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Steering Control and Geomagnetism Cancellation for an Autonomous Vehicle using MR Sensors

Hong-Reol Kim*, **Seok-Jun Son****, **Tae-Gon Kim****, **Jeong-Heui Kim****
Young-Cheol Lim**, **Eui-Sun Kim*****, **Young-Hak Chang******

Abstract

This paper describes the steering control and geomagnetism cancellation for an autonomous vehicle using an MR sensor. The magneto-resistive (MR) sensor obtains the vector summation of the magnetic fields from embedded magnets and the Earth. The vehicle is controlled by the magnetic fields from embedded magnets. So, geomagnetism is the disturbance in the steering control system. In this paper, we propose a new method of the sensor arrangement in order to remove the geomagnetism and vehicle body interference. The proposed method uses two MR sensors located in a level plane and the steering controller has been developed. The controller has three input variables (dB_x, dB_y, dB_z) using the measured magnetic field difference, and an output variable (the steering angle). A simulation program was developed to acquire the data to teach the neural network, in order to test the ability of a neural network to learn the steering control process. Also, the computer simulation of the vehicle (including vehicle dynamics and steering) was used to verify the steering performance of the vehicle controller using the neural network. From the simulation and field test, good result was obtained and we confirmed the robustness of the neural network controller in a real autonomous vehicle.

Keywords : autonomous vehicle, neural network, MR sensor, steering control, magnetic fields.

1. INTRODUCTION

This paper describes a method of driving an autonomous vehicle by sensing 3 dimensional magnetic fields from the magnets embedded in the center of the road. When the magnetic fields are sensed with the MR sensor, there exists magnetic fields from the embedded magnets and the geomagnetism. The geomagnetism acts as interference to the controller. Installed strong magnets were tried to be reduce the effect of the geomagnetism, but the cost was the problem. Another effort was made to mount another MR sensor at a place where the magnetic fields from the magnets in a road can not influence it and it senses the geomagnetism only. This method could remove the

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* 목포대학교 전자공학과 (Dept. of Electronic Eng., Mokpo Natl Univ.)
** 전남대학교 전기공학과(Dept. of Electrical Eng. and RRC, Chonnam Natl Univ.)
*** 서남대학교 전기전자멀티미디어 공학부(School of Electrical, Electronic and Multimedia Eng., Seonam Univ.)
**** 목포대학교 제어계측공학과(Major in Control and Instrumentation Eng.,Mokpo Natl Univ.)
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geomagnetism by taking the difference value sensed from one sensor to another one. But each sensor is affected by the vehicle body interference differently and it was not possible to measure the magnetic fields in a road uniquely[1].

So, we propose a new method to remove the influences of the geomagnetism and the body of a vehicle. This was realized by mounting two sensors side by side on the same level plain. A controller was developed producing a steering angle according to the sensed magnetic fields. The steering controller was realized using a neural network and a computer simulation program was developed to be learn the steering behavior of the vehicle relative to the magnetic fields values[2]. Also, autonomous driving was verified by adapting the proposed method to a self-made experimental vehicle. A method is shown of using the simulator to estimate the lateral distance error, which is difficult to measure on-line.

2.MAGNET EMBEDDED ROAD AND MR SENSOR

The road geometry information is extracted from the magnetic field characteristics from the road embedded magnets[3-8]. The magnetic sensing system provides a simple method to acquire the road direction, as well as obtaining the vehicle's lateral position. In this paper, a 3-axis MR sensor is used and Fig.1 shows the sensor mounted beneath the vehicle. B_x and B_y are oriented tangential to, and normal to the road center line respectively, while B_z is perpendicular to the road surface.

The analysis has been concentrating on the magnetic fields at x=0. The sensor moves along the y-axis, until B_x is zero, and B_y, B_z are non-zero. However, the geomagnetism and the vehicle body interference are excluded in Fig. 2. B_x is zero at all locations and B_z has the largest absolute value in the center of the road and decreases sharply as the distance increases to the left and right. B_y shows zero in the center of the horizontal axis and its absolute value is increased to a certain extent as the distance becomes larger to the left and right and decreases slowly after that. The value of B_y is symmetrical with respect to the origin.

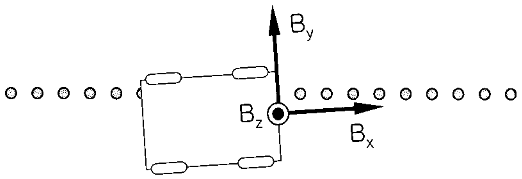

Fig. 1. Location of sensor and 3-axis.

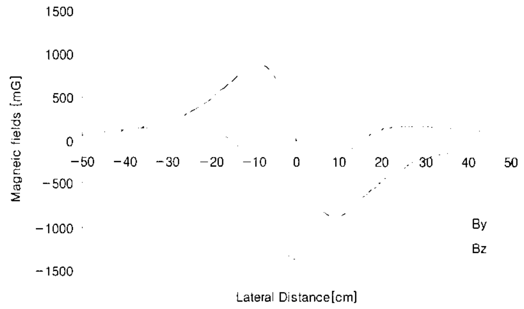

Fig. 2. Magnetic fields profiles.

The geomagnetism is about 500 to 600[mG] and has a component parallel to the earth's surface that always points towards magnetic north. This is the basis for all magnetic compasses. B_x and B_y show a 90[deg] phase difference for 360[deg] rotation in a level plane. The peak to peak amplitude is ±350[mG] shows a sinusoid shape. Therefore, geomagnetism has to be removed because it influences the controller seriously.

3. SENSOR ARRANGEMENT FOR GEOMAGNETISM CANCELLATION

Two sensors experience an influence of the geomagnetism in equal amounts, if they are installed in a level plane such as in Fig. 3. B_a and B_b, measured with the two sensors, can be expressed as in the following equations.

$$B_a = MB_1 + GB_1 + VB_1 \qquad (1a)$$

$$B_b = MB_2 + GB_2 + VB_2 \qquad (1b)$$

where, B_a is magnetic field at sensor 1, B_b is magnetic field at sensor2, MB is magnetic field from the permanent magnets, GB is geomagnetism and VB is the distorted magnetic fields from the vehicle. If the sensors are mounted close enough, equation (2) can be obtained from equation (1), because the magnetic distortion produced by the vehicle is small.

$$\begin{aligned} dB &= B_a - B_b \\ &= MB_1 - MB_2 + (GB_1 - GB_2) + (VB_1 - VB_2) \qquad (2) \\ &= MB_1 - MB_2 \end{aligned}$$

In equation (2), dB becomes the magnetic fields from magnets in the road only and other disturbances are ignored. And this equation can be applied equally to the 3 axis components dB_x, dB_y, dB_z of dB.

Fig. 4 is the graph of dB_y, dB_z when the sensor moves along the y-axis. When Fig. 4 is compared with Fig. 2, dB_z has the same shape as B_y, and dB_y has same shape as B_z. Fig. 5 shows dB_x, dB_y rotating from -30 to 30[deg] rotation in the road center. Because the sensor measures magnetic fields in the road center, dB_z is zero and the value of dB_x and dB_y changes according to the change of vehicle direction

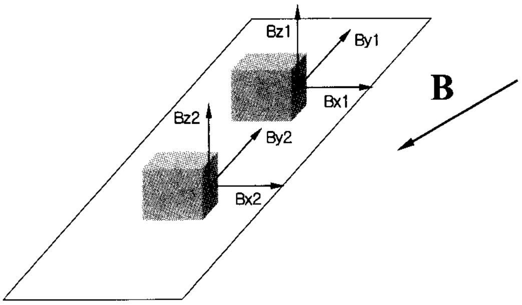

Fig. 3. Arrangement of sensor.

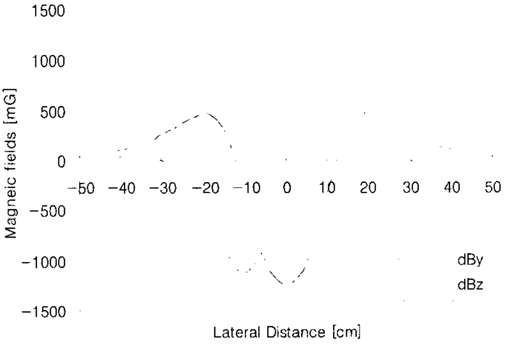

Fig. 4. dB_y and dB_z according to lateral deviation

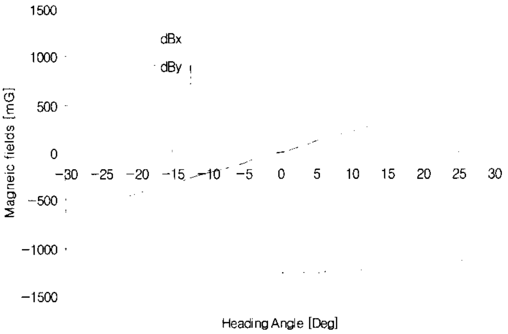

Fig. 5. dB_x and dB_y at the road center, responding to a change of vehicle direction

The value of dB_x, dB_y, dB_z contains the information of the lateral distance from the road center (LD) and orientation error of vehicle driving direction in relation to the road direction (HA). It is difficult to analyze the relationship of the magnetic fields and the HA, LD and steering angle. A linear controller has many problems in controlling the steering. In this paper, the designed controller uses a neural network with back-propagation, which is known to have excellent performance for non-linear systems. When the neural the network controller acquires the magnetic field values (dB_x, dB_y, dB_z), the controller will produce a steering angle.

4. DESIGN OF STEERING CONTROLLER

4.1 Architecture of the neural network steering controller.

In order to drive the vehicle in the center of the road, the vehicle must not drive outside the magnetic field's range. A lateral guidance system detects any lateral deviation of the vehicle from magnets in the road's center. The received information obtained by the difference value of the two MR sensors. The controller makes suitable steering commands from the information received. A linear controller has many problems in controlling the steering. As a result, the controller is designed with a neural network algorithm, because it has excellent performance with non-linear systems [8]. It uses a gradient descent method to minimize the total squared error of the output computed by the network. Fig. 6. shows the architecture of the neural network controller. The controller input layer includes magnetic fields in three-dimensions. There are 10 hidden layers and the output layer represents the steering angle (Table 1). After learning, the connection weights in the neural network appear as the property of the controller

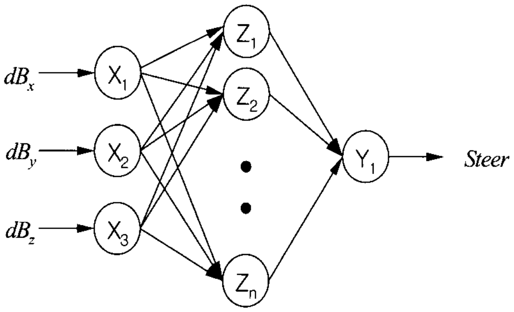

Fig. 6. Architecture of the neural network steering controller

TABLE 1. Neural Network Specifications

parameter	Value
Input Layers	3
Hidden Layers	10
Output Lsyer	1
Learning Rate	0.25
The number of Learning Patterns	743
The number of Learning Iterations	4000

4.2 Acquisition of the learning pattern

The best method for the learning pattern acquisition is when an expert drives on the road. However, human driving also includes inaccurate steering control. The learning pattern obtained by computer simulation can be better than that obtained by human driving. The learning pattern acquisition controller uses fuzzy logic with a max-min method and singleton, which is known to have excellent performance for non-linear systems. With simulation, the LD from the center of the road is known and so is the vehicle's direction. So, the vehicle can be controlled using the exact lateral deviation and driving direction angle.

Learning pattern was obtained by learning pattern acquisition controller for the many cases of road curvature and lateral distance.

Since a magnetic pole is assumed to be a magnetic dipole, the magnetic fields B at an observation point on a three-axis coordinate (x, y, z) could be expressed as follows[1].

$$B=\frac{M}{4\pi r^5}(3xz\ a_x+3yz\ a_y+(2z^2-x^2-y^2)\ a_z[wb/\ m^2] \quad (3)$$

where,

$r=\sqrt{(x^2+y^2+z^2)}$: distance from magnet ,

$a_{x,\ y,\ z}$: unit vector along x, y and z axes respectively,

M : magnetic moment

5. SIMULATION

The simulation program was developed to acquire the data to teach the neural network and to test the performance of the steering controller. The block diagram of the autonomous vehicle simulation is shown in Fig. 7. The process is to produce a dynamic model of the vehicle and include the steering response of the vehicle. The simulation used Visual Basic

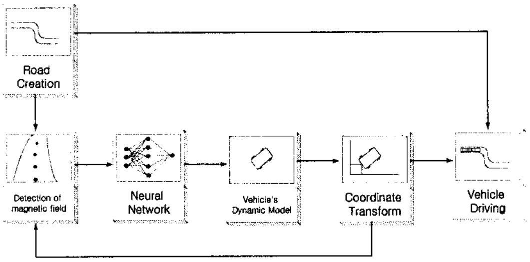

Fig. 7. Block diagram of autonomous vehicle simulation.

The simulator generates straight and curved roads. Starting the vehicle with an initial position and driving direction, the magnetic fields in three-dimensions can be calculated from equation(3). When the neural network controller acquires the magnetic fields values (dB_x, dB_y, dB_z), the neural network controller will produce a steering angle. According to the steering angle, the vehicle's dynamic model calculates the next position of the vehicle. The vehicle then moves to its next position in the simulation.

6. EXPERIMENTAL RESULTS AND DISCUSSION

The size of the hand-made test vehicle is 1/3 of a passenger car and Fig. 8 shows the vehicle. The mechanism of steering system has the same structure of physical passenger car, but the drive power is supplied by a motor. The maximum steering angle is allowed 25[deg] left and 25[deg] right. The vehicle is rear wheel drive, using a 3-phase induction motor with an 18:1 reducing speed gear. The control system consists of magnetic field sensors, steering system and neural network controller. An IBM compatible Pentium 200 [MHz] computer was used to manage the system. Honeywell MR sensors were used to measure the magnetic fields.

Fig. 9 shows the geomagnetism, which is measured by the vehicle while rotating 360[deg]. The peak to peak amplitude is 600[mG] and Fig. 10 shows the geomagnetism compensated using the proposed method. Each component is small compared to that in Fig. 9 and its maximum magnitude is reduced to 20[mG]

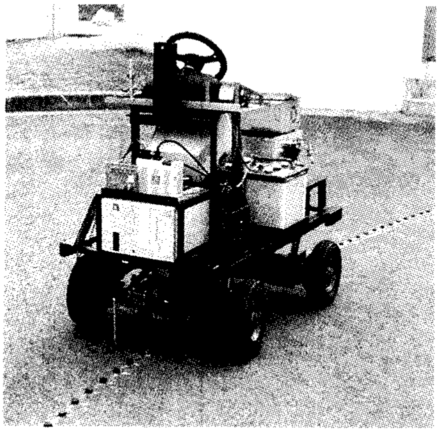

Fig. 8. Photograph of test vehicle.

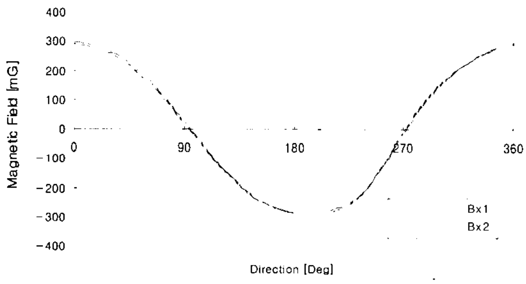

Fig. 9. Magnetic outputs X for 360[deg] rotation.

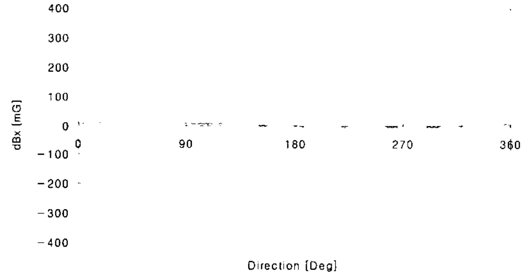

Fig. 10. Compensated geomagnetism.

Fig. 11 shows the shape of the experimental road and the total length is approximately 35[m]. The road includes 90[depg] curves and a reverse curve section. The 90[deg] curves have a radius of 7[m] and 9[m], and the test road was plain. Fig. 12 shows simulated and experimental steering results and vehicle speed was 2.5[m/s]. They have good similarity. The dotted line in Fig.12 shows calculated LD using the method we proposed and it shows the vehicle follows the road center.

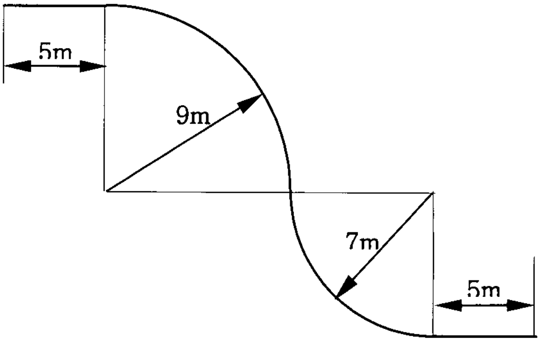

Fig. 11. Shape of road for autonomous driving test.

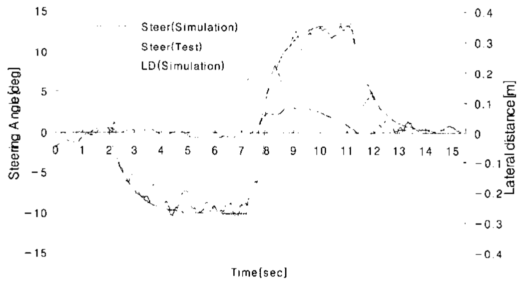

Fig. 12. Simulation and test results.

The next stage of this project would be to consider the effect of a change of the various road conditions, etc

7. CONCLUSIONS

This paper has described a lateral guidance system for an autonomous vehicle sensing the 3 dimensional magnetic fields from the magnets embedded in the center of the road.

We have proposed a method to cancel the influences of the geomagnetism as well as the body of a vehicle. This was done by mounting two MR sensors side by side on the level plane. The geomagnetism intensity is about 500 to

600[mG] and it was decreased to 20[mG] using the proposed method.

The steering controller was realized using a neural network. When the neural network controller acquires the magnetic field values, the controller produces a steering angle as its output. A test road was configured which includes 90[deg] curves and a reverse curve section. Each curve has a radius of 7[m] and 9[m]. Test driving was implemented

and a maximum magnitude of LD error was less than 0.06[m].

The computer simulation program was developed to obtain the learning pattern and to verify the adequacy of the controller design.

Autonomous driving was verified by adapting the proposed method to a laboratory made experimental vehicle. We showed a method of using the simulator to estimate the LD error, which is difficult to measure on-line.

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著者紹介

김홍렬(Hong-Ryol Kim)
1993년 호원대학교 전기공학과(공학사)
1997년 호원대학교 전기공학과(공학석사)
현재 : 목포대학교 전자공학과 박사과정
관심분야 : 센서 시스템, 신경회로망, 자율주행 시스템

임영철(Young-Cheol Lim)
1975년 전남대학교 전기공학과(공학사)
1977년 고려대학교 전기공학과(공학석사)
1990년 고려대학교 전기공학과(공학박사)
현재 : 전남대학교 전기공학과 교수
전남대학교 고품질전기전자부품 및 시스템 연구센터 소장
관심분야 : 퍼지, 신경망, 지능제어계측,전력전자

김의선(Eui-Sun Kim)
1981년 전남대학교 전기공학과 (공학사)
1987년 전남대학교 전기공학과 (공학석사)
1999년 전남대학교 전기공학과 (공학박사)
현재 : 서남대학교 전기전자멀티미디어 공학부 조교수
관심분야 : 신경회로망 및 퍼지이론, 지능제어시스템 이동로봇, 자율주행시스템, 전기자동차 구동시스템

김태곤(Tae-Gon Kim)
1985년 전남대학교 전기공학과(공학사)
1991년 전남대학교 전기공학과(공학석사)
현재 : 전남대학교 전기공학과 박사과정
관심분야 : 신경회로망 및 퍼지이론, 지능제어시스템 이동로봇, 자율주행시스템

손석준(Seok-Jun Son)
1999년 서남대학교 전기공학과(공학사)
2001년 전남대학교 전기공학과(공학석사)
현재 : 전남대학교 전기공학과 박사과정
관심분야 : 신경회로망 및 퍼지이론, 지능제어시스템 이동로봇, 자율주행시스템

김정희(Jeong-Heui Kim)
1998년 조선대학교 제어계측공학과(공학사)
2000년 전남대학교 전기공학과 대학원 입학
현재 : 전남대학교 전기공학과 석사과정
관심분야 : 신경회로망 및 퍼지이론, 지능제어시스템 이동로봇, 자율주행시스템

장영학(Young-Hak Chang)
1981년 전남대학교 계측공학과 공학사
1984년 전남대학교 전기공학과 공학석사
1991년 전남대학교 전기공학과 공학박사
현재 : 목포대학교 제어계측공학과 부교수
관심분야 : 퍼지제어, 센서시스템