A study on effect of geomagnetic sensor correction for pose estimation

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Abstract
In the research, we propose a method that corrects the geomagnetic sensor output even in high-rise buildings and underground without complicated procedures. We confirmed that the geomagnetic correction parameters can be estimated more easily and appropriately using the proposed method than the method of the previous research.

In recent years, technological development has led to the use of many sensors in everyday life. MEMS sensors have come to be used for various functions of smartphones and automatic driving system. The 9-axis motion sensor, which is one of the sensor modules, is equipped with a three-axis gyro sensor, a three-axis acceleration sensor, and a three-axis geomagnetic sensor. The sensors are becoming smaller and lighter due to technological development. Therefore, the 9-axis motion sensor is used for various purposes such as motion measurement. Although human pose estimation can be performed using only the gyro sensor. estimation accuracy decreases due to drift error. The sensor fusion using a 9-axis motion sensor equipped with an acceleration sensor and a geomagnetic sensor enables high-precision pose estimation [1]. The geomagnetic sensor output is utilized to measure the yaw angle, which is the angle around the Z axis. However, correcting the geomagnetic sensor output is important because there are various environments in which the magnetic field is liable to fluctuate. Several sensor fusion techniques which avoided the influence of magnetic field fluctuations have been proposed [2][3]. In addition, the authors have proposed the method that corrected the geomagnetic sensor output with long-team motion measurement in a varying magnetic field [4]. Furthermore, since the previous experiment was conducted outdoors, verifying the effectiveness of the method even in high-rise buildings and underground is required. In the research, we propose a method that corrects the geomagnetic sensor output even in high-rise buildings and underground without complicated procedures.

In an external measurement environment where the magnetic field fluctuates for accurate estimation, applying the geomagnetic sensor correction method using the angular velocity obtained from the gyro sensor [3], estimate the optimum geomagnetic parameters (sensitivity / offset). The relation between the geomagnetic sensor output and magnetic field is represented by Eq. (1);

$$M_t = Gm_t + B \ (1)$$

Where:

$$\mathrm{M_t} = \begin{bmatrix} \mathrm{M_{xt}} \\ \mathrm{M_{yt}} \\ \mathrm{M_{zt}} \end{bmatrix}, \ \begin{bmatrix} \mathrm{m_{xt}} \\ \mathrm{m_{yt}} \\ \mathrm{m_{zt}} \end{bmatrix}, \ \begin{bmatrix} \mathrm{G_x} & 0 & 0 \\ 0 & \mathrm{G_y} & 0 \\ 0 & 0 & \mathrm{G_z} \end{bmatrix}, \ \mathrm{B} = \begin{bmatrix} \mathrm{B_x} \\ \mathrm{B_y} \\ \mathrm{B_z} \end{bmatrix}$$

M_t is the geomagnetic sensor output, m_t is the corrected magnetic field, G is the sensitivity, and B is the offset.

Since the sensitivity and offset also fluctuate as the magnetic field fluctuates, estimating the geomagnetic parameters corresponding to the environment is required. Assuming that the total amount of magnetic field is constant, we constructed an algorithm to estimate the parameters. Eq. (2) represents the sum of the magnetic fields, and Eq. (3) represents the relation between the magnetic field in the i-link coordinates and those in the reference coordinates.

$$\sqrt{m_{xt}^2 + m_{yt}^2 + m_{zt}^2} = const \qquad (2)$$

$$0R_{i,t}m_t = {}^0R_{i,t-1}m_{t-1} = {}^0m = const \quad (3)$$

Then, ${}^0R_{i,t}$ is the rotation matrix from the i-link coordinates to the reference coordinates. Equation (4) shows the differential of Eq. (3), and Eq. (5) shows the differential of the rotation matrix using angular velocity.

$$\frac{d}{dt}({}^0R_{i,t-1}m_{t-1}) = {}^0\dot{R}_{i,t-1}m_{t-1} + {}^0R_{i,t-1}\dot{m}_{t-1} = 0 \ (4)$$

$${}^0\dot{R}_{i,t-1} = {}^0R_{i,t-1}[\omega_t \times] \ (5)$$

Here, ω_t is the gyro sensor output and $[\omega_t \times]$ is the cross product. Equation (6) is obtained by substituting Eq. (5) into Eq. (4) and discretized by the finite difference method. Equation (7) which represents the relation between the magnetic field and the angular velocity is obtained by eliminating the rotation matrix from both sides of Eq. (6).

$${}^0R_{i,t-1}m_t = {}^0R_{i,t-1}(m_{t-1} - T_s[\omega_t \times]m_{t-1}) \ (6)$$

$$m_t = m_{t-1} - T_s[\omega_t \times]m_{t-1} \ (7)$$

Here, Ts is the sampling period. The geomagnetic sensor output is corrected by estimating the geomagnetic parameters that satisfy Eq. (7). A nonlinear discrete-time system is developed to construct an extended Kalman filter for parameter estimation. The nonlinear state equation is constructed using Eq (7), which expresses the relation between the magnetic field and the angular velocity. The nonlinear observation equation is constructed using Eqs. (1) and (2). The nonlinear state equations and nonlinear observation equations are shown in Eqs. (8) and (9).

$$\mathrm{x}_{t+1} = \mathrm{F}(\mathrm{x}_t) + \mathrm{w}_t \ (8)$$
$$y_t = H(x_t) + v_t \ (9)$$

Where:

$$x_t = \begin{bmatrix} m_{xt} \\ m_{yt} \\ m_{zt} \\ G_x \\ G_y \\ G_z \\ B_x \\ B_y \\ B_z \end{bmatrix},\ F(x_t) = \begin{bmatrix} m_{xt} \\ m_{yt} \\ m_{zt} \\ G_x \\ G_y \\ G_z \\ B_x \\ B_y \\ B_z \end{bmatrix} - Ts \begin{bmatrix} \omega_{yt}m_{zt} - \omega_{zt}m_{yt} \\ \omega_{zt}m_{xt} - \omega_{xt}m_{zt} \\ \omega_{xt}m_{yt} - \omega_{yt}m_{xt} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$y_t = \begin{bmatrix} M_{xt} \\ M_{yt} \\ M_{zt} \\ 1 \end{bmatrix},\ H(x_t) = \begin{bmatrix} G_x m_{xt} + G_x m_{yt} + G_x m_{zt} \\ G_y m_{xt} + G_y m_{yt} + G_y m_{zt} \\ G_z m_{xt} + G_z m_{yt} + G_z m_{zt} \\ m_{xt}^2 + m_{yt}^2 + m_{zt}^2 \end{bmatrix} + \begin{bmatrix} B_x \\ B_y \\ B_z \\ 0 \end{bmatrix}$$

w_t, v_t is white noise. The extended Kalman filter is solved using the nonlinear state-space model. In the previous research, as the initial state values, m_{xt},m_{yt},m_{zt}, were determined using the geomagnetic measurement data. The initial state values G_x,G_y,G_z,B_x,B_y, and B_z were determined using the parameters obtained in advance. Therefore, the measurement procedure was complicated. In this study, constant values are inserted into the initial state value x_t The parameters for geomagnetic sensor correction are obtained only using the motion measurement data.

The magnetic field was measured using a 9-axis motion sensor (Sports Sensing, SS-WS1792) during the experiment. The 38 $\times$ 53 $\times$ 11 mm sensor weighs 30 g. The 9-axis motion sensor was fixed on the device shown in Figs. 1 and 2. The device was rotated around the x, y, and z axes of the sensor. The experiment was conducted on the first basement floor of Kogakuin University and Shinjuku Central Park. Figures 3 and 4 respectively show the X-axis results at Shinjuku Central Park and Kogakuin University, which were corrected using Eq. (1). Figures 3(a) and 4(a) are the magnetic fields corrected by adjusting parameters G and b manually using Eq. (1). Figures 3(b)and 4(b) are the magnetic fields corrected by the previous method. The previous method obtained the parameters by the Kalman filter algorithm (Eq. (8) and (9)) inserting the parameters G and b which were obtained manually using Eq.(1) as the initial state value. Figures 3(c)and 4(c) are the magnetic fields corrected by the proposed method in this study. The proposed method obtained the parameters by the Kalman filter algorithm (Eq. (8) and (9)) inserting arbitrary constants as the initial state value. The initial arbitrary constants used in this study were $m_{xt} = m_{yt} = m_{zt} = 0.01$, $G_x = G_y = G_z = 200$, $B_x = B_y = B_Z = 0$.

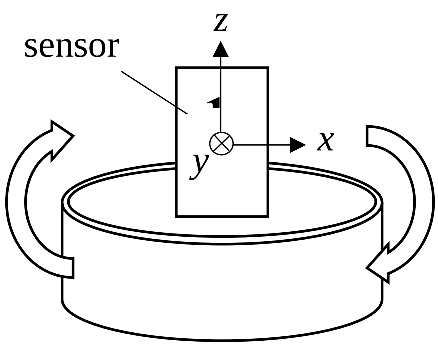


Fig.1. Frontal schematic view of the device

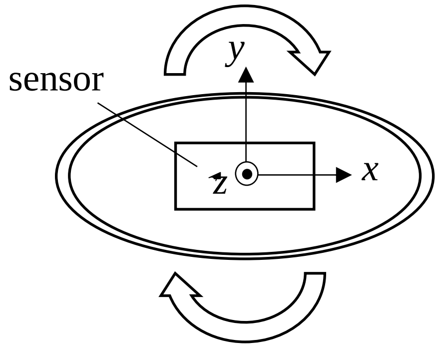
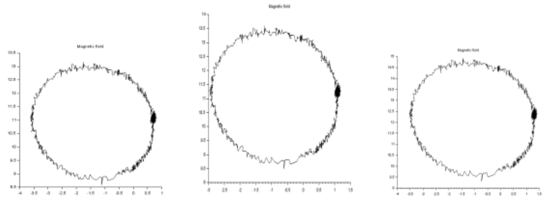
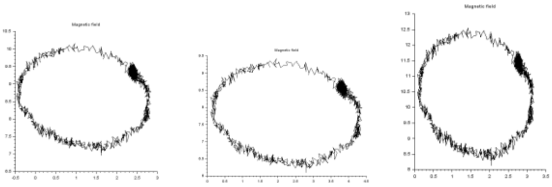


Fig.2. Plane schematic view of the device

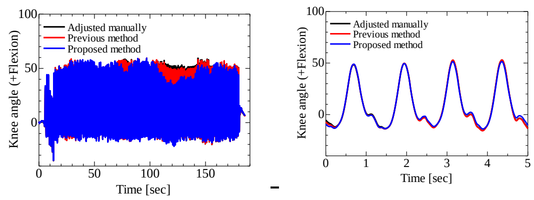


(a)Manual adjustment (b) Previous method (c) Proposed method
Fig.3. The corrected magnetic field around the X-axis (Shinjuku Central Park.)



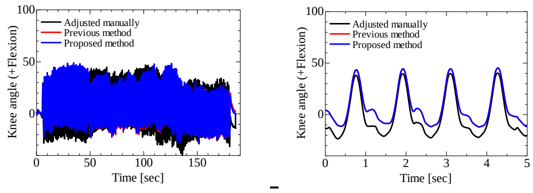
(a)Manual adjustment (b) Previous method (c) Proposed method
Fig.4. The corrected magnetic field around the X-axis (the first basement floor of Kogakuin University)

Figure 3 represents the results obtained in Shinjuku Central Park, and Fig.4 represents the results obtained in the first basement floor of Kogakuin University. These results are the corrected magnetic field around X-axis. The results in Shinjuku Central Park indicate that the almost perfect circles with all the correction methods were obtained. On the other hand, the results in the first basement floor of Kogakuin University indicate that the almost perfect circles only with the proposed methods were obtained.



(a) *(b)*

Fig.5. Estimated result of knee joint angle in sagittal plane (Shinjuku Central Park.)



(a) *(b)*

Fig.6. Estimated result of knee joint angle in sagittal plane (the first basement floor of Kogakuin University).

Figure 5 represents the estimated knee joint angles during walking obtained by using the corrected magnetic field in Shinjuku Central Park, and Fig.4 represents the estimated knee joint angles during walking obtained in the first basement floor of Kogakuin University. Black curves are the results by using the magnetic parameters which were adjusted manually using Eq.(1). Red curves are the results by using the magnetic parameters which were adjusted by the previous method. Blue curves are the results by using the magnetic parameters which were adjusted by the proposed method. Panel(a)s show the results over the entire measurement time of 3 minutes. Panel(b)s show the results between 20 and 25 s after the start of measurement.

The same tendencies as the flexion and extension of the knee angles during normal walking of a healthy person can be confirmed in Fig.5. However, the result which was adjusted manually in Fig.6 is different compared to Fig.5. It could not be estimated properly using the method which was adjusted manually. We confirmed that the geomagnetic correction parameters can be estimated more easily and appropriately using the proposed method than the method of the previous research.

References:

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