Robust Electric Compass to Dynamic Magnetic Field Interference

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Abstract: The purpose of this research is to improve the reliability of automobile navigation system that utilizes the magnetic compass for localization. On account of its sensitiveness against the dynamic external interference of the magnetic field, the electronic compass itself is not accurate enough to be used for the localization compared to the gyro-compass. To overcome this shortcoming, in this research, a robust electronic compass is designed by using two magnetic compasses to cancel out the dynamic interferences efficiently. That is, a dual compass predictive calibration algorithm against irregular external interference of magnetic field is newly proposed and implemented in this paper. When the dynamic interference can be eliminated from the electronic compass, it becomes much accurate than the gyro-based system that suffers from the accumulative drift error. The reliability and performance of the designed system have been verified through the real driving experiments.

Keywords: Electronic Compass, Magnetic Interference, Predictive Calibration Algorithm, Navigation System

1. INTRODUCTION

GPS/DR integrated navigation system has become standard vehicular navigation in recent years [1-4]. An azimuth sensor which is used at DR is an electric compass and gyro [5].

Electric compass have been used for maritime, aerial and land navigation for a long time. Although the sensor itself has become very accurate and compact for car-navigational use, terrestrial magnetic sensing is still very erroneous because of environmental factors [6-11]. Gyroscopes azimuth sensing, however, can become very erroneous as time passes because of accumulation of sensing errors [5]. In this paper, we used the electric compass for an azimuth sensor and presented a calibration method about the interfere magnetic field to happen in a electric compass.

Fig. 1 expressed the errors which the electric compass happens. The influence of fixed interfere magnetic field can revise to the present time [10]. But the error to be happened does not become the revision by unexpected interfere magnetic field. A present time's electric compass is incongruent to a DR sensor for the car navigation system of the vehicle. We studied robust at an unexpected interfere magnetic field electric compass. In this paper, the external interfere errors can be classified as time-invariant error and time-varying error and an each error presented the calibration method with the feature.

The time-invariant error appears in an inside environment change of the vehicle which the electric compass is installed. This appears to the movement and variant of the magnetic circle. This case can calibrate easily to 360 rotation calibration [5-6, 8, 10-12]. The time-varying error appears in the change of an external magnetic field, the tilt and inclination of load which happens among the vehicle movement. Each error will do the calibration to a predictive calibration algorithm which uses the two electric compasses.

II. External Interfere Error or Calibration

2.1 External Interfere Error

The magnetic source is measured in the compass, measured by slope and lean or material that contain iron of the earth magnetic field and nearly area with distortion.

Through following assumption, this can divide the effect to magnetic source into three classes.

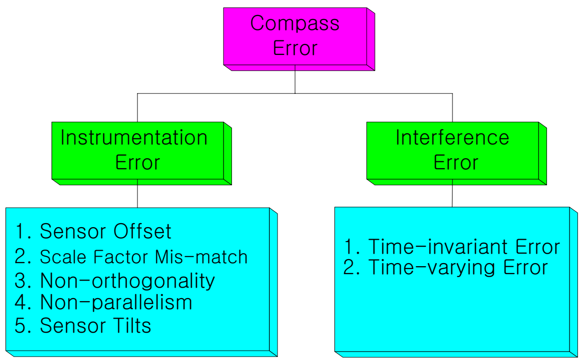

Fig. 1 Classification of compass error.

Case 1. The effect-the magnetic filed variety of inside vehicle to magnetic source-transforms the offset value of magnetic source.

Case 2. The effect-the outside interfere magnetic field to magnetic source-transforms the magnitude of magnetic source and represent into irregular forms.

Case 3. The effect-slope and lean to magnetic source-only transforms the axis-sensors or the magnitude element of y-axis sensors.

Since Case 1 is the error of environment variety in vehicle and have the fixed value while the environment inside vehicle didn't transform, Case 1 is defined the time-invariant error. Case 2, Case3 is defined time-varying error because the error is generated when the vehicle move and is variable according to the environment variety of outside vehicle.

2.2 Time-invariant error

The time-invariant error is affected by the vehicle body when the compass attach vehicle for direction measurement. The effective calibration for that is required for believable direction measurement.

Fig. 2 represents the effect that is vehicle body into the compass when the compass attach vehicle in the place where is not represent external interference magnetic filed, and the element of interference magnetic filed is the vehicle magnetic field. If the direction of the earth magnetic field and interference magnetic filed operate into the same direction between the direction of vehicle in 0 degree and the direction of the earth magnetic field in Fig. 2, the magnitude of two elements is added. If the vehicle rotate 180 degree, the direction of interference magnetic filed and compass is contrary the direction of the earth magnetic filed and is canceled each other.

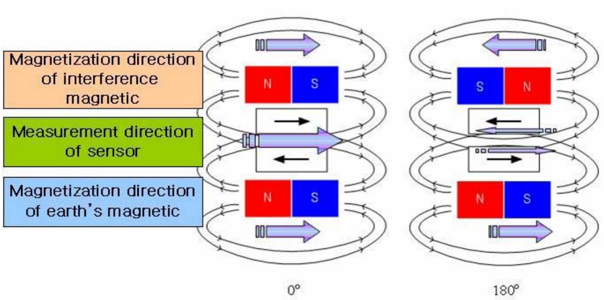

Fig. 2 Direction of a magnetic field between earth's field and interference field.

In conclusion, the magnetic source to be produced by the oneself of the vehicle is represented the form that is moved about a origin and change the magnitude.

Fig. 3 expressed the output of the X-axis sensor and Y-axis sensor after turning around the vehicle which is installed a compass module so that we have the 180 angle difference.

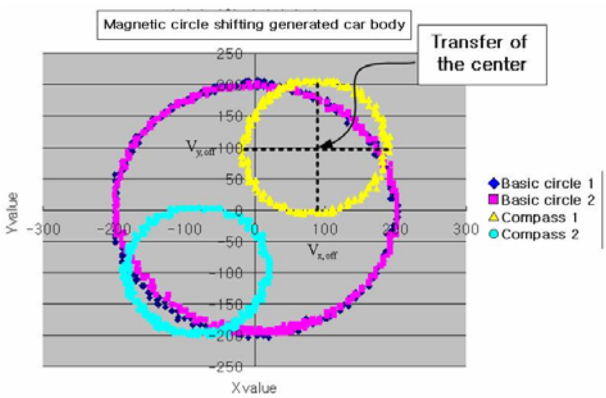

Fig. 3 Magnetic circle shifting generated by car body.

Without any magnetic interference, the diagram appears as a circle, having its center at (0, 0). "Hard iron effects" are caused by magnetized objects, which are at a fixed position with respect to the compass. These cause a magnetic field, which vectorially added to the earth field. Thus, in the test diagram this effect appears as a shift of the circle's centre to $(V_{x,off}, V_{y,off})$, where $V_{x,off}$ and $V_{y,off}$ are the components of the interference field of car frame.

With the Fig. 3, the size of the magnetic circle became the degrade when electric compass installed at the vehicle. This is in the condition of the worst because the electric compass installed at a GPS/DR module which is composed of a metal box to experiment.

The calibration about this is calibrated easily by 3 steps of the downside [8].

Step 1. Installed the electric compass at the vehicle and turned round in the plane slowly.

Step 2. Find X-axis and Y-axis sensors of maximum value V_{max} and minimum value V_{min}

Step 3. Calculated X-axis and Y-axis sensors of $V_{x,sf}$, $V_{y,sf}$, $V_{x,off}$ and $V_{x,off}$ with 4 values.

2.3 Time-varying error

We showed the revision about fixed interfere about the time until now. This chapter treats a calibration method of the dynamic magnetic field interference, the tilt and inclination of load to happen while the vehicle travels. This paper proposes a predictive calibration algorithm in a revision method of the dynamic magnetic field interference.

2.3.1 Dynamic magnetic field interference

A revision algorithm about the dynamic magnetic field interference did not become the introduction in existing research and can not present the resolution.

The Fig. 4 presented the relation of the earth's magnetic field with the external interfere magnetic field to happen as vehicle traveled. The interference magnetic field is the neighboring vehicle and tunnel as the environment change of the outside. The next is the influence of the external interfere magnetic field about a driving direction of the vehicle. The electric compass and vehicle direction revolves to 180° when the vehicle turn to 180° in 0° but the external interference acts to fixed direction.

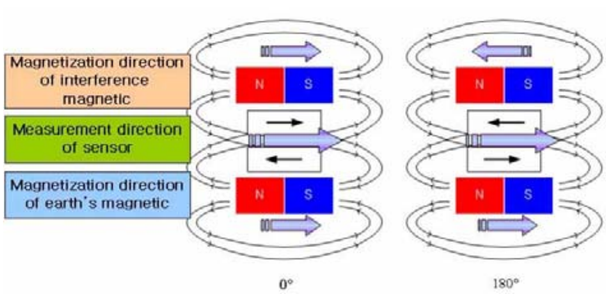

Fig. 4 Direction of a magnetic field between earth's field and dynamic interference field.

In the end the external interfere magnetic field has the form to change the magnitude of the magnetic circle. The temporary magnetic field interference takes the influence much at the vehicle over the medium size.

Fig. 5 illustrates that the influence of magnetic circle generated by neighboring vehicle. And the electric compass's direction and magnitude appear irregularly in the. But the external interfere transforms the magnitude of the sensor' value and the offset of the magnetic circle does not take the influence. Such temporary interference field can measure. The measurement of the magnetic field interference checks whether the sensor's value stays at the magnetic circle based on the magnetic circle.

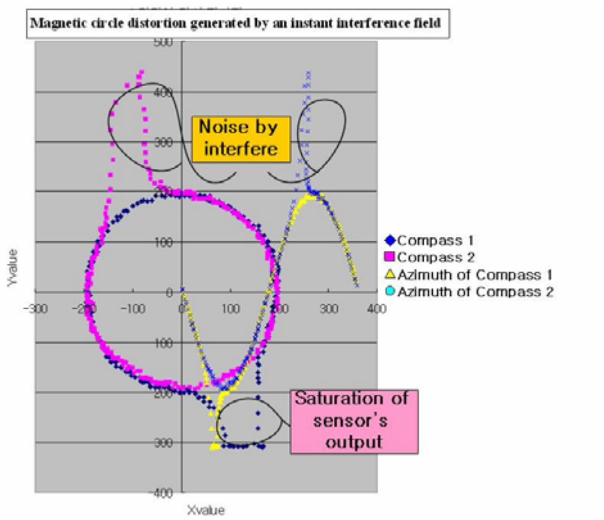

Fig. 5 Magnetic circle distortion generated by an instant interference field.

Fig. 6 illustrates that the form of the magnetic circle to be transformed by the interference to be the temporary. The basic magnetic circle is the calibrated magnetic circle which is the circle to appear when the rotation did the vehicle at the place without an outside interference. The circle in the inside and outside represents the magnetic circle of threshold value to distinguish the external strong interfere magnetic field from the error of minute sensor output.

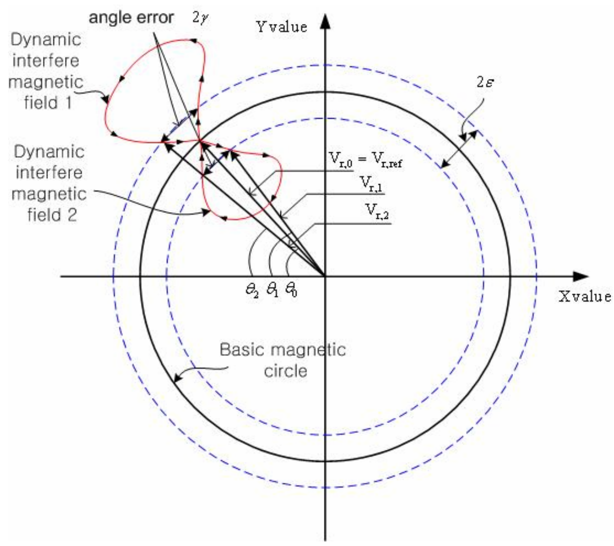

Fig. 6 Distortion modeling of magnetic circle generated by dynamic interference field.

This range of threshold value is important element which the user requests which determines the precision of the azimuth and must find the suitable value through the experiment about the environment to use.

Also, the change of the azimuth by an external interference induce temporary and rapid azimuth error compared with the change of the azimuth by the vehicle drive's going and can measure temporary interference by the threshold value of an azimuth error to be measured about the azimuth to be predicted.

The Dynamic interfere magnetic field is divided by 3 kinds conditional expression.

Condition 1. $|V_{r,read} - V_{r,ref}| < \varepsilon$, $\varepsilon = |V_{r,2} - V_{r,1}|/2$.

Condition 2. $|V_{angle} - \hat{V}_{angle}| < \gamma$, $\gamma = |\theta_2 - \theta_1|/2$. (1)

Condition 3. $|V_{x,read} - \hat{V}_x| > \varepsilon$, $|V_{y,read} - \hat{V}_y| > \varepsilon$.

A magnitude change of the magnetic circle by the magnetic field can detect by the conditional expression 1. Rapid azimuth change by the interference which is the temporary can detect by conditional expression 2. The error by the tile and inclination can distinguish by the conditional expression 3. In the result, the external interfere magnetic field is measured by an upside's 3 kinds of conditional expression.

This paper distinguished the error by the external interfere magnetic field and the tile and inclination and applied a calibration algorithm about an each error

The first, the irregularity change of magnetic circle by external interference revised with the previous average value.

The second, because the tile and inclination gives an x-axis or y-axis sensor the influence, the one axis to secede the magnetic circle used the predictive value and revised.

Fig. 7 classified the error and showed a predictive calibration algorithm to revise. The predictive value can calculate using the previous value which is saved at the FIFO.

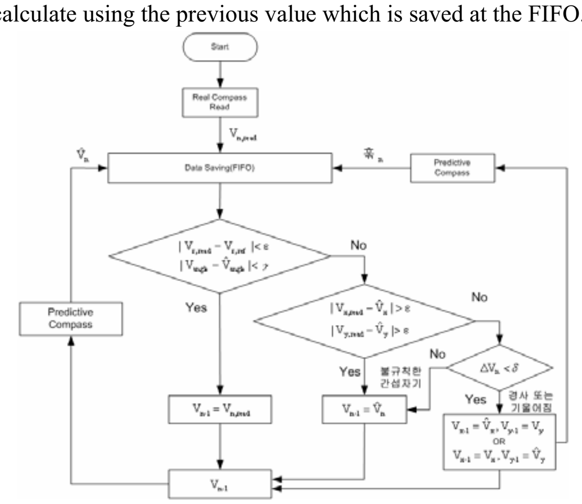

Fig. 7 Measurement of external interference field and calibration algorithm.

The predictive value can be expressed as follows:

$$\hat{V}_n = V_{n-1} + \frac{1}{n}\sum_{k=0}^{n-1}\Delta V_k$$
$$\hat{V}_{n,angle} = V_{n-1,angle} + \frac{1}{n}\sum_{k=0}^{n-1}\Delta V_{k,angle} \quad (2)$$

Where n is the size of FIFO, V_n is the present measurement, $\hat{V}_n$ is predictive value, ΔV_k is a difference value of dates which is saved at the FIFO.

We use the predictive value which obtains in an Eq. (2) to revise a present time's azimuth. The azimuth uses the present value if the difference of the present value and the predictive value is small. The case of the contrast uses the predictive value

$$\begin{cases} V_{n,angle} & |V_{r,read} - V_{r,ref}| < \varepsilon \;,\; |V_{n,angle} - \hat{V}_{n,angle}| < \gamma \\ \hat{V}_{n,angle} & \text{otherwise} \end{cases} \quad (3)$$

2.3.2 Tilt and inclination calibration

For the calibration about the tilt and calibration, the direction of the electric compass y-axis must make with a progress direction of the vehicle. In such case, the magnitude of the Y-axis is changed about the tilt. On the other hand, the magnitude of the X-axis is changed about the inclination.

Fig. 8 illustrates that Magnetic circle distortion and azimuth error generated by inclination and tilt. We use the conditional expression 3 to distinguish between the inclination and the tilt.

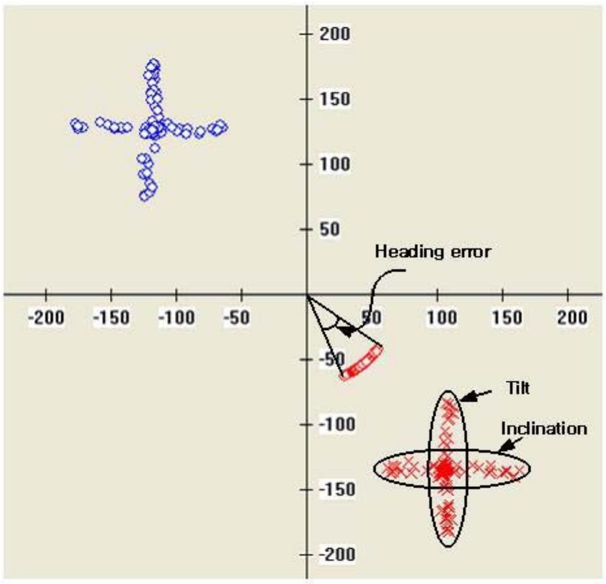

Fig. 8 Magnetic field distortion and azimuth error generated by inclination and tilt.

If it defines the tilt to the Y-axis of sensor, the distinction about the tilt can be expressed as follows:

$$\begin{aligned} &|V_{n,x} - \hat{V}_{n,x}| < \varepsilon \text{ and, } |V_{n,y} - \hat{V}_{n,y}| > \varepsilon, \\ &|V_{n,y} - V_{n-1,y}| = \Delta V_{n,y}, \\ &|\Delta V_{n,y} - \Delta V_{n-1,y}| < \delta \quad . \end{aligned} \quad (4)$$

Here a calibration method uses the measurement X-axis value V_x with the predictive Y-axis value $\hat{V}_y$.

$$\begin{aligned} V_{x,corrected} &= V_x, \\ V_{y,corrected} &= \hat{V}_y. \end{aligned} \quad (5)$$

In the same method, it defines the inclination to the X-axis of sensor and the distinction about the inclination can be expressed as follows

$$\begin{aligned} &|V_{n,x} - \hat{V}_{n,x}| > \varepsilon \text{ and, } |V_{n,y} - \hat{V}_{n,y}| < \varepsilon, \\ &|V_{n,x} - V_{n-1,x}| = \Delta V_{n,x}, \\ &|\Delta V_{n,x} - \Delta V_{n-1,x}| < \delta \quad . \end{aligned} \quad (6)$$

A calibration method uses the predictive X-axis value $\hat{V}_x$ with the measurement Y-axis value V_y .

$$\begin{aligned} V_{x,corrected} &= \hat{V}_x, \\ V_{y,corrected} &= V_y. \end{aligned} \quad (7)$$

3. Experiment and Result

We verify reliance which is installing our DR module in the vehicle and comparing other DR modules through traveling and turning for Navigation System. We travel a downtown, tunnels and compare rapid turning and gentle turning

3.1 DR module

Using Pentium III-800MHz Note Book in this experiment and installing our DR module under the assistant driver's seat. DR module is shown in Fig. 9. We are getting information of distance and direction from Speed meter and electric Compass

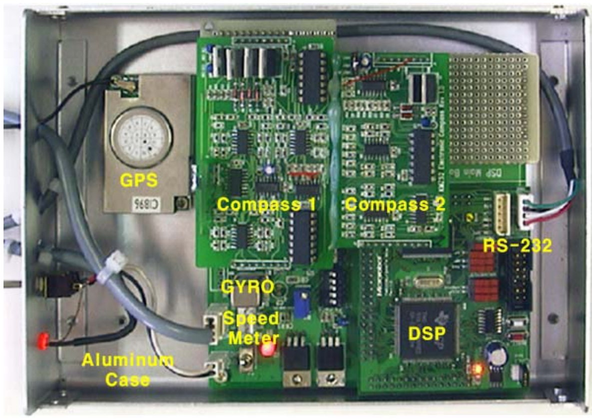

Fig. 9 Prototype DR Module.

3.2.1 Compensation of rotation and establishment of coefficient

When compass is installed first time in vehicle, it needs compensation of one rotation. If compass is rotated one time to plane, we can measure value of $V_{x,max}$, $V_{y,max}$, $V_{x,min}$, $V_{y,min}$ from compass1,compass2. And from this value, we can find value of $V_{x,sf}$, $V_{y,sf}$, $V_{x,off}$, $V_{y,off}$, V_r and V_{sf}. Additionally ε , γ and δ determine traveling environment and allowance range of error, and we found optimum value through experiment. FIFO is stored about compass' present data of measurement, error, prediction. Follow table shows initial setting coefficient value at 10Hz

3.3 Traveling experiment

We verify and compare through traveling, between our prototype compass (compass3) and the existing compass (compass1), Gyro in magnetic area. Vehicle's traveling experiment does around Pusan University, traffic jam area and tunnels. We show each sensor's characteristic and result of short distance, long distance and rapid turning and gentle turning, gentle slope.

Table 1. Setting coefficient of compass1 and compass2.

List	Compass1	Compass2	Explanation
$V_{x, max}$	120	215	Maximum of X-axis sensor
$V_{x, min}$	-206	-153	Minimum of Y-axis sensor
$V_{y, max}$	262	129	Maximum of Y-axis sensor
$V_{y, min}$	-127	-267	Maximum of Y-axis sensor
$V_{x, sf}$	1.1933	1.0761	Magnitude ratio of X-axis and Y-axis sensors
$V_{y, sf}$	1.0000	1.0000	Magnitude ratio of X-axis and Y-axis sensors
$V_{x, off}$	43.0	-33.3	DC offset of X-axis sensor
$V_{y, off}$	-67.5	74.2	DC offset of Y-axis sensor
V_r	194.5	192.7	Radius of magnetic circle
V_{sf}	1.0000	1.0090	Magnitude ratio of compass1 and compass2
ε	30.0	30.0	Threshold value of magnetic circle
γ	50.0	50.0	Threshold value of azimuth error
δ	20.0	20.0	Threshold value of tilt and inclination
FIFO	100 (10sec)	100 (10sec)	Size of FIFO

3.3.1 Traveling experiment in Campus

Traveling experiment in Pusan University for comparing characteristic between existing compass, gyro and suggested compass, because there is little interference magnetic compare than other area. There is rapid, gentle turning and slope.

Fig. 10 is shown the result of traveling 2.75km in Pusan University under the 40km/h. Compass1 where is upper side of Fig. 10 is direction value of existing compass module, Compass 3 is direction value of compass module which is using prediction compensation algorithm, Gyro is direction value of gyro module, Speed is number of speed pulse per second, Rref is a radius of basic magnetic circle, Rread is a radius of basic magnetic circle of currently measuring. And 81.6m is ratio of map at right side down

Direction of three modules has been united at starting point A. Compass 1 and Compass-three have absolute azimuth for magnetic north. Therefore, they have the same of direction. GYRO has more turn error than heading From starting point-A to point-B, because, this section is a radical inclination section. On the other hand, the proposed compass is robust against inclination by tilt calibration. C section is a radical inclination section too. Therefore compass-one has a large angle of direction-error. Section D and Section E are gentle slopes.

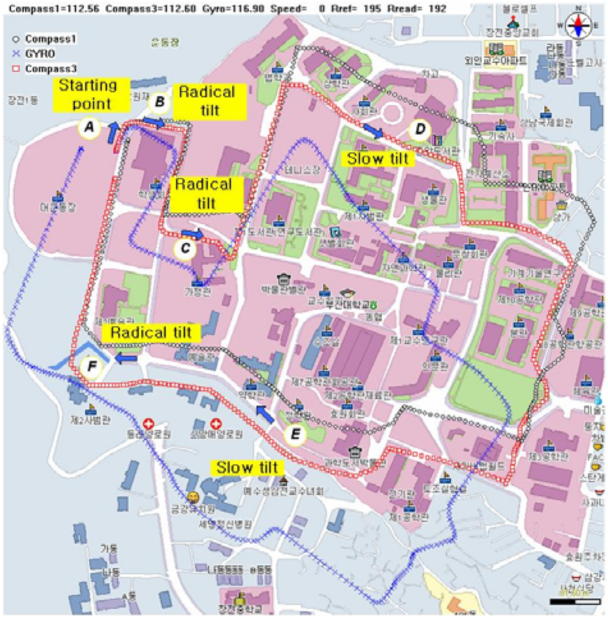

Fig. 10 Navigation of Pusan National University.

Therefore Compass-one and compass-three has a angle of direction-error at this section. This error is broken out by a reason that tilt calbration isn't applied at this section because, the inclination-error is low than the external interfere magnetic field of threshold value(ε).

3.3.2 navigation of A traffic congestion region and a tunnel section

Fig. 11 is shown the result of traveling 5.58km in navigation of A traffic congestion region and a tunnel section

We have given to GYRO at A point and started. Many vehicles are driven from A-point to B-point, and there are high-storied buildings by the side of road. In this section three modules are all following the road without error, turning of at B-point we can see error of GYRO.

Fig. 11 Navigation of traffic-jam area and tunnel.

At the section of tunnel, compass 2 and GYRO follows the road at C-point, but compass 1 has little error of direction near a way out.

When we comparing direction angle of three modules at D-point, we can see compass 1 has little direction error on traveling, but the final direction error was not happened because of it always indicates absolute direction, and we can see increasing the final direction error because GYRO is accumulated small error by turning and direct section

In this suggested compass prevents in instant interference using prediction compensation as traveling, and you can see this is the most approached traveling real traveling direction of vehicle.

4. Conclusion

This paper proposed to the method to revise impossible magnetic field change, time varying error and inclination/tilt at existing. For the system to be each other the supplementation organized a dual electric compass. The going experiment by the vehicle proved the possibility as an azimuth sensor for the Car Navigation System.

However, irregular interval of the magnetic field has the error if it comes to be long without becoming correct revision. In such case added the GPS and Gyro which not to take the influence at interfere magnetic field may organize the system to precision.

But the system must be designed in apply taking a price, performance, convenience into account. This paper showed strong electric compass at external interfere magnetic field.

Table 2. Comparison a conventional compass and a GYRO with a proposed compass.

Comparison / Model	Capacity	Cost	Convenience
Existing Compass	Absolute Azimuth	Low cost	Simplicity
GYRO	Relative Azimuth	High cost	Complexity
Proposed Compass	Absolute Azimuth	Low cost	Simplicity

5. UNITS AND SYMBOLS

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