Improvement of Reliability of Environmental Recognition on Automatic Driving System by Using Data of Objects

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This study proposes a method of environmental recognition by using detail position data of objects in the course such as white lines, road shape, light poles, road signs and so on. The proposed method realizes efficient detection of surrounding objects based on object's position data. Moreover, it estimates the vehicle's position and detects obstacles from visionary information and object position data. Experimental results show that the vehicle can continue to run under GPS-based automatic driving, even when the GPS information is not available by means of the proposed method. Also, these results show that the vehicle can detect obstacle with high probability.

Keywords: *Automatic Driving System, Intelligent Vehicle, Environmental Recognition and Intelligent Transport System*

1. Introduction

In these days, there are serious traffic problems. In order to solve these problems, the vehicles and traffic systems are expected to become more intelligent. There have been many researches on ITS (Intelligent Transporting Systems) in order to solve the traffic problems[1-5]. This paper is concerned with environmental recognition of automatic driving systems, and driver assistance systems in ITS. This paper focuses on the automatic driving systems, and aims to enhance the system to solve current traffic problems. To achieve this, the system's environmental recognition must be reliable, and this research addresses this issue by storing detailed data of the route beforehand. In this paper, the environmental recognition is indicated as estimating the position and detecting obstacles.

This study proposes the method of estimating the vehicle's position by using visual information from the CCD camera, and position data of objects in the course such as white lines, road shape, light poles, road signs and so on. This method was evaluated by a series of experiments. In addition, this study also proposes the method of detecting obstacles by using image and position data of objects, and visual information from CCD camera and laser radar sensor. This method was also evaluated by experiments.

There have been many researches as to the methods of estimating the vehicle's position. For example, methods using magnet-markers, electric-markers or D-GPS, and recognition of white lines[6-9]. We have proposed the method using D-GPS and developed an automatic driving system by using the vehicle's position and desired course[10]. This system's advantage is that it does not require new infrastructure, which reduces cost. It can also obtain information about the desired course in advance, and reconstruct and adapt to the desired course. As a disadvantage, it is difficult to travel in areas where the system cannot receive GPS information due to surrounding buildings.

As for detecting objects, there are proposed methods using vision sensor, laser radar sensor and microwave sensor. There are great interests in researches on fusion systems for improving the reliability of the system[11-13].

This paper explains the proposed method of improving the reliability of automatic driving system by utilizing reference database about detail positions of objects in the course. Even without any signal from the D-GPS, this system can estimate the vehicle's position and continue to run under automatic driving by using this proposed method. This system can also detect objects by using information from the results of laser radar and visual sensor, and by referring to a database about detail positions and images of objects at the estimated vehicle position. Our proposed method uses existing infrastructures such as white lines, light poles, and so on. It does not require new infrastructure which saves costs, and the database can be easily updated.

2. Method of estimating vehicle's position

2.1. Outline

The position data of objects in the course are saved to a PC. This allows the system to refer to objects, which can then be used to estimate the vehicle position from the database. Using this method, the system can obtain information efficiently, which leads to high speed image processing. In addition, the system calculates the detail position data and corrects the dead reckoning information by using the results from the image processing.

This method requires constructing a database in Keio Shin-Kawasaki Town Campus in advance. In this study, we measured and stored the position data of white lines, road shape, light poles and indicators that existed in this course. The experimental vehicle was equipped with two cameras, which were placed in the front and side of the vehicle to estimate the vehicle's position. The cameras that were used had a 1/4 inch CCD, with a resolution of 640 by 480 pixels.

This method recognizes the distance between the vehicle and the white line by using the front camera. For example, when the course is straight, the vehicle's position can be generated as a linear function which is parallel with the white line. The system calculates the relative position in comparison to the white line. Therefore, it is able to estimate the vehicle's detail position by using the side camera in addition to the front camera.

The proposed method does not use the result of image processing to control the vehicle like lane-keeping systems. Instead, the results are used to estimate the vehicle's position. As a result, the system enables the vehicle to keep traveling automatically by referring to the relationship between the vehicle's position and desired course. This allows the system to keep traveling in sharp corners and in intersections where it is difficult to keep in lane.

2.2. Data of objects and image processing

Position data of objects in the course are saved as a reference database in a PC. To construct this database, we used RTK-GPS to measure the position data of white lines, grooves, light poles and indicators in the course. For white lines and grooves, we measured the position data discretely, and stored the information as a whole series of points. For light poles and indicators, we stored position data of objects directly. In this paper, global coordinates are set as: the origin is where the RTK-GPS installed and X and Y axis are set to the East and North directions.

The absolute position of light poles is referred directly. For white lines and grooves, the system picks out three of the nearest points in the *Dc*, where image processing is used. The system makes a collinear approximation from those three points and the vehicle position. Those data are stored as a whole series of points. The system makes an expression of the absolute position of white line (shown in Fig.1). This allows the system to deal with not only lines, but also gentle curves when it uses the method of estimating the vehicle's position described in section 2.3. It is also more convenient to construct and refer to object data.

The proposed method uses visual information from the front and side cameras. The front cameras are used to recognize white lines and grooves. The side cameras are used to detect light poles. Using the vehicle's position and database, the system can predict the visual information from the camera in advance. This narrows down the area it needs to process, which frees up the resources to process only the relative objects. Therefore, this image processing method achieves both high reliability and high efficiency. The system can predict if a light pole exists or not by utilizing the database and vehicle's position. When the vehicle travels in the area where the light pole exists, the visual information from the side camera is also used to improve the precision of the pole.

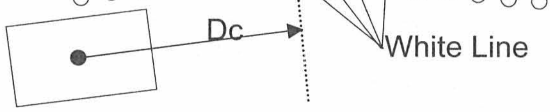

Figure 1. Reference of white line's data

2.3. Method of estimating vehicle's position

2.3.1. Estimating vehicle's position from front camera. Image processing results from the front camera is used to measure the distances (D_{s1} and D_{s2}) from the white line to the center of the screen (shown in Fig.2). The dotted frame means on-screen in Fig.2. The system recognizes the distance from the white line to the vehicle by calculating the distances (d_1 and d_2). Since the relation of the absolute coordinate system of the white line is known, the relational expression can be calculated by moving in parallel d_1 or d_2 from the expression.

We first calculate the distance between the lines in parallel to the vehicle's direction and white line at D_c ahead from vehicle's position. Then the system detects the white line by on-screen image processing, which calculates D_{s1} and translates to real distance D_{r1}. From Fig.2,

$$d_1 = -D_c \cdot \sin\alpha + D_{r1} \cdot \cos\alpha \quad \cdots\cdots (1)$$

is calculated. In this regard, the angle between the white line and the vehicle's direction is set to α. With this method, we calculate Dc by not one situation but N situations to estimate from $d_1[0]$ to $d_1[N\text{-}1]$. All d_1 should be the same, but in the situation when they are not the same due to error from the image processing, the system decides the average d_1 without the irregular data. The vehicle's point exists on a line moved from d_1 in parallel from expression of white line. One-dimensional expression of white line in Fig.2 is set to:

$$Y = a_w X + b_w \quad \cdots\cdots (2)$$

where a_w and b_w are constants for one-dimensional expression of white line. The vehicle's position is expressed in the following equation:

$$Y = a_w X + b_w - d_1\sqrt{a_w^{\ 2}+1} \quad \cdots\cdots (3)$$

2.3.2. Estimating vehicle's position from side camera. The system estimates the distance relationship between the light pole and vehicle by using the side image. Yet, it is difficult to estimate the precise distance relationship between the light pole and vehicle by using only the side visual information. This is why the system uses relation of absolute coordinate system of the vehicle.

The system detects the light pole on-screen by image processing of side image and calculates the distance (E_{s1}) on-screen from light pole to center of screen. The dotted frame means on-screen in Fig.3. It converts E_{s1} to real distance (E_{r1}). In this conversion, it requires the distance (E_v) from the line which is parallel to the vehicle's direction through the light pole to the center of the vehicle's position. This is why the light pole stands vertically, which makes it is difficult to calculate the distance to the light pole by image processing unlike in the case of white line. If the vehicle position's calculated one-dimensional expression in subsection 2.3.1 is set to:

$$Y = a_v X + b_v \quad \cdots\cdots (4)$$

where a_v and b_v are following:

$$a_v = a_w \quad \cdots\cdots (5)$$

$$b_v = b_w - d_1\sqrt{a_w^{\ 2}+1} \quad \cdots\cdots (6)$$

(4) equals the distance between the line which vehicle position fulfills the absolute position (X_L, Y_L) of light pole, so E_v is calculated as following :

$$E_v = \frac{|a_v X_L - Y_L + b_v|}{\sqrt{a_v^{\ 2}+1}} \quad \cdots\cdots (7)$$

The relationship between the vehicle's absolute position (X_C, Y_C) and light pole's absolute position is expressed in the following equation:

$$X_c = X_L - E_{r1}\cos(\alpha + \tan^{-1} a_v) + E_v \sin(\alpha + \tan^{-1} a_v) \quad \cdots (8)$$

$$Y_c = Y_L - E_{r1}\sin(\alpha + \tan^{-1} a_v) - E_v \cos(\alpha + \tan^{-1} a_v) \quad \cdots (9)$$

This allows the vehicle's absolute position to be estimated. In this regard, the right direction of the screen is set to be positive about E_{r1}.

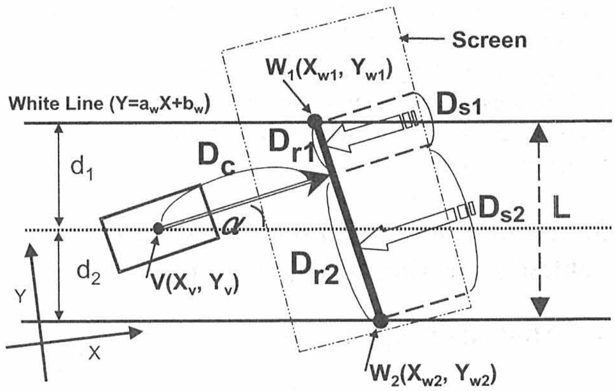

Figure 2. Estimating position from front scene

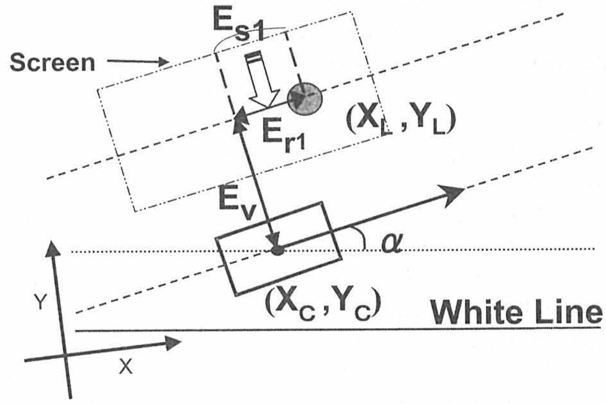

Figure 3. Estimating position from lateral scene

2.3.3. Correcting the vehicle's head angle from image processing. In this paper, the heading angle is calculated by integrating the yaw rate from the gyro sensor. Errors are accumulated over time. This system corrects the heading angle by using three methods of image processing.

First way is that the system corrects the heading angle when the vehicle is parallel with the white line. Second way is that the system corrects the heading angle when it detects white lines on both the left and right side. Third way is that the system corrects the heading angle when it detects white lines on either the left or right side. This study corrects the heading angle by using the first, second and third way preferentially in order which is less influenced due to the pitch of the vehicle and image processing error.

2.3.4. Method of correcting vehicle's position. The estimated vehicle position described in sub section 2.3.2 produces a delay. This is due to the time necessary for the system to calculate, capture and process images. To interpolate for the delay, dead reckoning is used to calculate the real-time vehicle position.

Also, when the system corrects the estimated vehicle position, it produces a discontinuity of data. This discontinuity results in discrete control input in automatic driving system, which leads to poor ride quality and tracking. The system takes this into account, and divides the correction for this reason. By utilizing these methods, this system is compatible with a wide range of velocity.

3. Evaluation of method of estimating vehicle's position by experiments

3.1. Method of experiments

The experimental vehicle used in these experiments is equipped with RTK-GPS for estimating the vehicle's position, a PC with image processing board, a gyro sensor, and a velocity sensor. Front and side cameras are set on top of the vehicle. In addition, this vehicle has actuators for controlling the throttle, brake and steering.

The desired course is set in our campus (shown in Fig.4). The start point is set to A. The goal point is set to B. The sharpest corner's turning radius is 5[m] which is around the C area. Objects used for image processing are also shown in Fig.4. Black lines in Fig.4 mean white line and groove, white circles in Fig.4 mean light pole. If there is no object to process, the system estimates the vehicle's position by only dead reckoning. The method is evaluated by two situations in both manual and automatic driving situations.

In manual driving situation, the driver controls the throttle and brake. The system estimates the vehicle's position by the proposed method, and compares the estimated positions between the proposed method and RTK-GPS. This system is evaluated by five experiments in this situation

In automatic driving situation, by referring to the relationship between the data of desired course and vehicle position, the system controls the steering, throttle and brake. The system's ability to keep the vehicle traveling automatically using the proposed method is evaluated. The control method is the same as reference[10], but the system uses RTK-GPS for estimating the vehicle position in reference[10]. On the other hand, the vehicle position is estimated by the proposed method in this experiment. The velocity of the vehicle is set to approximately 6[m/s] on the straight line, very slowly around C area, and about 2[m/s] on other corners.

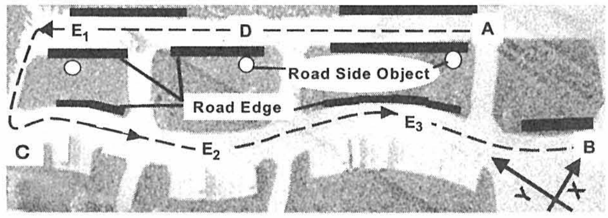

Figure 4. Desired course and objects

3.2. Results of experiments

Table.1 and Fig.5 shows the estimation error between the proposed method and RTK-GPS in manual driving situation. Table.1 shows the average estimation error in each experiment. These results show the system has the reliability of estimating the vehicle's position. Figure.5 shows the 4th experimental result in detail. The deviation is under 0.6[m] except for the area where the vehicle travels around the C area. The estimation accuracy of the proposed method is equal to that of RTK-GPS when the image processing is available. In addition, the deviation is very small for the first 120[m] from the starting line because the system corrects the vehicle's position by detecting white lines on both sides. As the vehicle travels in the C area, there are no objects for the image processing to refer to, which results in errors stored up from dead reckoning. On other areas, the system can correct the position by using image processing, thus the deviation is small.

Figure.6 shows the experimental result in automatic driving situation. It shows the trajectory that the vehicle travels automatically by using the proposed method. The full line in Fig.6 shows the desired course and the dotted line shows the trajectory of the vehicle. As the result, we proved that the proposed automatic driving system can be realized with precision equal to that of using RTK-GPS. Experimental results show that the vehicle can continue to travel based on GPS automatic driving under the fault of GPS information by means of the proposed method.

Table 1. Experimental result (average error)

Experiment No	Average error [m]
1st	0.35
2nd	0.28
3rd	0.3
4th	0.25
5th	0.43
All	0.32

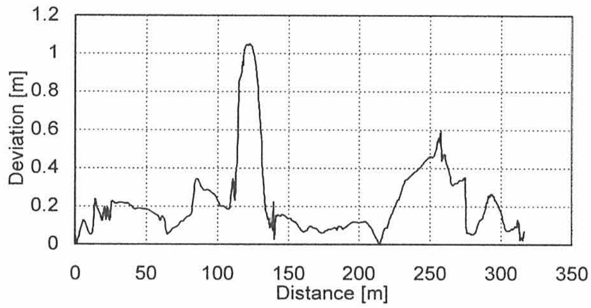

Figure 5. Experimental result (estimation error between proposed method and RTK-GPS)

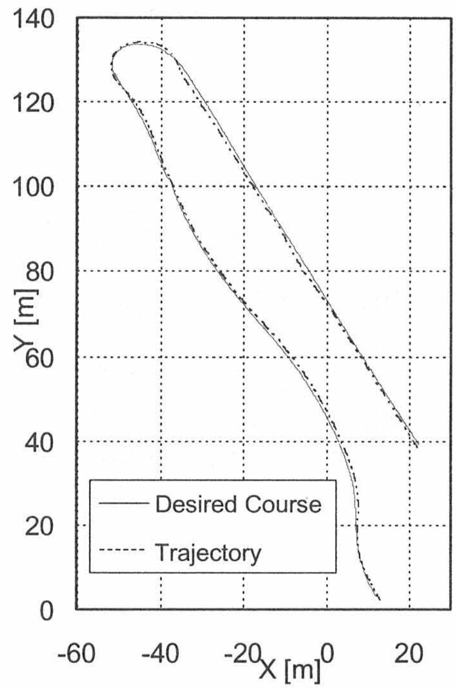

Figure 6. Experimental result (desired course and trajectory)

4. Method of detecting obstacle

4.1. Outline

Image data of each objects are added to the database used in section 2.2. The system can predict image data captured from the camera by the heading angle, vehicle's position, and the database. In addition, by calculating the positional relationship between the vehicle and the object using a laser radar sensor, it can easily identify the object on-screen.

In the situation that the system detects the object on the course which does not exist on database, the system identifies that object as an obstacle. As the result, even in situations where it is difficult to differentiate objects from visual information, the proposed method enables to improve the performance of detecting obstacles. Global coordinates are also set as: the origin is where the RTK-GPS is installed, and X and Y axis are set to the East and North directions. Our proposed method can detect obstacles under situations where the camera can capture the road surface which it travels. The proposed method is not active in situations where it is dark, or when it is too bright caused by oncoming headlight.

4.2. Method of detecting objects

Image data of roads, indicators and light poles are added to the database using the method described in section 2.2. The object data is referred to when the object is within range of the laser radar sensor.

The proposed method uses visual information from the front camera of the vehicle. As with section 2.2, the system can approximately predict the image from the camera by using the vehicle's position and database, it can process with high reliability and high efficiency. In addition to section 2.2, the system uses image and pattern matching to detect the light pole and indicators. The system compares images between the data from the database and the camera except for the areas where indicators do not exist. It can distinguish obstacles and non-obstacles existing on the road because the system recognizes the area from the database in advance. The proposed method prevents the system from recognizing an indicator as an obstacle by mistake. It filters and detects edges, in order to check whether an object exists or not. If an object exists on the road, the system calculates the size and position of the objects on-screen. If the obstacle size is larger than a child, the proposed system marks the object as an obstacle.

The system seeks for the objects in the database by using the data from the laser radar sensor. Figure.7 shows the example of four objects being detected. In Fig.7, the system recognizes number 1 and 2 delineators as a light pole by using the database. Laser radar sensor sometimes incorrectly detects white lines due to reflections. But by using the database, it recognizes number 4 delineator as white line. The system seeks for information about the number 3 delineator on road, and searches the database information, but it is nonexistent in the database. If an object is detected, and is not registered on the database, the system can recognize it as an obstacle.

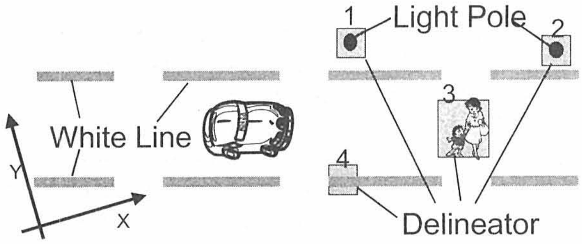

Figure 7. Example of detection results

4.3. Method of detecting obstacle by using image processing, laser radar and database

The system uses two methods to detect obstacles. One is by using image processing with a database and the other by laser radar sensor with a database.

If each method detects an obstacle, the system analyzes the situation to consider if the obstacle exists for safety reasons. Figure.8 shows the flow of detecting an obstacle. If the system recognizes an obstacle using one of these methods, the system avoids the obstacle by reducing the speed, or stops the vehicle.

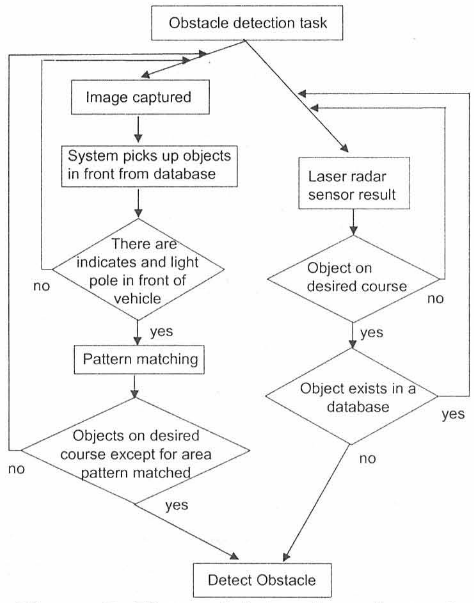

Figure 8. Flow of detecting obstacle

5. Evaluation of method of detecting objects by experiment

5.1. Method of experiment

In the experiment, laser radar sensor is added to the vehicle used in chapter 3. A laser radar sensor is put on the front bumper of the vehicle. The laser radar detects four objects and reads out the distances. The desired course is set in our campus, same as in section 3.1 (shown in Fig.4). The starting point is set at point A. The goal point is set at point B. The obstacle is put in point D. Three indicators are drawn on each E_1, E_2 and E_3 (shown in Fig.9).

Steering is controlled by the driver, and the system controls the throttle and brakes automatically. The velocity of the vehicle is about 6[m/s]. If the system detects an obstacle, it makes the vehicle stop before it collides with the obstacle.

The proposed method for detecting obstacles is evaluated in two conditions. The first experimental condition is set to clear weather. The second experimental condition is set to rainy weather. It is difficult for the laser radar sensor to detect objects in rainy conditions. In addition, image processing is also difficult to detect objects due to the low contrast of the image (shown in Fig.10). The proposed method is evaluated by experiments under these conditions.

In addition, the proposed method for preventing false detection is evaluated by experiments. These experiments' were done to evaluate the validity of the proposed system to reduce false detection. If the system does false detection in automatic driving system, the system produces needless acceleration and deceleration. This results in poor ride comfort, and engenders instability. There is no obstacle in these experiments. Other conditions are the same as the experiments for detecting obstacle. Under the same condition, the proposed system is evaluated by several experiments.

Figure 9. Indicator around E_2

Figure 10. Image on rainy condition

5.2. Experimental results

Figure.11 and 12 show the experimental results for detecting obstacle in dry condition. Figure.11 shows the relationship between time and distance from the vehicle to the obstacle. Figure.12 shows the obstacle detected by proposed method. Figure.13 and 14 show the experimental results in rainy condition. Figure.13 shows the relationship between time and distance from the vehicle to the obstacle. Figure.14 shows the obstacle detected by the proposed method. These results show that the vehicle detects an obstacle and the system made the vehicle stop before the obstacle automatically. From these experiments, we prove the validity of the proposed method of detecting an obstacle.

Figure.15 and 16 show the experimental results around E_2 for preventing false detection. In Fig.15, the triangle plots show the result that the system detected without a database. In Fig.16, the triangle plots show the result that the system detected using a database. Without using a database, the system detects the indicator as an obstacle. But the proposed system using a database can distinguish between obstacles and indicators. From these results, the proposed system can prevent false detection.

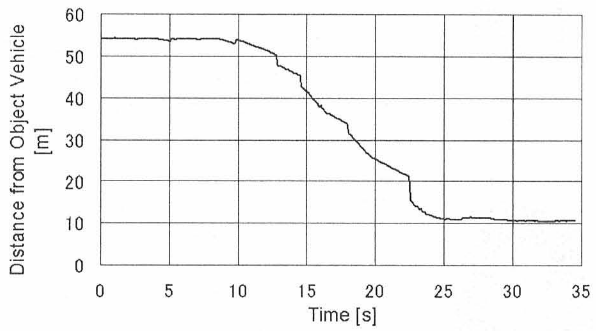

Figure 11. Experimental result (dry condition)

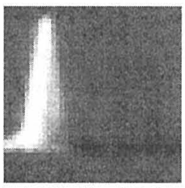

Figure 12. Detected obstacle (dry condition)

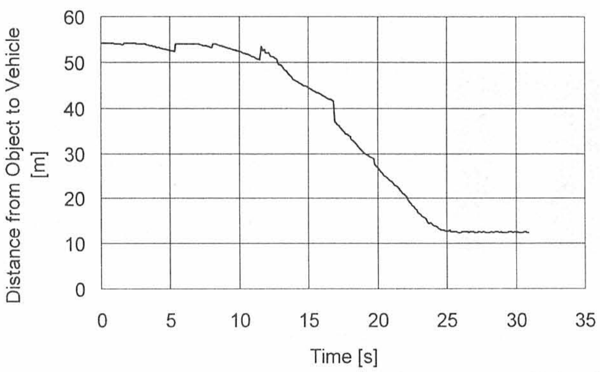

Figure 13. Experimental result (rainy condition)

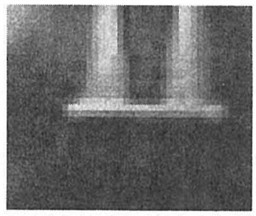

Figure 14. Detected obstacle (rainy condition)

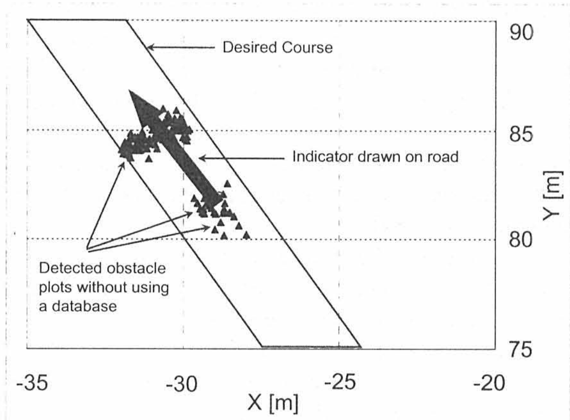

Figure 15. Experimental result around E_2 (detected obstacle without database)

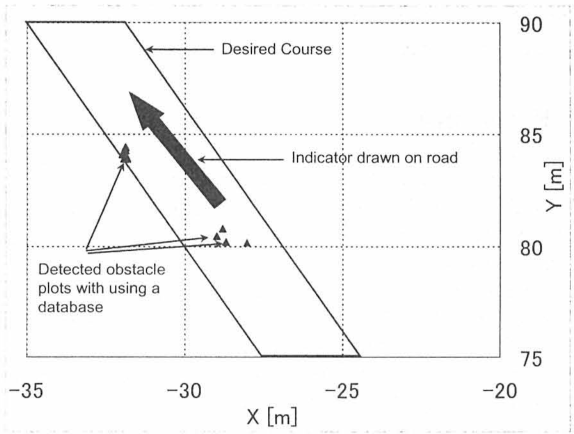

Figure 16. Experimental result around E_2 (detected obstacle with database)

6. Conclusions

This paper explains the proposed method of estimating the vehicle's position and obstacle detection, and verified the validity of this method by experiments.

As for estimating the vehicle's position, this paper explains the object data, method of referring data, image processing, and the method of estimating the vehicle's position and correcting the heading angle. The proposed method of estimating the vehicle's position is evaluated by experiments. Experimental results show that the proposed method has the accuracy that is equivalent to that of RTK-GPS to estimate the vehicle's position. It is also valid on automatic driving system under conditions where the RTK-GPS system is unavailable.

As for detecting obstacles, this paper explains the position and image data, method of referring to objects, and the method of detecting the obstacle by using image processing and a laser radar sensor. The proposed method of detecting an obstacle is evaluated by experiment. Experimental result shows that the proposed method is valid for detecting obstacles.

In order to use these proposed methods, the system requires the detailed position and image data of the local objects in advance. Thus, the proposed methods are limited to only confined traffic environments. One solution to this restriction is the many researches done on the internet car, which enables the system to obtain and update data[14].

One of the future works is to evaluate the proposed system on more situations; for example at high speed, with many variations and large number of obstacles. We also plan to propose a method that can easily construct a database for using this proposed method. Because the database used in this paper is constructed manually, it takes time to collect each data. We also plan to construct an algorithm that fuses the position data from the RTK-GPS, camera and dead reckoning by using the database, including an estimation of each data's reliability.

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