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Simple detecting method of turning radius using geomagnetism sensor for light electric vehicle

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Summary

In this study, we propose a simple detecting method to detect the turning radius of the light electric vehicle (LEV) and confirm the possibility by using geomagnetism sensor. We carried out two types of experiments to detect the turning radius, First, we measured the turning radius when the LEV runs at a constant velocity. In the second, we measured in the a real racing circuit. According to the experimental results, it is possible to measure the turning radius of a curve although it could not be measured accurately.

Keywords: Car, EV, <turning radius>, <geomagnetism sensor>

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1 Introduction

A geomagnetism sensor is possible to measure three-dimensions signal with high precision; X-axis, Y-axis and Z-axis. This sensor output either the maximum value of geomagnetism when one axis faces north or the minimum value when one axis faces south. Using these features, when the car turns around a curve, a sinsodial waveform from geomagnetism sensor can be obtained. Usually, Geomagnetism sensor is used as electric compass of a car [1] and aircraft navigation system.[2, 3] These are mainly used to know the direction.

There is a light electric vehicle (LEV) competition, which is called “ECO-Run” in japan and our EV team participate in the competition every year. The most important point in the racing is how fast the car can turn at the curve; it depends on the technique of the driver. In other words, the driver needs a lot of time and experience for training in the racing. In addition, because the LEV has a small width, it is easy to roll over when turning the corner at high speed.

In this paper, in order to prevent the roll over accident and achive high speed turning at the corner, we investigate and consider a simple detection method of the turning radius using the geomagnetism sensor. The microcomputer and the geomagnetism sensor are used to calculate the turning radius. And, we carry out two kind of experiments to detect the turning radius by the detecting system, In the first experiment, we measure the turning radius of the LEV turning around a round course at a constant velocity. In the second experiment, we measure the output of sensor on a real racing circuit. The first one is the car turns the round course at the constant velocity, the second experiment is the car runs on the real racing circuit. The result of the first experiment shows that the turning radius was calculated by the proposed detecting system using the geomagnetism sensor. But, the second experimantal measurement in the field of racing circuit could not show enough results by the interference from the magnetic field of motor.

2 LEV for ECO-Run

The EV ECO-Run racing is held in the Sport Land SUGO located in Sendai city in Japan.[4] The rules of this racing competition is the running distance after two hours run with a fixed battery weight. In the case of lead-acid battery, which is mainly used in the competition, is limited under 12kg weight. A super capacitor, such as electric double-layer capacitor is also allowed.

Fig.1 shows the LEV which were made by the EV team of our college. [5] The table 1 shows the specification. The 2kW maximum power brushless DC motor is connected to the rear wheel by mechanical gears. Table 2 shows the specification of electrical system mounted in LEV. The motor also uses regenerative breaks and super capacitor charged regenerative energy when the breaking mode.

Figure 1: LEVs manufactured by NIT, Ibaraki College.

Table 1: Vehicle Specifications.

Overall Length	2500mm
Overall Width	750mm
Overall Height	600mm
Wheel Base	1300mm
Wheel Distance	700mm
Overall Body Weight	50kgw

Table 2: Electrical Specifications.

Motor	Brushless DC motor, 2 kW peak output power
Battery Pack	4×12V, 7.5Ah cells in series
Super Capacitor Bank	30 V max 58.3 F ; 12×2.5 V max 350 F cells in series and 2 in parallel
DC link Capacitance C_{DC}	63 V max 4980 µF; 6×63 V max 820 µF cells in parallel

3 Detection of turning radius

3.1 Geomagnetism sensor

In this study, we used the MPU9250 as the geomagnetism sensor.[6] This sensor is a nine-axis seonsor; it has three-dimensions accelerometers, three-dimesnions gyros and three-dimensions geomagnetism sensors. The direction of each axis and the magnetisim of the geomagnetism sensor shown in Fig. 2. It can be used to measure the geomagnetism and the maximum value is detected when each axis of the sensor faces north. When the car turns at the corner, if the driver turns at too high of a speed, the LEV will roll over. The equation for the limit speed of the car due to prevent roll over can be calculated as the following: [7]

$$v = \sqrt{\frac{rg(hsin\theta+cos\theta)}{hcos\theta-wsin\theta}} \quad (1)$$

Fig. 3 shows the parameters when the car is on the slope. Where "*r*" is turning radius, "*g*" is gravity, "*h*" is height, "*w*" is width and "*θ*" is the bank angle. Gravity and the bank angle are the constants, so the only unknown value is the turning radius "*r* ". It is calculated by using the output signal from geomagnetism sensor in the next section.

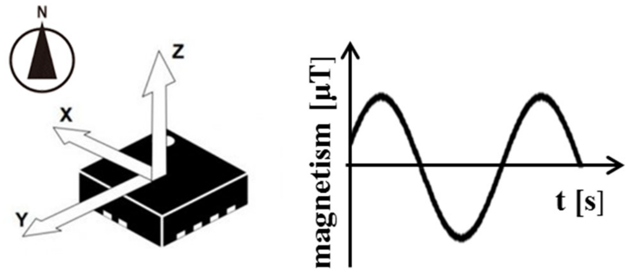


Figure 2: Geomagnetism sensor output signal.

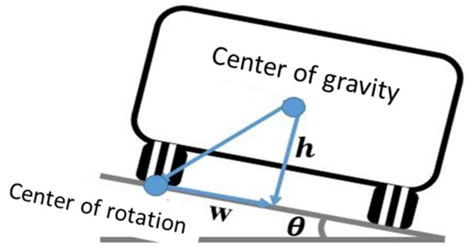


Figure 3: Illustration when the car is on the slope.

3.2 Calculation method of the turning radius

Fig. 4 shows that an arc drawn when a car moves from point A to point B. The define the angle when the car moves from point A to point B as "α", the distance as "a ", the speed of the car as "*v*" and the time as "*t*". Then, the distance "a" is calculated as the following:

$$a = \frac{2\pi r\alpha}{360} = \frac{v}{t} \quad (2)$$

Hence, the turning radius is calculated as:

$$r = \frac{360v}{2\pi t\alpha} \quad (3)$$

In here, since θ is an unknown value, it is calculated the according following steps;

Step1: The graph is divided into half periods because the inclination of the sinsodial wave is assumed almost liner. The absolute value between the peak-to-peak value of the sinsodial wave is normalized by 180 degrees.

Step2: To calculate the angle, the changed value from geomagenetism sensor is achived in each calculation sampling period. Also, the distance is calculated by equation (2). The transition value of sensor output is converted into angle "α" in each sampling period.

Step3: The turning radius is calculated by equation (3).

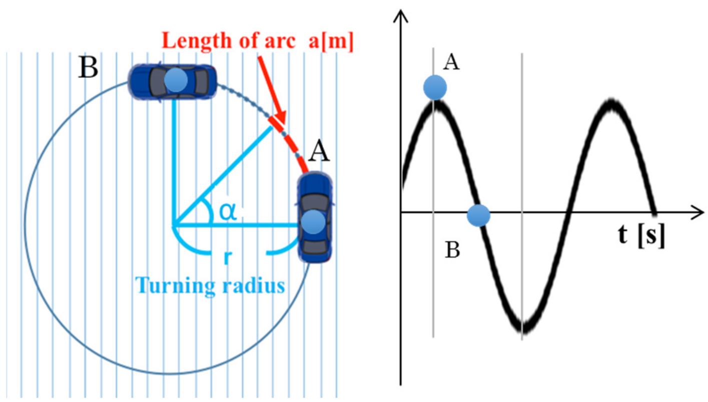


Figure 4: An arc drawn when car moves from A to B.

4 Simulation Results

Befor the measurement in the racing circuit, we cattied out experimental measurement at our college campus. The geomagnetism sensor will mounted in the center of the car and it can be used to detect 3 dimensions. The turning radius is only calculates the X- and Y-axis values, also the Z-axis values is used to calculate the sea level of the car. In this case the peak-to-peak value the geomagnetism is normalized by 80 and the cycle is about 5 seconds when the car turns clock wise at a radius of 2 meters at 15km/h. Therefore, the sinsodial waveforms can be measured from the geomagnetism sensor as shown in the Fig. 5 when the car turns clockwise with a radius of 2 meters.

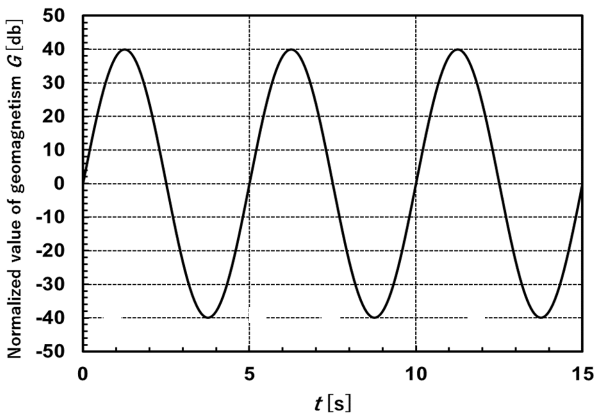
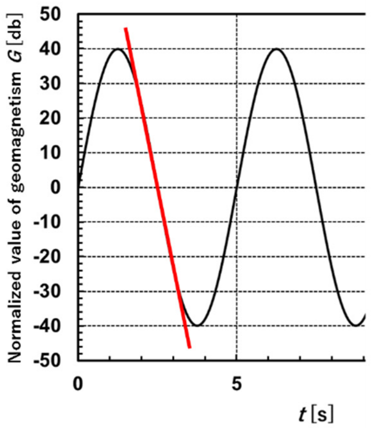
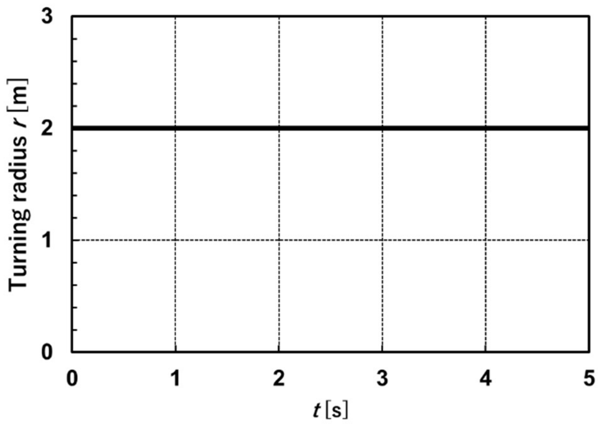


Figure 5: Simulation result of geomagnetism.

4.1.1 Result by calculating the first order approximation





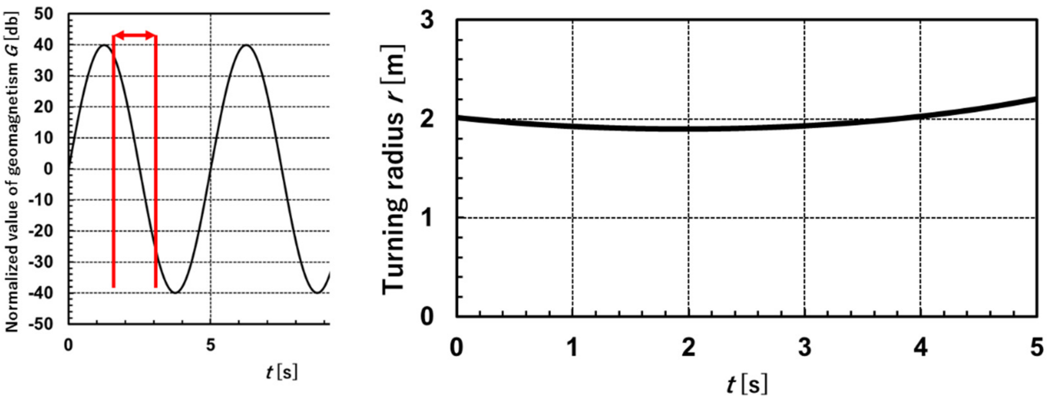
(a) Graph applying the first order approximation to Fig. 5 (b) The result of the calculated turning radius

Figure 6: First order approximation method from Fig. 5.

In this simulation, we used the first order approximation method to calculate the turning radius of the car. For the calculation method, first, the geomagnetism data is prepared by the sensor and an approximation equation as indicated by red-line in the Fig. 6(a) is calculated. Next, the turning radius according to the steps of 3.2 is calculated. The simulation result shows the very stable turning radius value. However, it is nesseary to obtain the results of the geomagnetism value for at least one cycle because of the linear approximation.

4.1.2 Result by real time calculating

The real time calculating method is also considered to calculate the turning radius. The simulated result within the range of red line is shown in Fig. 7. In this case, the differences between the current value and previous values are needed and just repeating step of section 3.2.



(a) Graph applying the real time calculating to Figure5 (b) The result of the calculated turning radius

Figure 7 : Simulation result by real time calculating method

In this simulation, since it is assumed that the car runs on the circuit, it is nessesary to acquire the turning radius in real time. So we choose this method for detecting the turning radius.

In addition, because the maximum peak to the minimum peak of geomagnetism wave is assumed almost horizontal, it is programmed to retained the previous value instead of calculating in real time due to hold the previous value without calculating in real time.

5 Experimental Results

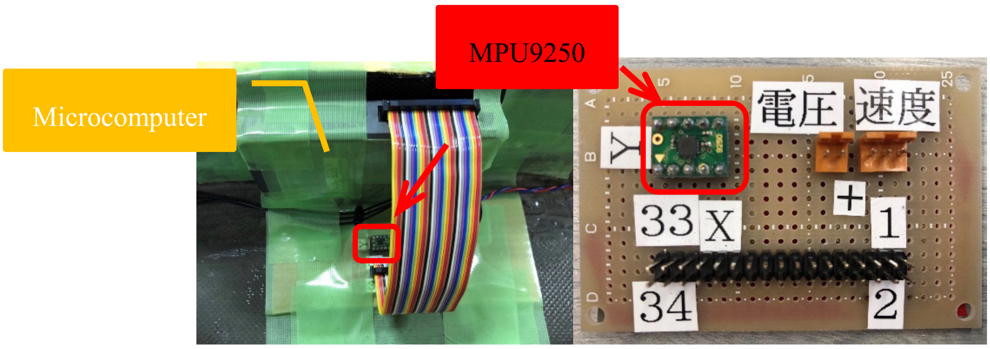
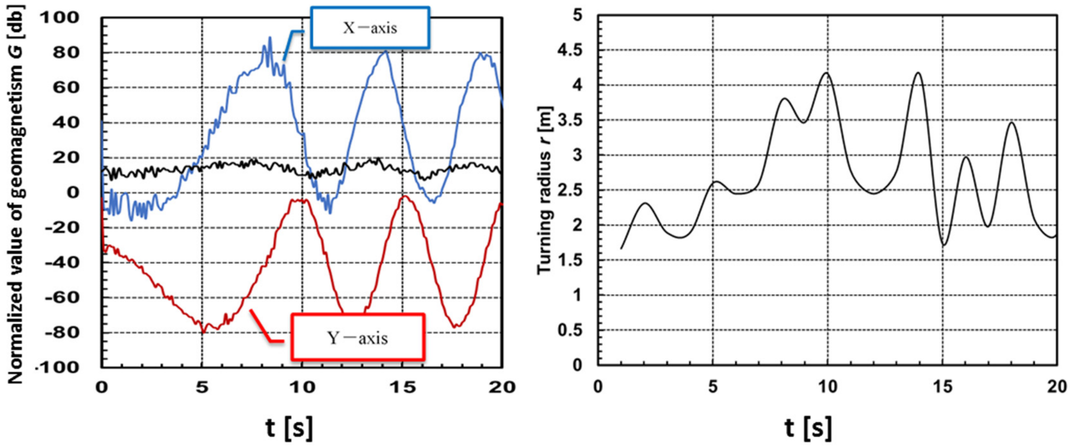


Figure 8 : Photo of sensor.

In this experiment, an experimental devices was placed the center of the LEV as shown in the Fig. 8, and the geomagnetism and turning radius were measured with a radius of 2 meters at 15km/h in college campus.



(a) Geomagnetism sensor output signal (b) Calculated turning radius

Figure 9 : Result of the geomagnetism and the turning radius of the car.

Fig. 9(a) shows the result of geomagnetism when the car turns clockwise. The blue line shows the geomagnetism value of X-axis, red one is Y-axis's, and black one is Z-axis's. The amplitude of both X-axis and Y-axis is approximately 80, and the cycle of them is approximately 5 seconds. In this case, because the test road is very flat, the geomagnetism value of Z-axis shows almost flat value. Fig. 9(b) shows the calculated turning radius by the geomagnetism value. The truth value of turning radius is 2 meters, however, the result shows unstable value from 4 m to 1.8 m.

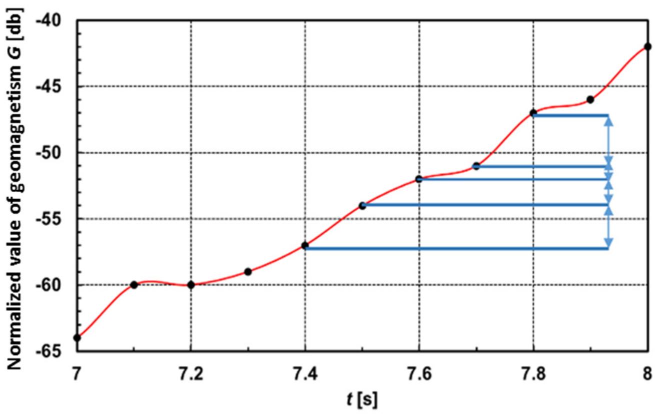


Figure 10 : A plot of observation points on the enlarged view of a part of Fig. 9

Fig. 10 shows an enlarged Y-axis's valu in Fig. 9(a) from 7 s to 8 s. The reason why the turning radius was not at a constant value is not only the road of our college was not completely flat but also the speed of car is not constant. This means that the geomagnetisma sensor was influenced from road and speed conditions. Moreover, geomagnetism sensor detected the magnetic field from the brushless DC motor. Because of these reasons, the distance between points of each calculation sampling period becomes nonuniform as shown in Fig. 10.

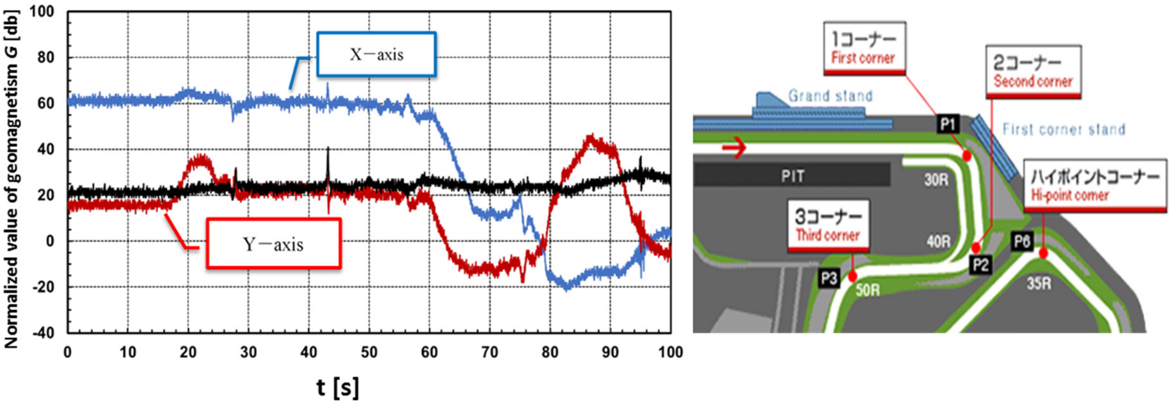


Figure 11 : Experimental result in the racing circuit from the straight to the third coner.

This experimental measurement was carried out at the Sports Land SUGO circuit. Fig. 11 shows waveforms from geomagnetism sensor when the car moved from the starting line to the third corner. In the straight section, geomagnetism was also straight. In the first corner, because both the X-axis and Y-axis values decrease from the maximum value, this means that it is turning from east to south. In the next section, geomagnetism is straight which means that the car run in straight line. In the second corner, because X-axis decreases and Y-axis increases which means that the car turning from south to west. In this experiment, we understand that the outer shape of the circuit can be measured.

6 Conclusion

In this paper, we confirmed the possibility to calculate the turning radius of the car and that it can be applied for the LEV. We are able to confirm that it was detectable, However, the result of the turning radius was fluctuated. The experimental result at the circuit was not able to detect the turning radius of the car due to some technical issues. However the outer shape of the circuit was able to detect which means that it is possible to calculate the turning radius.

In this experiment, the geomagnetism sensor was mounted only one at the center of the car. Future work may involve the introduction of two gomagnetism sensors the end of the car to obtain more accurate values.

References

[1] Wei Li and Jinling Wang : "Magnetic Sensor for Application : An Overview", pp.1(2013)

[2] James Lenz and Alan Edelstein: "Magnetic Sensors and Their Applications", *IEEE Sensors Journal* pp.645-646(2006)

[3] E.R. Benson, T.S. Stomabaugh, N. Noguchi, J.D. Will and J.F. Reid : "An evaluation of a geomagnetic direction sensor for vehicle guidance in precison agriculture applications", *An ASEA Meeting Presentation*, pp.3-7,10-12(1998)

[4] Sport land Sugo, http://www.sportsland-sugo.co.jp

[5] K. Sung, N. Watanabe, and K. Kawamura : "Experimental results of series or parallel changeover system using battery with EDLC for electric vehicle", *9th International Conference on Power Electronics and ECCE Asia (ICPE – ECCE Asia)*, pp.2911-2916 (2015)

[6] The datasheet of MPU9250 http://www.invensense.com/wp-content/uploads/2015/02/PS-MPU-9250A-01-v1.1.pdf

[7] The equation for a car not roll over, https://courses.lumenlearning.com/physics/chapter/6-3-centripetal-force/

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