VEHICLE NAVIGATION USING UHF RFID SYSTEM UNDER LOW VISIBLE CONDITION CAUSED BY HEAVY SNOWFALL - DEVELOPMENT OF FOUR ANTENNA SYSTEM -

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Autonomous driving technology needs to cope with the low visibility caused by snowstorms. Therefore, we study a vehicle navigation system using a UHF RFID system against a low visibility in heavy snowfall. In this paper, we propose a new RFID system for vehicle navigation. Our previous system, three RFID tags in a RFID tag's row and distance between RFID tag's rows is 2 m. This system has a cost problem of a large number of RFID tags installed. In order to solve this problem, we introduced a new system. This system equips four RFID antennas in front of the experimental vehicle while our previous system has two antennas. The number of RFID antennas is doubled, but we can reduce the total amount of RFID tags. It becomes a third part of the previous numbers. On a straight lane, driving experiment is conducted with a Four RFID Antenna system. As a result, the Four RFID Antenna system has good navigation accuracy.

Key Words: *RFID system, Vehicle Navigation, Four Antennas system, Straight driving lane*

1. INTRODUCTION

In recent years, many companies have developed autonomous driving technologies and already have autonomous vehicle. For example, obstacles and painted line on the driving lane are detected by optical devices. Using millimeter-wave radar, distance from obstacles is measured. And vehicle position is learned by GPS and quasi-zenith satellite system.

However, if a whiteout occurs due to a snowstorm, optical devices cannot identify any objects. If a multipath occurs in a mountain corridor, the accuracy of position estimation by GPS may decrease. Autonomous driving technology needs to cope with the low visibility caused by snowstorms.

Therefore, we study a vehicle navigation system using a UHF (Ultra High Frequency) RFID (Radio Frequency Identification) system against heavy snowfall in winter. In previous our studies, UHF RFID tags are buried in road surface and two antennas are equipped on vehicles. We have made experimental navigation drives on straight lanes, curved roads, and intersections.

In these experiment, three UHF RFID tags are buried in one RFID tag's row, and the RFID tag's rows are spaced out 2m apart. According as a length of driving lane, the number of UHF RFID tags increases. As the matter of course, costs for making RFID tags' row and maintain them also increase. In order to cut off these costs, the number of RFID tags should be declined.

In this paper, we propose a new RFID system for vehicle navigation against the low visible condition. We reduce the number of RFID tags in one RFID tags' row from three to one. For the purpose of detecting the RFID tags, the number of UHF RFID antennas on the vehicle becomes double from two to four. The number of RFID antennas is doubled, but we can reduce the RFID tags. The number of RFID tags becomes a third part of the previous numbers.

We will show the results vehicle navigation on the straight lane using this Four RFID Antenna system.

2. VEHICLE NAVIGATION SYSTEM

The outline of the vehicle navigation system is shown (Fig. 1).

Four UHF RFID antennas are mounted in front of the vehicle so that it is parallel to the RFID tag buried at an angle of 30 ° under the road surface. The information on the RFID tag is read by the RFID antenna That information is sent to a computer via a RFID reader/writer. It has a lane specification and RFID tag's location on the lane.

The vehicle heading angle (absolute angle) from magnetic north is acquired from the INS (Inertial Navigation System) installed in the vehicle.

The steering angle is obtained from the multi-rotation potentiometer attached to the steering wheel shaft, and the wheel angle is calculated.

Furthermore, the vehicle speed is calculated by the signal from pulse counter.

Using that information, the computer provides navigation instruction for the driver. Navigation instructions are displayed on the monitor, and voice instructions are emitted from the speaker.

3. RFID COMMUNICATION RANGE

The RFID system reader/writer and antenna have been updated from the conventional system.

The communication range between one RFID antenna and one buried RFID tag is measured. The new communication range between one RFID antenna and one buried RFID tag is regarded as a circle with a diameter of 85 cm.

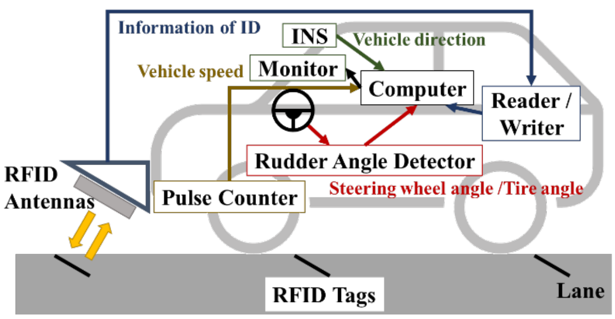

Fig. 1 The schematic of vehicle navigation system

4. ARRANGEMENT OF FOUR RFID ANTENNAS

It shows the arrangement of four RFID antennas mounted on the vehicle, the communication range, and the buried RFID tag at the center of the driving lane (Fig. 2). The four RFID antennas were placed at equal intervals on the antenna frame so that the antenna frame would not exceed the vehicle width.

RFID antenna's numbers are allotted sequentially to 1, 2, 3, and 4 from left to right. Due to the communication range on the driving lane and distance between adjacent antennas, one RFID tag can be read up to three neighboring antennas.

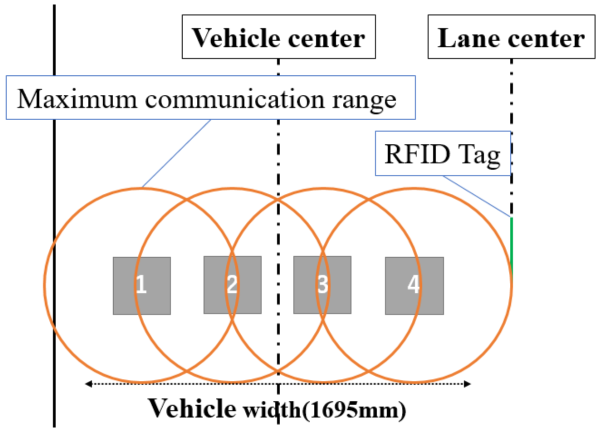

Fig. 2 Position of 4 RFID antennas and a RFID tag

5. RFID TAG PLACEMENT AND VEHICLE POSITION ESTIMATION

We discuss the placement of RFID tags and vehicle position estimation in this section.

(1) Outline of straight lane and placement of RFID tags

We make the straight lane (50m length, 4m width). On the experimental road, one RFID tag will be buried under the road at an angle of 30 degrees along the straight lane. The distance between these buried RFID tags is 2m (Fig. 3).

(2) Information to be written on the RFID tag

We write 5-digit hexadecimal information on the RFID tag of the straight lane (Table 1).

The first and second digits are the direction of the driving lane from magnetic north. The third digit is the type of driving lane. For example, 0 means the straight line, 1 is the straight-line within 30m of the stop line. The fourth digit is the row number of the RFID tag, repeat from 0 to F. The fifth digit is the lateral position in RFID tag's row. In this study, there is only one RFID tag in RFID tag's row. This digit is assigned a value of two.

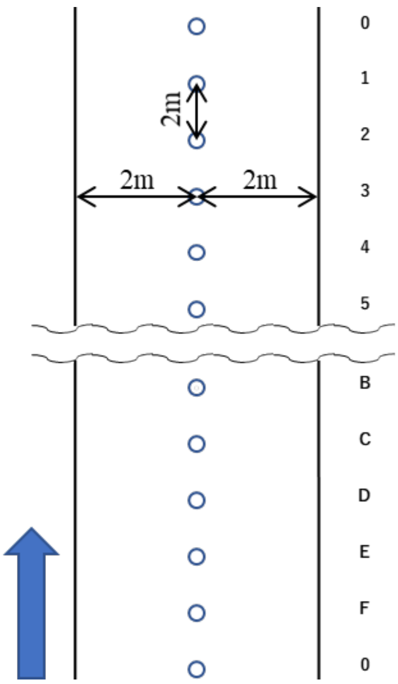

Fig. 3 Driving experiment road
(○: RFID tag installed point)

Table 1 The information in the RFID tag

Digit	Straight lane
1	A driving lane direction in Hexadecimal (Clockwise is the positive direction)
2	
3	0: Straight lane
	1: Straight lane within 30m before stop line
4	RFID tag's row number (Repeat 0 to F)
5	Lateral position : 2

Table 2 7 estimated positions and average distance from the center

Estimated position	Antenna that read RFID tag	Average distance[m]
(1)	Antenna 4	**0.7125**
(2)	Antenna 3 and 4	**0.4125**
(3)	Antenna 3	**0.2**
	Antenna 2, 3 and 4	
(4)	Antenna 2	**0**
(5)	Antenna 1, 2 and 3	**-0.2**
	Antenna 2	
(6)	Antenna 1 and 2	**-0.4125**
(7)	Antenna 1	**-0.7125**

(3) Vehicle position estimation using 4 RFID antennas

In order to estimate the lateral vehicle position on the driving lane, vehicle position is divided into 7 positions (Table 2).

These 7 vehicle locations on the driving lane are derived from antennas' numbers of which read the embedded RFID tag. Using this vehicle location, the average distance from the center of the driving lane to the center of the vehicle can be calculated.

6. VEHICLE NAVIGATION METHOD ON A STRAIGHT LANE

Navigation instructions are designed for the purpose of guidance to the RFID tag at the center of the driving lane, where 10m away from the present position.

The ideal vehicle heading direction θ [°] is derived by

$$\theta = \tan^{-1}\left(\frac{D}{10}\right) \qquad (1)$$

where D is present lateral distance from the center of driving lane.

If the present vehicle heading angle is different from the driving lane direction, the ideal vehicle heading direction θ is modified using the difference between the present vehicle heading angle and the driving lane direction.

7. VEHICLE NAVIGATION GUI (GRAPHICAL USER INTERFACE)

In this paper, vehicle navigation instructions are displayed by a GUI (Graphical User Interface) on LCD (Liquid Crystal Display). These instructions are made from the vehicle lateral position, the vehicle heading angle, and the direction of driving lane.

The LCD for vehicle navigation is mounted in front of the driver's seat (Fig. 4).

①: Black two rectangles represent the current wheel angle (relative angle).

②: Green arrowhead represent vehicle lateral position and vehicle heading angle on the straight lane.

③: Red characters show lane category.

④: Blue bar represents the current vehicle speed.

⑤: The upper number shows the current vehicle speed, and the lower number represents the safe speed limit.

⑥: Angular measure represents the operation handle angle from the current handle position to the ideal handle position.

⑦: Small red triangle on the steering wheel shows current steering wheel position. This steering wheel on GUI is connected to the steering wheel of experimental vehicle. Current steering wheel position is derived from multi-rotate potentiometer on

steering wheel shaft. Navigation in instruction is given by big orange arrow, drivers operate real steering wheel so that the small red triangle on the steering wheel corresponds to the big orange arrow on GUI.
⑧: Small green arrowhead represents the lateral vehicle position on the driving lane.
⑨: Reading RFID antenna's number and the information of the RFID tag are given in the box.

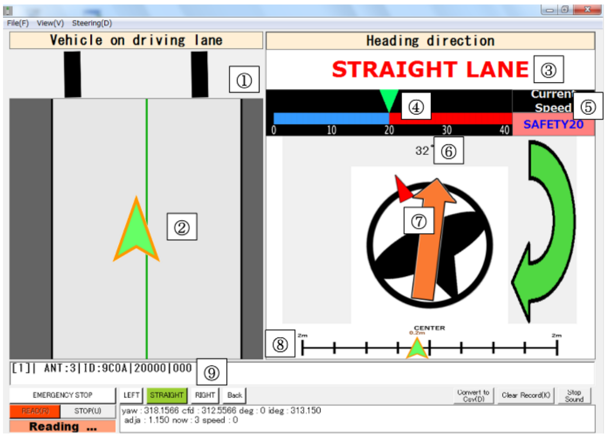

Fig. 4 GUI for straight lane navigation

8. DRIVING EXPERIMENT

The vehicle navigation system is installed in the experimental vehicle and a driving experiments are be conducted.

In order to make low visibility condition, bubble wrap with black vinyl sheet on the windshield and bubble wrap is put on the left, right sides of the driver's seat, and the rear glass during the driving experiments (Fig. 5).

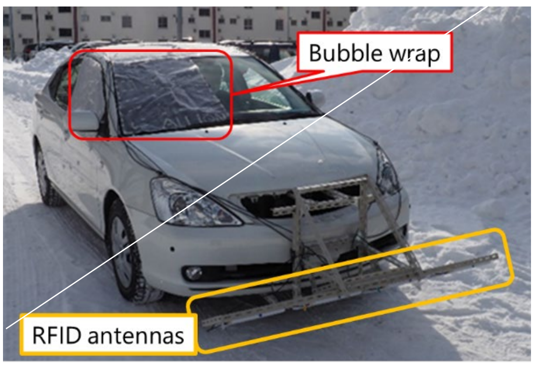

Fig. 5 The driving experiment vehicle

The starting position is set to the center of the road, the left, and the right. The navigation accuracy is verified at the end stop position. Navigation accuracy is evaluated by actually measured vehicle lateral distance from the center of the driving lane. We call this deviation an endpoint deviation. The driving experiment is conducted 126 times by four drivers with different driving experiences.

Driving experiment results

One of the driving experiment results, we have the driving locus (solid line) started from the right side of the road (Fig. 6), from the left side (Fig. 7), and from the center (Fig. 8).

Among all running experiments, the endpoint deviation becomes 0 five times, and vehicle has never gone out from the driving lane.

The endpoint deviations are shown (Table 3). The maximum deviation is 27cm to the left and 28cm to the right. The average deviation of all trials is 2.81 cm on the right from the center of the driving lane. And a standard deviation of all trials is 13.8 cm. Considering the average deviation from the center of driving lane and standard deviation, the vehicle can be navigated to the approximate center of driving lane. During all driving experiments, vehicle average speed is 5.47 km/h, the maximum speed is 9.68 km/h.

Since we are considering navigation in rural road with low speed limit in the winter, the system always read RFID tags. In that area, the maximum speed limit is 60km/h. Especially, we deal with snow stormy weather and low visibility, and on snow-covered roads, vehicle speed is slow down.

9. CONCLUSIONS

In this paper, vehicle navigation system on a straight road with four RFID antennas is studied.

The number of RFID tags to be buried is one-third that of the conventional system. The number of on-board antennas has doubled cost problem of our previous system is diminished.

In order to improve the reliability of autonomous driving, we tackle the situation where the optical sensors and GPS cannot work in the heavy snowfall.

The RFID system is one of alternative positioning system in such hard condition. For our positioning system with RFID system, installation cost problem is pointed out for our previous system. In this paper, we succeed at reducing the number of RFID tags to one-third.

We will apply this vehicle positioning system with RFID system to curved roads and intersections.

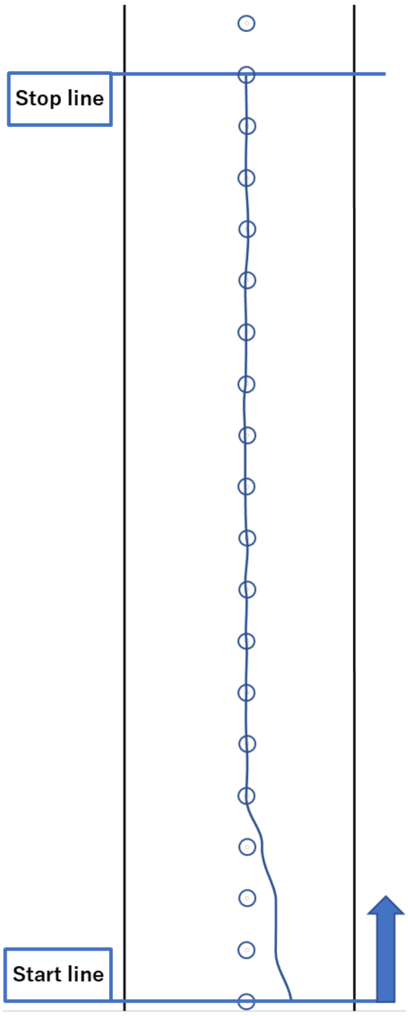

Fig. 6 The driving locus
(start from the right side of the straight lane)

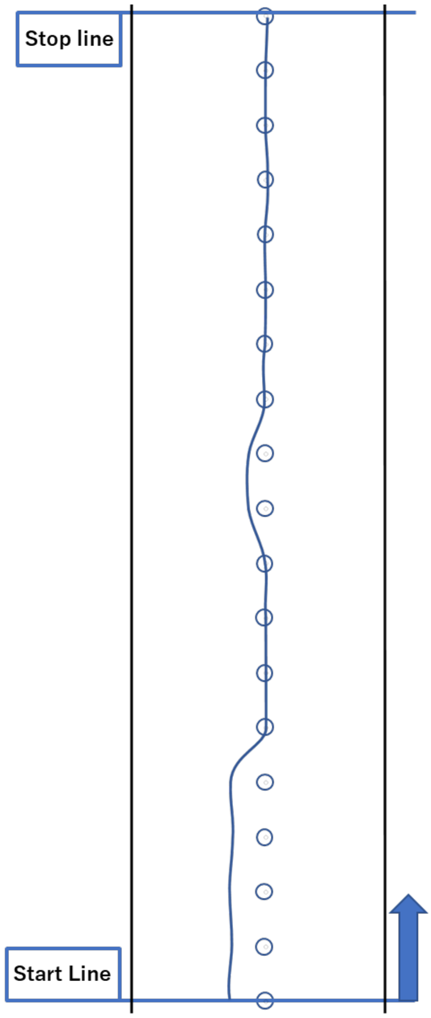

Fig. 7 The driving locus
(start from the left side pf the straight lane)

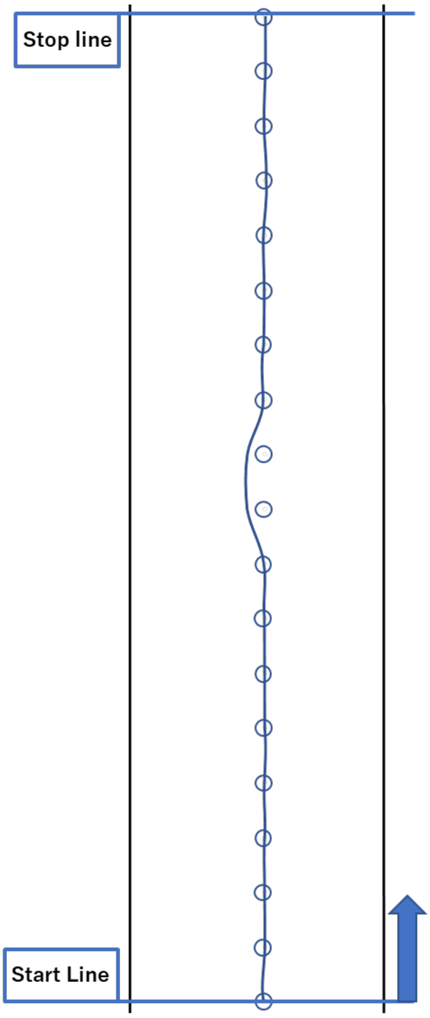

Fig. 8 The driving locus
(start from the center of the straight lane)

Table 3 Maximum / minimum / average deviation and standard deviation at stop position

Value	The endpoint deviation [cm] (Positive to the left with respect to the forward direction)			
	Max	Min	Average	Standard deviation
Measured	27	-28	-2.81	13.8
Estimated	41.25	-41.25	-3.52	12.17

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