Magnetic Anomaly-Matched Trajectory and Dead Reckoning Fusion Mobile Robot Navigation

Yong Hun Kim, Bo Sung Ko, and Jin Woo Song*

Department of Intelligent Mechatronics Engineering and Department of Convergence Engineering for Intelligent Drone, Sejong University, Seoul, Korea

*Corresponding author: jwsong@sejong.ac.kr

Background and Objectives

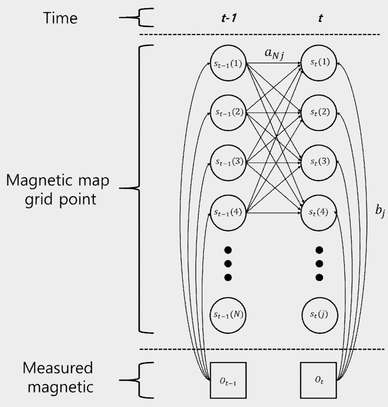
Background

- Recent studies mainly focus on suppressing positional divergence to achieve acceptable navigation accuracy indoor and do not consider the cost.
- Considering the cost, the magnetic anomaly matching localization method can be a superior solution.
- But, owing to the similar steel structure inside the building, there are multiple distorted magnetic fields with similarities, which results in position errors.
- For this reason, magnetic-based navigation is not a major use.

Objectives & Contributions

- In this study, to solve the low position accuracy problem, the position result calculated through magnetic anomaly localization is configured as a trajectory and used for navigation.
- The calculated trajectory is compared with dead reckoning, which calculates using a mobile robot wheel spin and gyroscope. In optimizing the trajectory, the navigation sensor error was calculated to compensate for the navigation.
- The proposed algorithm was verified using an open dataset, and as a result, it was confirmed that can implement a stable and accurate indoor navigation algorithm at an inexpensive price.

Magnetic Anomaly-matched trajectory



Transition probability

$$a_{Nj} = \frac{1}{\sqrt{2\pi}\sigma_d} exp\left(-\frac{(\|\boldsymbol{Map}(N)-\boldsymbol{Map}(j)\|^2)}{2\sigma_d^2}\right)$$

$\mathbf{Map}(\cdot)$ is a matrix that magnetic map

$\boldsymbol{N}, \boldsymbol{j}$ is a matrix index representing a row

σ_d set $\sqrt{3}$ (the variance according to the distance)

Emission probability

$$b_j = \frac{1}{\sqrt{2\pi}\sigma_m} exp\left(-\frac{(\mathbf{Mag}(j)-mag)^2}{2\sigma_m^2}\right)$$

mag is the magnetic field measured.

σ_m is $var(\mathbf{Mag})$

Forward probability

$$s_t(j) = \Sigma_{i=1}^{N} s_{t-1}(i) a_{ij} b_j$$

Fig 1. HMM model for magnetic anomaly-matching

- Fig. 1 shows the HMM in which each parameter is connected at the current time t and previous time t-1. Each hidden parameter of the HMM was selected as a magnetic map grid point within 3 m based on the previous location.
- After calculating the parameter probability, and decoding using the Viterbi algorithm to form the trajectory.
- The trajectory is constructed by the grid points with the maximum probability among the forward probabilities.

Simulation results

- The proposed algorithm was verified using the MagPIE dataset [Ref: https://ieeexplore.ieee.org/abstract/document/8115961].
- The algorithm accuracy was analyzed for three trajectories out of the entire dataset, and the magnetic map grid size was selected as 0.2 m.

TABLE I
Price for the navigation system

Sensor	Example	Cost
IMU	Invensense MPU-6500	\$3.5
Magnetometer	NXP MAG3110	\$1.46
For the ground truth		
Camera	Mv BlueFOX-MLC200w	\$310
LiDAR	Velodyne PUCK VLP-16	\$7,999

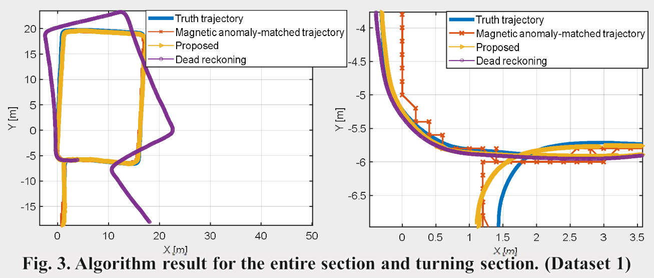


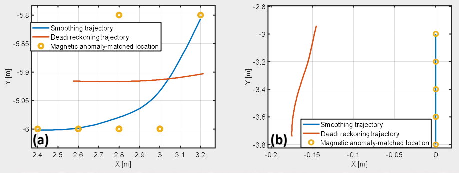
Fig. 3. Algorithm result for the entire section and turning section. (Dataset 1)

TABLE II
Position RMSE (MM is magnetic anomaly matching)

	DR (m)	Proposed (m)
Dataset1	7.4037	**0.2976**
Dataset2	7.0465	**0.3572**
Dataset3	18.708	**0.5583**

Key-frame detection and error compensation

- In the case of the turning section, wheel slip occurs significantly. Thus, the odometry scale factor error and gyro bias are compensated through trajectory information.
- The turning and straight sections were detected according to the gradient change in the magnetic anomaly-matched trajectory.



Optimization function

$$e(o_s, bg) = \underset{o_s, b_g}{argmin} \|\mathbf{M}_{tr} - \mathbf{D}_{tr}\|^2$$

$\mathbf{M}_{tr}$ is magnetic anomaly-matched trajectory

$\mathbf{D}_{tr}$ is the trajectory calculated by DR

$\boldsymbol{o_s}$ is odometry scale factor

$\boldsymbol{b_g}$ is gyro bias

Fig. 2. Magnetic anomaly-matching result and smoothed trajectory (a) detected turning section (b) detected straight section.

Magnetic matched trajectory and DR fusion

- When the straight is detected, perform the EKF measurement update using a magnetic-matched position.
- When the turning motion is detected, perform optimization for estimating the sensor error.

EKF state and system model

$$\delta\mathbf{q} = \left[\delta\mathbf{p}^T\ \delta\psi\ \delta v\ b_g\right]^T$$

$$\mathbf{F} = \begin{bmatrix} 0 & 0 & cos(\psi)\cdot v^{odo} & \sin(\psi) & 0 \\ 0 & 0 & -sin(\psi)\cdot v^{odo} & \cos(\psi) & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & -\tau_v & 0 \\ 0 & 0 & 0 & 0 & -\tau_{b_g} \end{bmatrix}$$

$$\delta\dot{\mathbf{q}} = \mathbf{F}\delta\mathbf{q} + \boldsymbol{\xi} \qquad \boldsymbol{\xi} \sim N(0, \mathbf{Q})$$

$-\tau_v$ and $-\tau_{b_g}$ represents Markov process model.

EKF measurement model

$$\delta\mathbf{z} = \mathbf{H}\delta\mathbf{q} + \boldsymbol{\varepsilon} = \left[DR^X\ DR^Y\right]^T - \left[M^X\ M^Y\right]^T \quad \boldsymbol{\varepsilon} \sim N(0, \mathbf{R})$$

$\left[DR^X\ DR^Y\right]^T$ is the position calculated by DR

$\left[M^X\ \ M^Y\right]^T$ is the position calculated by magnetic matching

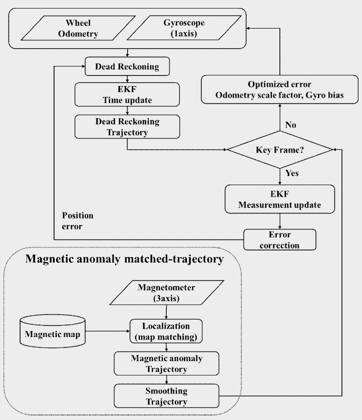


Fig. 3. Full block diagram of the proposed navigation algorithm

Conclusion

- The proposed algorithm can perform navigation accurately and stable by compensating for the error with an optimization method in a turning section with less accuracy.
- So that reason, when using the proposed technique, the DR performance and localization accuracy of the magnetic anomaly matching technique are improved.
- The price of the sensor used in this study is about 5 dollars including the IMU and magnetometer. The system can be configured much cheaper than using a camera or LiDAR.
- If the proposed technique is used, the navigation system construction cost is very low, and it is thought that it can be widely used in fields where an indoor navigation solution is desired at a low price.
- In the future, we plan to conduct more rigorous verification by conducting our own experiments.