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# Vision-based Vehicle Navigation Using the Fluorescent Lamp Array on the Ceiling

By

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**Abstract**

In this paper, autonomous navigation based on a TV vision system on board a vehicle is proppsed. Our method is to use fluorescent lamp arrays on the ceiling as a lighthouse for vehicle motion.

First, experimental study of vehicle control based on information from photo-sensors, set up on a TV screen, is worked out using an actual size model. Then, numerical simulations for this control scheme are carried out in detail. Moreover, a more vision-based approach is investigated which extracts information aspects from the images of fluorescent lamp arrays to realize more exact motion along the lamp array.

Finally, a practical autonomous vehicle which is controlled by a photo-sensor system is constructed and its experimental results are shown.

## 1. Introduction

Efficient and flexible transportation systems are essential for the productions of varieties and of small amounts in recent factories. For realizing such systems, many studies of autonomous navigation have been proposed (Shirai, 1991; Iwatsuki et al., 1991; Hirose, 1991; Chamnongthai et al., 1991). However, as most of the existing schemes adopt high level technologies, many problems remain to be solved for practical use.

The authors carried out an investigation on the limitation of function that can be realized by ordinary devices at each technical level. Our proposed method uses a fluorescent lamp array on the ceiling for positioning and controlling the vehicle (Hashino et al., 1985; Hashimoto et al., 1991; Takamidoh et al., 1991; Hashimoto et al., 1992).

The merits of using the fluorescent lamp array are as follows:

(a) It can provide high contrast and stable images.

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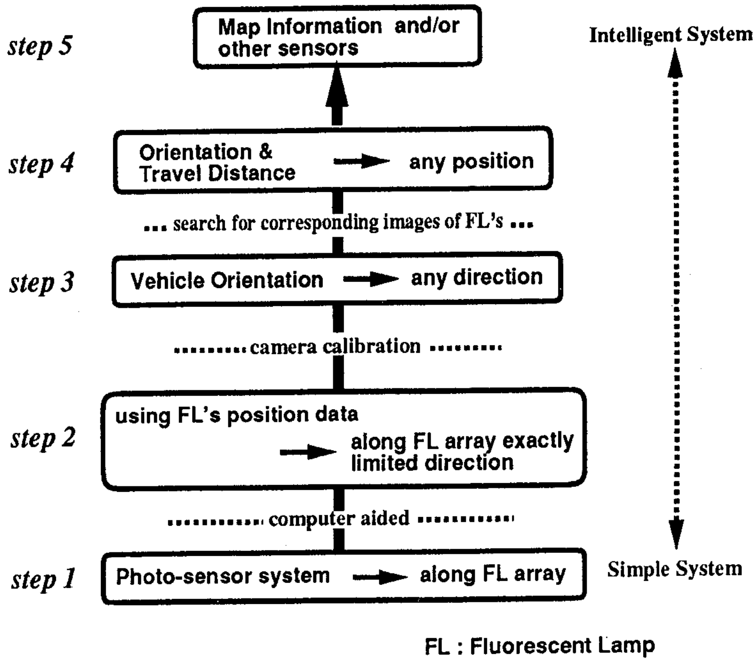



Fig. 1 Hierarchy of technology levles in proposed vision-based system.

(b) Fluorescent lamps already exist in many factories. We can make use of them.

(c) The system can be composed of simple and relatively low cost devices.

In our method, the image processing techniques are applied to the image data of the ceiling fluorescent lamps.

This work is divided into several technical levels as indicated in Fig. 1. The upper levels is the higher one and the boundaries between each level are not clear. This repoıt is concerned with steps 1 and 2.

## 2. The control method

In this section, we propose the simplest control method which keeps the projected fluorescent lamp image close to the reference line on a TV monitor screen. The mehtod uses "photo-sensors" set up on the TV screen. This photo-sensor method is considered one of the image processing technique which has low resolution. The method can process the fluorescent lamp image by an analog circuit, so that continuous control and smooth movement can be achieved.

### 2.1 Controlling procedure

The ceiling fluorescent lamp is projected on a TV monitor screen by a video camera. The photo-sensor arrays are set up on the monitor screen symmetrically with respect to the vertical center axis of the screen. This axis corresponds to the reference line.

The output voltages of the left sensors and those of the right sensors are compared. If the output of the left/right sensor is higher (this means that the lamp image is displaced to the left/right of the reference line), the rudder is controlled to the right/left. When the fluorescent lamp image cannot be obtained, the rudder is controlled so as to be parallel to the vehicle.

In the experimental system, since the sensor arrays are set along the center line with the camera facing up, only the upper half area of the TV screen is used. In the next stage, the arrangement of the sensor arrays and the camera angle will be improved to achieve more effective control.

### 2.2 Methods and conditions of experiment and numerical simulation

First, the possibility of the method is examined by the experiment. Also, the numerical simulation concerned with the condition which is difficult to realize in the actual environment is carried out on our work station.

In the experiment, an actual size model is used. This model is a four-wheeled carrier which is equipped with a video camera, and is manually operated. In order to investigate the vehicle control in the various conditions, a personal computer was used instead of photo-sensors.

The environment co-ordinates are chosen such that the running direction is +y axis and the right direction is +x axis.

Experimental and simulation parameters are as shown below:

**Vehicle—**

| | |
|---|---|
| length | : 0.68 m |
| wheels | : 4 |
| control interval | : 0.01 m |

It is supposed that the vehicle has a characteristic of deviating to the right by 2°, this is called "vehicle deflection" in the following consideration.

**Video camera—**

| | |
|---|---|
| field of view | : 63° |
| distance* | : 2 m |
| direction | : facing up |
| lens characteristic | : $2\,sin\,(1/2\,\theta)$ |

image pixels : $512\times512$ (experiment)
: $256\times256$ (simulation)

The camera is positioned 8 cm ahead of the vehicle front axle. Distance* means the length between the ceiling and the camera.

**Fluorescent lamp**— In the experimental environment, three fluorescent lamps are on the ceiling and the distances between these lamps are 3.28 and 3.11 m from the start line along the axial direction. The length and width of the lamps are 0.56 and 0.025 m, respectively. The axial direction of the lamps are aligned along y-axis.

**Control**— The gap between the sensor arrays (called "dead zone") is $\pm5$ pixels in the experiment, and $\pm2.5$ pixels in the numerical simulation.

As shown in Fig. 2, the reference line is parallel to the y-axis and passes through the left side of the fluorescent lamp image. In control mode, the position of the lamp image is indicated by the average x co-ordinates.

If the lamp image deviates from the reference line by $\pm5$ pixels, the rudder is controlled. The rudder angle adopted is only $\pm10°$ and $0°$. This control is carried out every 15 cm.

In the numerical simulation, the camera images are pre-processed into binary images and the typical position of the fluorescent lamp is taken at its center of gravity. The reference line is fixed to the center of the image in all simulations. These are the major differences between the experimetal and simulated results.

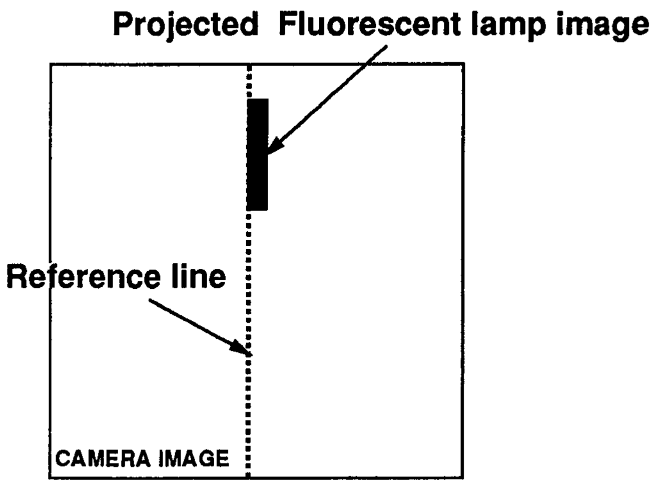



Fig. 2 Decision of the reference line

## 2.3 Results

### 2.3.1 Experimental tests using the actual size model

In Fig. 3 and 4, results of the practical tests using the actual size model are shown. The travelling distance is about 9 m. It is illustrated by the solid line in the figures whether or not the fluorescent lamp image is in sight.

Fig. 3 shows the track of the actual model without control and the effect of the vehicle deflection. As shown in this figure, at the distance of 6 m from the start line, about 1 m displacement is produced. This displacement occurs as a result of the vehicle characteristic mentioned above.

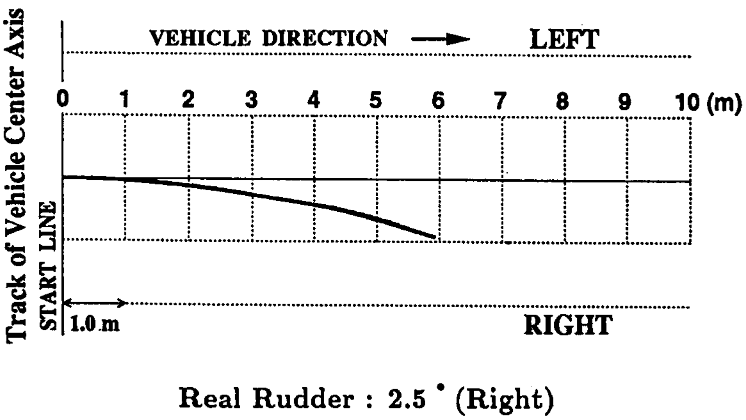



Fig. 3 Track of vehicle (deflection).

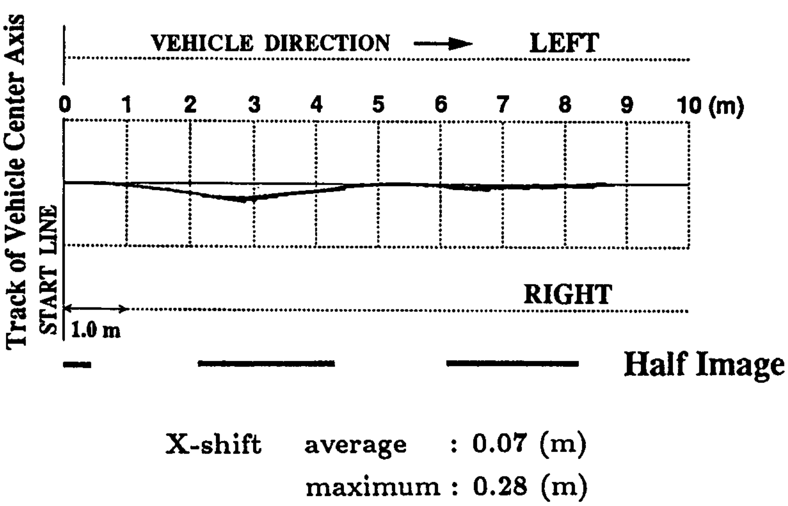



Fig. 4 Track of vehicle (controlled by "photo-sensors").

Fig. 4 shows some results when controlling with one pair of photo-sensor arrays. It is observed that the maximum displacement is about 20 cm in the area where the fluorescent lamp image is not obtained. However, the actual model can roughly travel along the standard orbit.

### 2.3.2 Investigation on the limitation of control conditions by numerical simulation

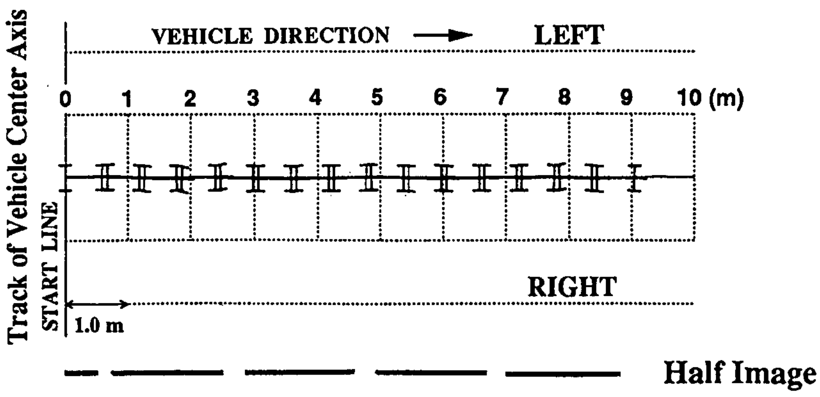
A numerical simulation using the same parameters as those used in the actual model experiment is carried out in advance. Then, the agreement between the experimental and simulated results is proved. We investigated the following three items by simulation.

1. The deat zone between photo-sensor arrays, the number of photo-sensor arrays and the rudder angle.
   (a) By changing the dead zone from 0 to 20 pixels by 10 pixels, the displacement of vehicle was examined. With a 20 pixel gap, the displacement was several centimeters from the standard orbit. Thus, about a 10 pixel gap is recommended.
   (b) Using two pairs of sensor arrays and changing the rudder angle by two steps, the vehicle approaches the standard orbit gradually without overshooting.
   (c) When the rudder angle was set at $\pm 5°$, the vehicle could not return to the standard orbit. On the other hand, if the rudder angle was set at $\pm 20°$, the rudder was controlled frequently, and the track was similar to that of $\pm 10°$ mentioned above.
2. Changing the distance between the fluorescent lamps in the axial direction and the camera field of view.

   These parameters are the most important ones, and each of these has the same effect on the control stability of the vehicle. For instance, as shown in Fig. 5, if the distance between the lamps was changed to 1.5 m i.e. half the experimental distance, the maximum displacement was approximately 3 cm. Also, if the field of view of the camera lens was set to 90°, the vehicle moved along the reference line with only a small displacement.

   Special attention should be paid to the effect of the lens distortion when the super-wide-angle lens is used.
3. The effect of the starting points.

   The stability of this control method, with respect to the relative position between the starting points and the fluorescent lamp, was checked.




X-shift average : 0.02 (m)

maximum : 0.03 (m)

Fig.5 Track of vehicle (1.5 meters distance).

When the vehicle was started from a position shifted by 30 cm in the x-axis and 56 cm in the y-axis, where the fluorescent lamp was out of sight, the vehicle could not retrun to its original track.

## 3. Advanced method

### 3.1 Control procedure

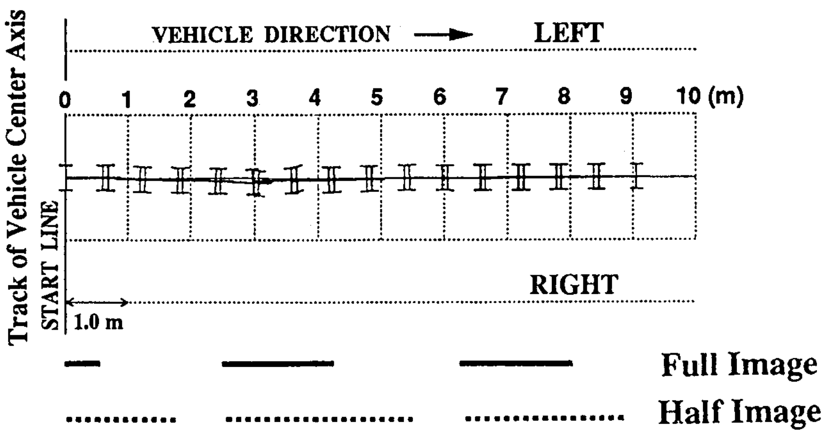
In this section, we state briefly the control methods which keep the displacement of vehicle within a few centimeters in the area where the projected fluorescent lamp image cannot be obtained on the TV screen. In these methods, we use a personal computer instead of photo-sensor arrays.

1. Control using the angle of the fluorescent lamp image on TV screen co-ordinates.

   The fluorescent lamp is a long and small diameter tube. The angle of the fluorescent lamp image is determined using the least squares method on TV screen co-ordinates. This angle is equivalent to the orientation of the vehicle, if the camera is facing up. Thus, the vehicle can be controlled by means of this angle information.

2. Presumption and correction of the vehicle deflection angle.

   When the vehicle deflection angle is constant, the angle is presumed and then correction on the next rudder angle calculation is performed to bring back the track to the standard orbit.




X-shift average : 0.02 (m)
maximum : 0.08 (m)

Fig. 6 Track of vehicle (advaned method).

### 3.2 Results

Fig 6 shows the simulated result using the proposed method. In this caes, the photo-sensor array control is also used. The maximum displacement from the standard orbit which is located just under the fluorescent lamp array is only 8 cm, and it is clear that the vehicle is reasonably controllled in this way.

In detail, small deviation is observed at a distnace of 2 and 3 m, however, beyond 5.5 m, the displacement is kept within a few centimeters by the effect of coreection.

## 4. The practical vehicle

In order to carry out experimental tests, a practical autonomous vehicle equipped with a photo-sensor system was constructed. Fig. 7 shows the picture of the vehicle.

This is the same type of vehicle as the magnetic tape controlled ones which are used in factories, and is partially modified for our experiments. It has three wheels and can move by 30 m/min carrying a weight of about 100 kgs. The front wheel drives the vehicle by the motor set beside it, and steers the vehicle. As the steering motor is controlled by the open-loop PWM method, it is difficult to set the rudder angle precisely. The rudder angle adopted is only about $\pm 10°$ and $0°$ the same as those of the actual size model.

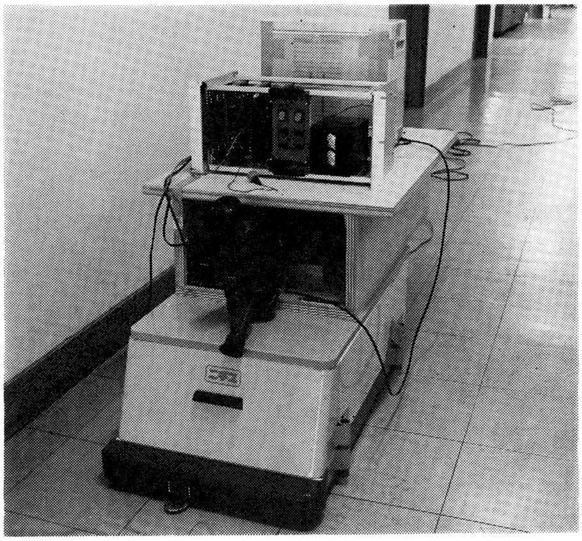


Fig. 7 Photo of the practical autonomous vehicle.

The photo-sensor system on the vehicle is composed of the VTR camera, photo-sensors on the TV screen and the control unit. The number of right/left photo-sensor arrays is six, and of the center array is one. Most of the sensor arrays are composed of 16 sensors. So the total number of sensors is about 200. The dead zone, one of the most important parameters, is 1.25 cm. This length was selected to keep the vehicle deflection within 15 cm.

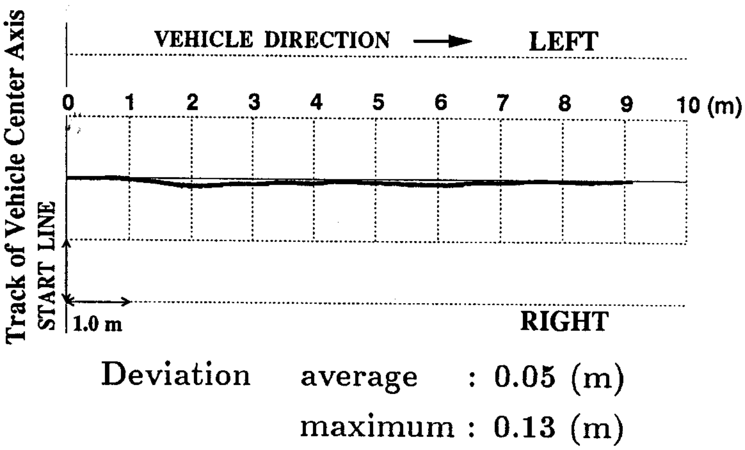
The control unit is composed of three parts: the interface from photo-sensor output to logic circuits input, logic circuits to decide rudder direction and a mono-stable multivibrator to control the rudder angle. These circuits are made of analog/digital circuits so that the vehicle can be controlled quickly.

The major differences between the actural size model experiments and this experiment are as follows:

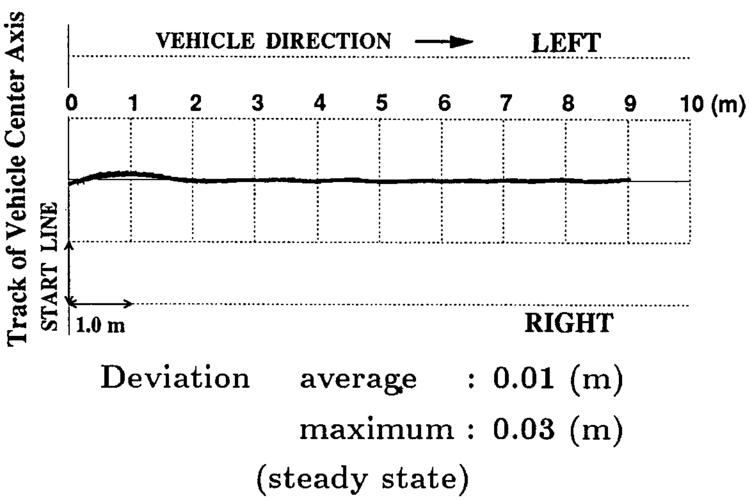
(a) The camera is tilted forward by about 30° in order to take a wider area.

(b) At the dark-zone where fluorescent lamp images disappear, the rudder is not controlled so as to be parallel to the vehicle.

In Fig. 8, the results of autonomous movements in a real environment using the practical vehicle are shown. Fig. 8(a) shows one example of the vehicle track when the vehicle started on the standard orbit without the inclination angle referred to the standard orbit. The vehicle track indicates two times larger deviations to the right hand side, and the maximum displacment is about 13 cm. But these




(a) initial condition: straight position




(b) initial condition: inclinated position

Fig. 8 Tracks of the practical autonomous vehicle.

deviations are small enough compared with the theoretical deviation based on the dead zone of the photo-sensors.

Another exmaple of results is shown in fig.8(b). In this case, the vehicle started with a small angle of about 15°. This figure shows the immediate reeover of the vehicle to the standart orbit.

It is obvious from these tracks and other experimental results that the vehicle can be controlled close to the standard orbit by the photo-sensor system.

## 5. Conclusion

The fundamental experiments of an autonomous navigation system using fluorescent lamp array on the ceiling were investigated.

Using the actural size model, it was confirmed experimentally that this simple method, based on the displacement of the fluorescent lamp image, could control the vehicle along the standard orbit.

According to the experimental results, the limitations of control conditions were checked by numerical simulation using a work station, and the possibility of stable control was confirmed. To reduce the displacement of the vehicle from the standard orbit, a system using a personal computer and the photo-sensor system was tested. By this system, the displacement was kept within a few centimeters.

A practical autonomous navigation system was constructed to carry out experimental tests and the validity of the control method proposed in this paper was confirmed.

In actural factories some fluorescent lamps are covered by white plastic and/or the arrangment of lamps is random. For such circumstances, the flexibility of our method should be more developed. It will be the subject of our future study.

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