 6. A shopkeeper can drive the shop to the destination. In the destination, he can open the shop and serve coffee.

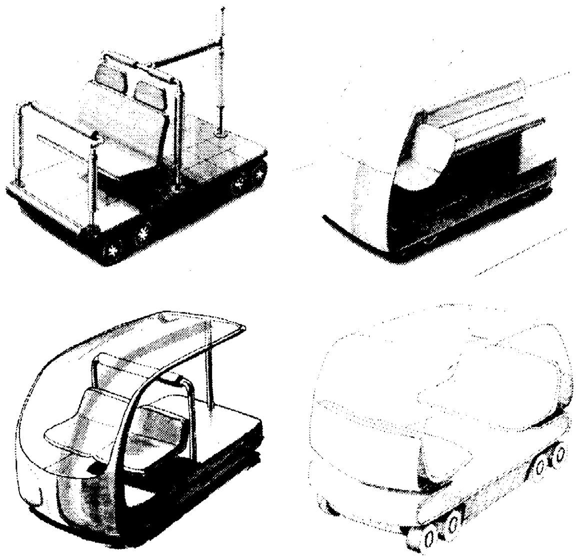

**Fig. 5** Design sketches of commuting kart

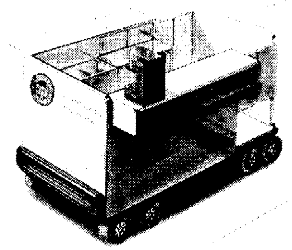

**Fig. 6** Design sketch of mobile coffee shop

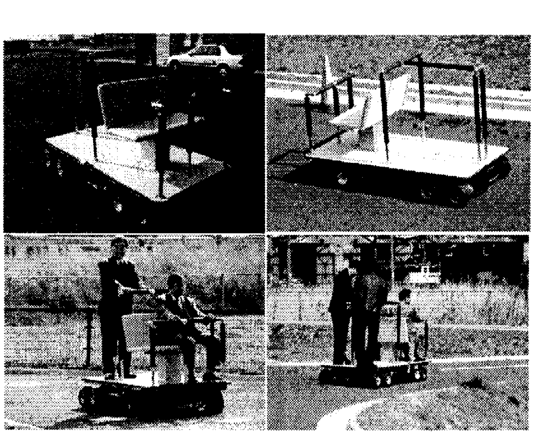

**Fig. 7** Commuting kart

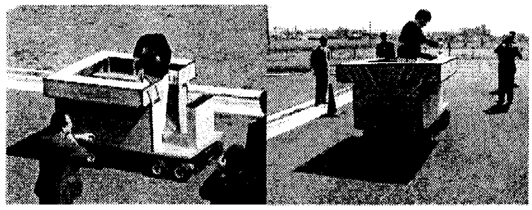

**Fig. 8** Mobile coffee shop

### *4.3 Application of automated guiding control*

This section describes developed application of automated guiding control for the multi-purpose small EV. Two kinds of automated guiding system are developed. One is automated guiding system using the RTK-GPS and digital map, and the other is using an USB camera detecting the white line on the road. In the following subsections, system configuration, recognizing position, motion control algorithm and experimental results are described of each automated guiding control.

#### *4.3.1 Automated guiding system using RTK-GPS and digital map*

This subsection explains automated guiding system using the RTK-GPS and the digital map. In the following sections system configuration, position measurement, vehicle motion control algorithm, and experimental results are described.

(1) System configuration

The vehicle is controlled to track the course based on the relationship between the position of the vehicle and desired course. This system needs only a laptop PC, the RTK-GPS and the multi-purpose small EV. Figure 9 shows the system configuration. The top picture in Figure 9 is shown as RTK-GPS sys-

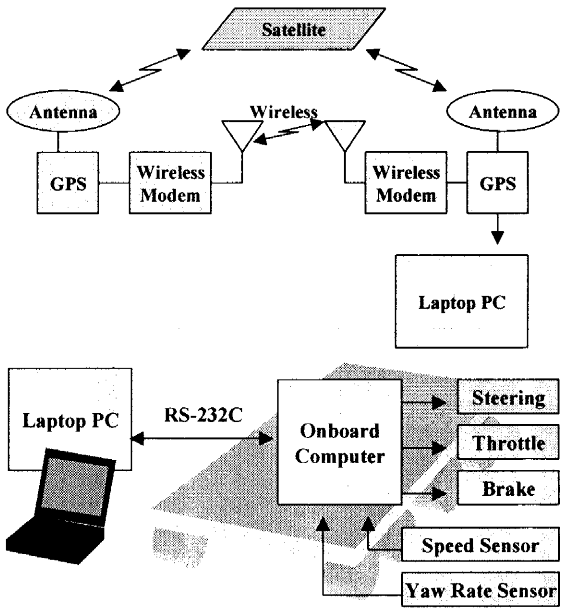


**Fig. 9** System configuration (using RTK-GPS)

tem briefly. The RTK-GPS is the GPS receiver which realizes very precise position measurement by using differential correction signal sent from base station. A GPS antenna is equipped on the vehicle and connects a GPS receiver. A laptop PC receives the position data from GPS receiver using a RS-232c connection. A wireless modem is equipped on the vehicle for obtaining differential correction of the RTK-GPS. The down picture in Figure 9 is shown as this system configuration briefly. In this system, a laptop PC connects the onboard computer on the small multi-purpose EV using a RS-232c connection. This PC sends data to the onboard computer for the steering, the throttle and the brake. This PC receives dates from the onboard computer about the information of speed sensor and yaw-rate sensor every 100[ms].

(2) Position measurement

The absolute vehicle position and yaw angle are estimated by the Kalman filter integrating information from the RTK-GPS and vehicle motion sensors[Omae et al., 1999]. This system obtains the vehicle position and yaw- angle information every 100[ms]. The vehicle is controlled to track the course by relationship between the vehicle position and the desired course stored in the PC as position data. In this study, the position data are composed of a series of position information including X(east), Y(north), distances and point ID. The desired course in our campus used in the experiment is shown in Figure 10.

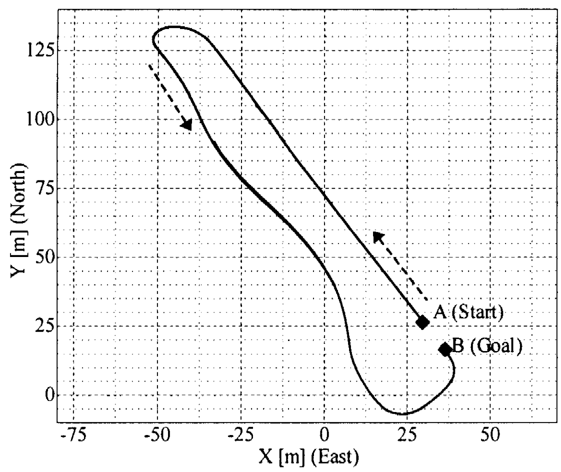


**Fig. 10** Desired course

(3) Control algorithm

The objective of the algorithm is to determine the steering angle to track the desired course. The algorithm controls the necessary amount of the steering from calculating the future and present lateral deviation from the center of the road. The future position of the vehicle is estimated by calculating the velocity and yaw rate of the vehicle. The lateral deviation is assumed to be obtained by GPS sensor. Figure 11 shows the valuables used in the algorithm. Assuming that the controlled vehicle travels at a constant velocity, the yaw rate, the estimated a future lateral displacement ($y_{vf}$) in $t_p$[s] is given by:

$$y_{vf} = \frac{1}{2} V \cdot \gamma \cdot t_p^{\ 2} \qquad (1)$$

where, $\gamma$ and $V$ are denote yaw rate[rad/s] and velocity[m/s] respectively.

To reduce future deviation of the controlled vehicle from the desired course ($y_{vf}$ - $y_{cf}$) to zero, the required change of yaw rate ($\Delta\gamma_{des}$) should satisfy the following equation:

$$y_{cf} = \frac{1}{2} V(\gamma + \Delta\gamma_{des}) \cdot t_p^{\ 2} \qquad (2)$$

From the equation above, the required change of yaw rate given by:

$$\Delta\gamma_{des} = \frac{2y_{cf}}{V \cdot t_p^{\ 2}} - \gamma \qquad (3)$$

The amount of steering ($\Delta\delta$) is determined using $\Delta\gamma_{des}$ and a present lateral deviation ($\varepsilon$) as follows:

$$\Delta\delta = K_1 \cdot \Delta\gamma_{des} + K_2 \cdot \varepsilon \qquad (4)$$

In the above equation, the former part is the feed-forward term and the latter is the feedback term. $K_1$ and $K_2$ are constant gains. $K_1$ and $K_2$ are tuned by experiments.

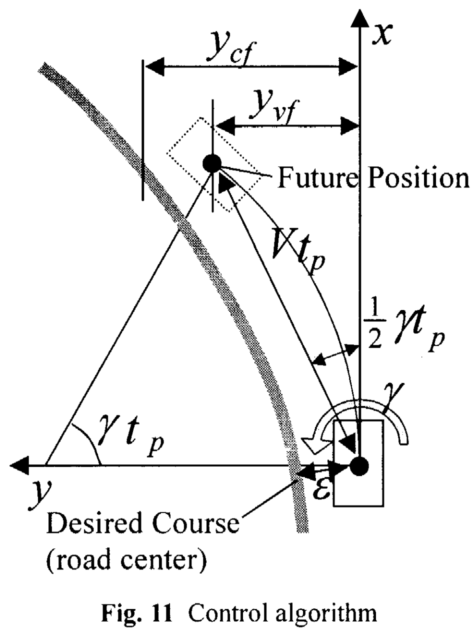


**Fig. 11** Control algorithm

(4) Experimental results

The automated guiding system using the RTK-GPS is evaluated by experiments. The desired course is shown in Figure 10. The vehicle starts at point A in arrowhead direction, and stops at point B. One person is inside the vehicle for safety reasons. The experimental result is shown in Figure 12. Figure 12 shows a trajectory of the vehicle at a speed of 2.5[m/s]. The vehicle travels along the road center in the campus. The proposed system realizes automated guiding without depending on infrastructures on the road such as a white line.

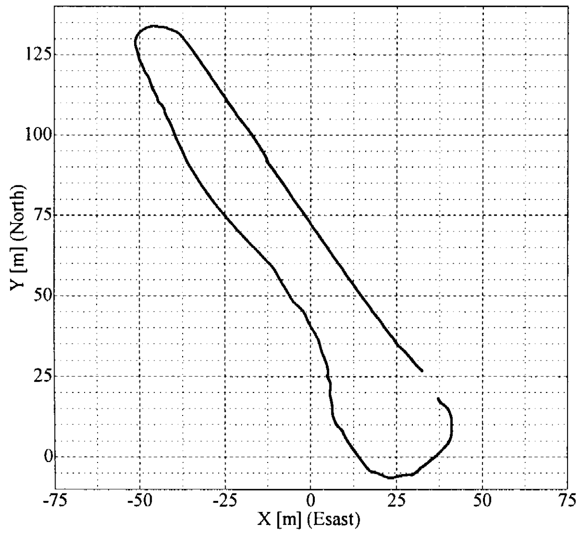


**Fig. 12** Experimental result

#### *4.3.2 Automated guiding system using an USB camera detecting line on road*

This subsection explains automated guiding system using an USB camera. In the following sections, system configuration, image processing, vehicle motion control algorithm and experimental results are described of each automated guiding control.

(1) System configuration

The vehicle is controlled to track the desired course based on the position of the white obtained by image processing and the information of vehicle motion. Figure 13 shows this system configuration. This system has only an USB camera, a laptop PC and the multi-purpose vehicle. This system uses an USB camera, because it is compact and easy to connect to a laptop PC. This camera is fixed on the front part of the vehicle in 0.5[m] height. The camera used in this system is CMOS type and supports video capture 320x240. A laptop PC connects the onboard computer on the small multi-purpose EV using a RS-232c connection. This PC sends data to the onboard computer for the steering, the throttle and the brake. This PC receives dates from onboard computer about the information of speed sensor and yaw-rate sensor every 100[ms].

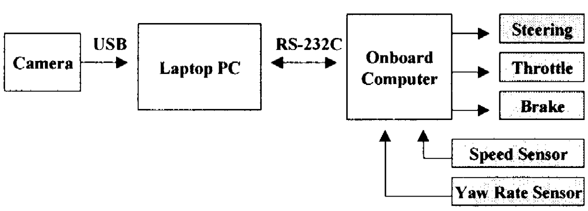


**Fig. 13** System configuration (using an USB camera)

(2) Image processing

The USB camera using the image processing detects the white line 1[m] ahead of the vehicle. This camera image is grabbed every 100[ms]. The algorithm is detecting the white line on the road. In detail, this algorithm differentiates the grab image in horizontal direction. Moreover, this algorithm refers the color values of the grabbed pixels and expected white line positions calculated by vehicle motion and previous position.

(3) Vehicle motion control algorithm

The purpose of the algorithm is to trace the line. This algorithm is similar to the control algorithm described in subsection 4.3.1. In this case, relative lateral position of the white line corresponds to $y_{cf}$ shown in Figure 11. The future position of the vehicle is estimated by using the velocity and yaw rate of the vehicle. This algorithm controls the amount of the steering in order to decrease the future error to zero. The difference between this algorithm and that described in subsection 4.3.1 is that this algorithm does not use current lateral error and that $t_p$ is $D/V$. The required change of yaw rate ($\Delta\gamma_{des}$) should satisfy the following equation:

$$y_{cf} = \frac{1}{2}V(\gamma + \Delta\gamma_{des})\cdot(D/V)^2 \qquad (5)$$

where, $D$ denotes the longitudinal distance between vehicle's CG and white line position detected by the camera.

From the equation above, the required change of yaw rate given by:

$$\Delta\gamma_{des} = \frac{2y_{cf}}{V\cdot(D/V)^2} - \gamma \qquad (6)$$

The amount of steering ($\Delta\delta$) is determined using $\Delta\gamma_{des}$ as follows:

$$\Delta\delta = K_3 \cdot \Delta\gamma_{des} \qquad (7)$$

$K_3$ is control gain, which is tuned by experiments.

(4) Experimental results

The proposed automated guiding system using an

USB camera is evaluated by experiments. One person is inside the vehicle for safety reasons. Experiments are conducted on three kinds of courses. The three courses are named as course1, course2 and course3 in this paper. Course1 is straight line. Course2 is curved line whose radius of curvature is 300[m]. Course3 is curved line whose radius of curvature is 10[m]. The velocity of the vehicle is 2.5[m/s].

Figure 14 shows the lateral deviation of course1. Initial lateral deviation is about 0.3[m]. The lateral deviation is converging smoothly without overshooting. While the vehicle is tracing the course1, the lateral deviation is kept less than 0.02[m]. The RMS of this result after converging is 0.0081[m].

Figure 15 and 16 show the lateral deviation of course2 and 3. The each lateral deviation are less than 0.03[m] on course2 and less than 0.15[m] on course3. The RMS of these results is each about 0.011[m] and 0.071[m] respectively. These results show the system is valid under straight course and variable corner courses.

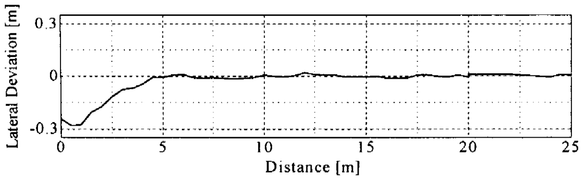


**Fig. 14** Experimental result (course1)

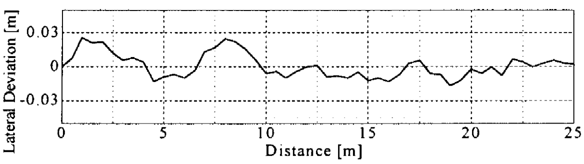


**Fig. 15** Experimental result (course2)

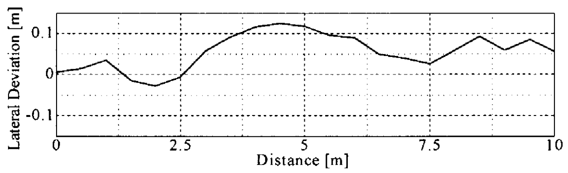


**Fig. 16** Experimental result (course3)

## 5. CONCLUSIONS

This paper explains a prototype small EV. The EV is developed based on the concept of smallness and multi-purpose of 'structure' and 'control'. Main concepts, components and application of the developed EV are described. This study evaluated two systems of applications of this developed vehicle by experiments. As experimental results, automated guiding system using the RTK-GPS can track the desired course accurately, and the system using an USB camera is valid under straight course and variable corner courses. In addition, this study proved the multi-purpose feature of the EV. Moreover, this study shows the EV has the cooperativeness with the future application systems.

The developed EV will contribute not only to solving the problems of air pollution, energy consumption and congestions, but also to reducing cost of production resulting in wider and faster prevalence because of the multi-purpose feature.

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