https://doi.org/10.20965/jrm.2014.p0177

Paper:

A Robust Navigation Method for Mobile Robots in Real-World Environments

Sam Ann Rahok*, **Hirohisa Oneda****, **Akio Tanaka***, **and Koichi Ozaki*****

*Oyama National College of Technology
771 Nakakuki, Oyama, Tochigi 323-0806, Japan
E-mail: rahok@oyama-ct.ac.jp
**Yuge National College of Maritime Technology
1000 Yuge, Kamijima, Ehime 794-2593, Japan
***Utsunomiya University
721 Yoto, Utsunomiya, Tochigi 321-8585, Japan

[Received December 5, 2013; accepted February 7, 2014]

This paper describes a robust navigation method for real-world environments. The method uses a 3-axis magnetic sensor and a laser range scanner. The magnetic field that occurs in the environment is used as key landmarks in the proposed navigation method, and physical landmarks scanned by the laser range scanner are taken into account in compensating for the mobile robot's lateral error. An evaluation experiment was conducted during the final run of the Real World Robot Challenge (RWRC) 2013, and the result showed that the mobile robot equipped with the proposed method robustly navigated a 1.6 km course.

Keywords: mobile robot, navigation, magnetic field

1. Introduction

To successfully navigate in a real-world environment, a mobile robot must be able to deal with dynamic changes in its surroundings, and this still remains a major problem in mobile robot navigation. In Japan, a Real World Robot Challenge (RWRC) called the Tsukuba Challenge started in 2007 to give all interested a chance to share learned experience in mobile robot navigation in a real-world environment.[1] Since then, various navigation methods have been developed, and some outstanding ideas have been implemented to strengthen the robustness of mobile robot navigation against dynamic changes in the environment. For instance, T. Yoshida et al. presented a method using gyro-assisted odometry and a rotating 2D laser range scanner [1]. Rotating the 2D laser range scanner to obtain an accurate 3D map was remarkable. K. Okamura et al. also applied a similar idea, but the laser range scanners were used in a different way: they were installed in a high position to scan upper part of tall landmarks, such as trees and buildings [2]. The effectiveness of these ideas was proved when their mobile robots successfully completed the 1 km course of the navigation missions in 2009 and 2010. Another idea, called "Mag-Navi," was to use the magnetic field that occurs in the environment [3]. It was presented by our team and first applied in the RWRC in 2009 [4]. That year, our mobile robot was one among the five mobile robots that successfully completed the navigation mission.

In 2010 and 2011, when the courses became longer and more difficult, using a stand-alone Mag-Navi to complete the navigation missions became extremely difficult for our team. The main reason was lateral error, which was hard to correct using only the magnetic field [5]. Since then, we have combined the Mag-Navi with a laser range scanner [6]. The idea of switching between the Mag-Navi and a scan matching method based on the ambient environment was presented in [6], where the switching process was manually preset. This idea worked well in the RWRC2011; our mobile robot successfully completed the navigation mission. However, its robustness against unexpected changes in the environment, such as the presence of a crowd, still remains a problem. There have been unexpected changes everywhere in the RWRC, especially around the start and goal positions, that have forced many teams, including our team, not to use physical landmarks in mobile robot's navigation in those areas. It is not a good idea to preprogram the mobile robot to use any specified navigation methods in any specified areas, because we never know what will happen during navigation in the real world.

In this work, we present a navigation method that uses a low cost 3-axis magnetic sensor and a laser range scanner for robustness against unexpected changes in the environment. The challenge involved in using this low cost sensor, which is widely used in mobile smart phones, in long distance navigation is one of the points of interest of the proposed method.

2. Magnetic Sensor

The 3-axis magnetic sensor used in this work is shown in **Fig. 1**. It is a combination of a sensor chip (AMI603)

1. http://www.tsukubachallenge.jp/

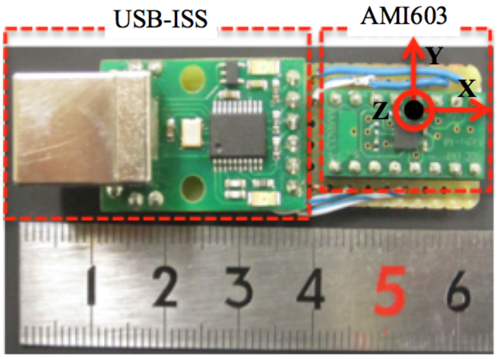

Fig. 1. Magnetic sensor.

Table 1. Specifications of AMI603.

Output	B_x, B_y, B_z (Magnetic Field) A_x, A_y, A_z (Acceleration)
Measurement range [mT]	±1.2
Magnetic field resolution [uT]	±0.4
Angle resolution [degree]	±3
Update rate [Hz]	2000
Interface	I2C

and an USB-I2C interface converter (USB-ISS). The AMI603 is the integration of a 3-axis magnetic sensor and a 3-axis accelerometer. The USB-ISS works as a converter between the I2C interface of the AMI603 and an USB interface of the mobile robot. The AMI603's specifications are given in **Table 1**.

2.1. Estimation of Heading Direction

The AMI603 can measure the magnetic field and acceleration with the two modes of normal state (measurement with a specified cycle) and force state (measurement with a request from the host). The force state is applied in this work; its measurement sequence [a] is shown in **Table 2**, and its measurement algorithm is shown in **Table 3**.

If B_x and B_y are the two orthogonal components of the magnetic field measured by the AMI603, the magnetic heading direction can be estimated by using the following equation:

$$\text{Heading direction} = \tan^{-1}\frac{B_y}{B_x}. \qquad (1)$$

However Eq. (1) is correct only when the AMI603 is perfectly level. If it is tilted, B_x and B_y change, and the heading direction cannot be correctly estimated. It is therefore necessary to compensate for the tilt with an additional tilt angle sensor (accelerometer) [7].

2.2. Compensating for Tilt in Calculating Heading Direction

With the integrated accelerometer, the AMI603 can provide angles of rotation around the X-axis and Y-axis. If roll angle θ and pitch angle φ are defined as rotation

Table 2. Measurement sequence.

Step1:	Activate AMI603 *(Force State)*
Step2:	Enable DRDY*1 function
Step3:	Set offx_dat, offy_dat, offz_dat *(offset of B_x, B_y, B_z)*
Step4:	Enable Accelerometer
Step5:	Send measurement request
Step6:	Check whether DRDY is high
Step7:	Read (B_x, B_y, B_z, A_x, A_y, A_z)
	Go to Step5:

*1DRDY signal is high when the measurement process is done and ready for a host to read.

Table 3. Measurement algorithm.

```
Write*2("0x55 0x1E 0x1B 0x01 0xC0"); Step1
Read(ACK);
If(ACK == 0x00*3) then
   Exit;
Write("0x55 0x1E 0x1C 0x01 0x80"); Step2
Read(ACK);
If(ACK == 0x00) then
   Exit;
; Step3 is skipped (it is done on control PC instead)
Write("0x55 0x1E 0xB4 0x01 0x01"); Step4
Read(ACK);
If(ACK == 0x00) then
   Exit;
Write("0x55 0x1E 0x1D 0x01 0x60"); Step5
Read(ACK);
If(ACK == 0x00) then
   Exit;
Write("0x55 0x1F 0x18 0x01"); Step6
Read(ACK);
If(ACK == 0x00) then
   Exit;
Write("0x55 0x1F 0x06 0x0C"); Step7
Read(Bx, By, Bz, Ax, Ay, Az);
Go to 14:
```

*2Write(A, B, C, D, E1, E2, ...): A is USB-ISS's address, B is AMI603's address to write/read, C is address of register to write/read, D is number of bytes to write/read, and E1, E2, ... are data to write/read.
*30x00: Return byte if write command failed.

around the X-axis and Y-axis, as shown in **Fig. 2**, the roll rotation matrix C_r and the pitch rotation matrix C_p can be defined as follows:

$$C_r = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{pmatrix} \qquad (2)$$

$$C_p = \begin{pmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\varphi & 0 & \cos\varphi \end{pmatrix}. \qquad (3)$$

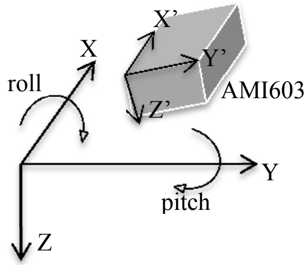

Fig. 2. Coordinate system.

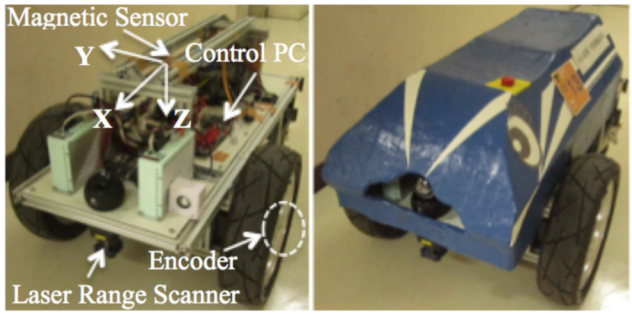

Fig. 3. Mobile robot.

Thus, the rotation matrix that transforms the coordinates from the stationary coordinate system of XYZ to the rotated tilted coordinate system of $X'Y'Z'$ can be defined as follows:

$$\begin{pmatrix} B_{x'} \\ B_{y'} \\ B_{z'} \end{pmatrix} = C_r C_p \begin{pmatrix} B_x \\ B_y \\ B_z \end{pmatrix} \quad \ldots\ldots\ldots\ldots (4)$$

$$\begin{pmatrix} B_{x'} \\ B_{y'} \\ B_{z'} \end{pmatrix} = \begin{pmatrix} \cos\varphi & 0 & -\sin\varphi \\ \sin\theta\sin\varphi & \cos\theta & \sin\theta\cos\varphi \\ \cos\theta\sin\varphi & -\sin\theta & \cos\theta\cos\varphi \end{pmatrix} \begin{pmatrix} B_x \\ B_y \\ B_z \end{pmatrix} \quad \ldots\ldots (5)$$

For heading direction estimation, the coordinates of the AMI603 should be converted to the stationary coordinate system. That conversion is performed by using an inverted matrix:

$$\begin{pmatrix} B_x \\ B_y \\ B_z \end{pmatrix} = \begin{pmatrix} \cos\varphi & \sin\theta\sin\varphi & \cos\theta\sin\varphi \\ 0 & \cos\theta & -\sin\theta \\ -\sin\varphi & \sin\theta\cos\varphi & \cos\theta\cos\varphi \end{pmatrix} \begin{pmatrix} B_{x'} \\ B_{y'} \\ B_{z'} \end{pmatrix} \quad \ldots\ldots (6)$$

As shown in Eq. (1), since the z-coordinate is not used for heading direction estimation, the tilt-compensated value for B_x and B_y can be evaluated as follows:

$$B_x = B_{x'}\cos\varphi + B_{y'}\sin\theta\sin\varphi + B_{z'}\cos\theta\sin\varphi \quad (7)$$

$$B_y = B_{y'}\cos\theta - B_{z'}\sin\theta \quad \ldots\ldots\ldots (8)$$

where $B_{x'}$, $B_{y'}$ and $B_{z'}$ are the three components of the magnetic field measured by the magnetic sensor, and θ and φ are the roll and pitch angles. The roll and pitch angles can be computed based on the gravities of the accelerometer and the magnetic sensor. If G_a and G_m are the gravities of the accelerometer and the magnetic sensor, the rotation transformation from the stationary coordinate system of XYZ to $X'Y'Z'$ can be defined as follows:

$$G_m = C_r C_p G_a \quad \ldots\ldots\ldots\ldots (9)$$

$$\begin{pmatrix} A_x \\ A_y \\ A_z \end{pmatrix} = \begin{pmatrix} \cos\varphi & 0 & -\sin\varphi \\ \sin\theta\sin\varphi & \cos\theta & \sin\theta\cos\varphi \\ \cos\theta\sin\varphi & -\sin\theta & \cos\theta\cos\varphi \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ g \end{pmatrix} \quad \ldots\ldots (10)$$

By using the inverted matrix, the gravity of the accelerometer can be calculated as follows:

$$\begin{pmatrix} 0 \\ 0 \\ g \end{pmatrix} = \begin{pmatrix} \cos\varphi & \sin\theta\sin\varphi & \cos\theta\sin\varphi \\ 0 & \cos\theta & -\sin\theta \\ -\sin\varphi & \sin\theta\cos\varphi & \cos\theta\cos\varphi \end{pmatrix} \begin{pmatrix} A_x \\ A_y \\ A_z \end{pmatrix} \quad \ldots\ldots (11)$$

The y-component of Eq. (11) defines the roll angle θ as follows:

$$A_y\cos\theta - A_z\sin\theta = 0 \quad \ldots\ldots\ldots (12)$$

$$\Longrightarrow \theta = \tan^{-1}\frac{A_y}{A_z} \quad \ldots\ldots\ldots (13)$$

The x-component of Eq. (11) defines the pitch angle φ as:

$$A_x\cos\varphi + A_y\sin\theta\sin\varphi + A_z\cos\theta\sin\varphi = 0 \quad . (14)$$

$$\Longrightarrow \varphi = \tan^{-1}\frac{-A_x}{A_y\sin\theta + A_z\cos\theta} \quad \ldots\ldots (15)$$

where A_x, A_y and A_z are the output values of the accelerometer. From Eqs. (7) and (8), the tilt-compensated heading direction can be determined as follows:

$$\text{Heading direction} = \tan^{-1}\frac{B_y}{B_x}. \quad \ldots\ldots (16)$$

By substituting the roll and pitch angles from Eqs. (13) and (15), the tilt-compensated heading direction can be calculated. However, in order to retain the accuracy of the heading direction estimation in the real-world environment, the roll and pitch angles should be low-pass filtered before being inserted into Eq. (16). In this work, we used a low-pass filter with a 25 Hz cut-off frequency to filter both the roll and pitch angles.

3. Mobile Robot Platform

Our mobile robot is shown in **Fig. 3**. It is equipped with a 3-axis magnetic sensor, two rotary encoders, and a laser range scanner. The magnetic sensor is mounted at the center of the mobile robot, 0.2 m above the control PC to avoid magnetic interference from other devices. For the calibration, we used a simple method [8]. We made the mobile robot turn 360° on the soccer field on our campus, and then we took the middle value between the maximum and minimum of measured B_x, B_y, and B_z as the offsets. The laser range scanner (UTM-30LX-EW) was mounted upside down at the front, 0.2 m up from ground

Table 4. Structure of magnetic database.

Travel distance [m]	Heading direction [deg]	Magnetic field B_z [G]
l_0	ϕ_0	bz_0
l_1	ϕ_1	bz_1
$\vdots$	$\vdots$	$\vdots$
l_{100}	ϕ_{100}	bz_{100}
l_{101}	ϕ_{101}	bz_{101}
$\vdots$	$\vdots$	$\vdots$
l_n	ϕ_n	bz_n

level. As its scan data are used in the navigation method, installing the laser range scanner at such a low position is a big challenge. This is not only because the scan range of the laser range scanner is limited to 180°, but also because it is easily affected by any changes in the surrounding environment.

4. Navigation Method

Our experience with the Mag-Navi has shown us thus far that two of its strong points are that it never loses its heading direction and it never mislocalizes its self-position. However, its shortcoming is that it produces lateral error during navigation. These three factors are the keys for us to design the proposed navigation method by using the laser range scanner to overcome the weakness of the Mag-Navi. In the next sections, the Mag-Navi and a scan matching method using a laser range scanner will be briefly described. Then, the combination of these two methods to form a robust navigation method will be described.

4.1. Mag-Navi

We build a magnetic database by using a joystick to operate the mobile robot along a desired route while recording the travel distance, the magnetic heading direction, and the z-component of the magnetic field at each position at an update rate of 10 Hz. The structure of the magnetic database is shown in **Table 4**.

The control system of Mag-Navi is shown in **Fig. 4**. The mobile robot navigates by matching the current travel distance against the travel distance stored in the magnetic database to load the heading direction and B_z. The heading direction is matched against the one estimated by the AMI603 to possibly keep the mobile robot on its taught trajectory, and B_z is used in localization. The localization is performed by matching the peaks of log data scanned during the navigation against the peaks of the magnetic database, as shown in **Fig. 5**. The estimated error from the localization is used to correct the odometry of the mobile robot, as shown in **Fig. 6**.

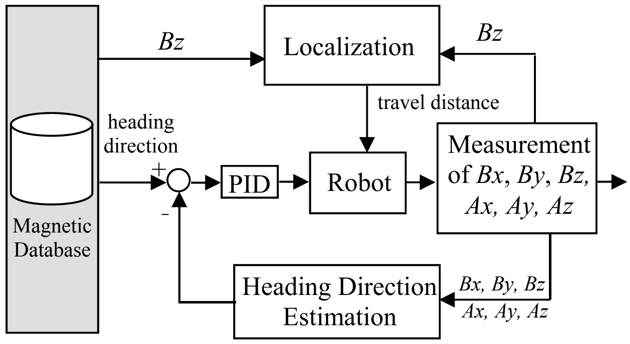

Fig. 4. Control system of Mag-Navi.

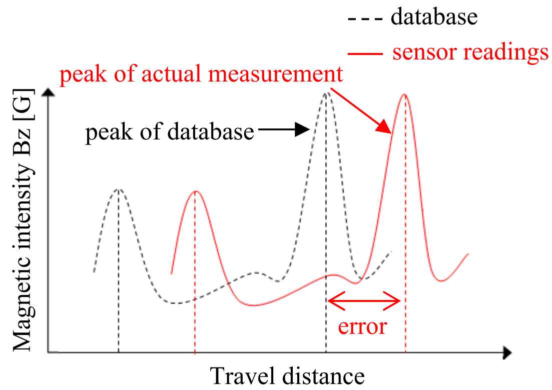

Fig. 5. Localization.

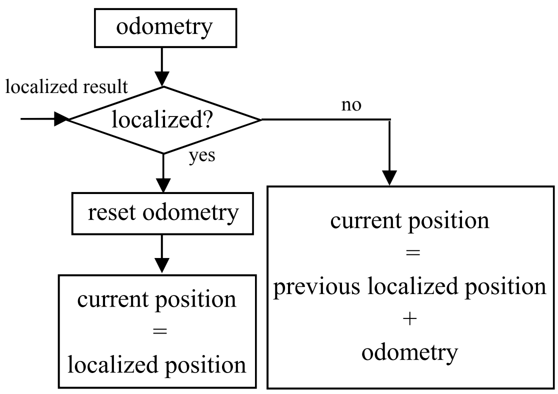

Fig. 6. Odometry correction.

4.2. Scan Matching Using a Laser Range Scanner

We use a grid map to store the physical landmarks scanned by the laser range scanner. The grid map is built in the same way as the magnetic database, by operating the mobile robot with a joystick along a desired route and recording the existence probability of the surrounding landmarks on each grid. The grid size is set to 0.1 m × 0.1 m, and no SLAM is used in this mapping process.

For the localization, the particle filter [9–11] is implemented. During the navigation, the mobile robot uses its movement model to randomly generate particles. It then uses the current scan data of the laser range scanner to evaluate each particle by matching the scan data from

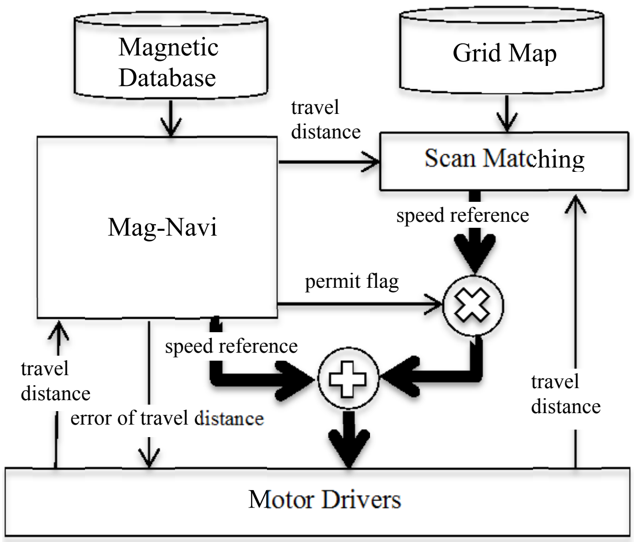

Fig. 7. Proposed navigation method.

each particle against the grid map. Finally, the particle that had the highest match rate is used as the current position of the mobile robot.

4.3. Proposed Navigation Method

The process of the proposed navigation method is shown in **Fig. 7**. The mobile robot uses two different maps in its navigation. These maps are built at the same time during the manual operation of the mobile robot along the desired route. In the navigation, both the Mag-Navi and scan matching are executed in parallel and their speed references are combined before being sent to the motor drivers. However, the speed reference of the scan matching method is available only when there is permission from Mag-Navi. In this work, this permission is given when the difference between the actual heading direction of the magnetic sensor and that from the database is less than 10°. This means that the scan matching has a maximum of 10° to steer the mobile robot to its localized position, or the Mag-Navi will return the mobile robot to a heading direction from the database. This also means that even if there are mismatches in the scan matching, the mobile robot will never head in any completely wrong directions. For the localization, the peak-to-peak matching method of the Mag-Navi, which we believe to be a robust method in dynamic environments, is applied. The localized results from this method are used to correct the odometry of the mobile robot and the self-position of the scan matching method.

The ideas applied in the proposed method are completely different from the ideas presented in [6], where the mobile robot needs to be preset to choose between using Mag-Navi or scan matching methods in specified areas due to the ambient environment. Moreover, in [6], the localization is done by the scan matching method, which we believe not to be robust enough to cope with dynamic changes in the environment.

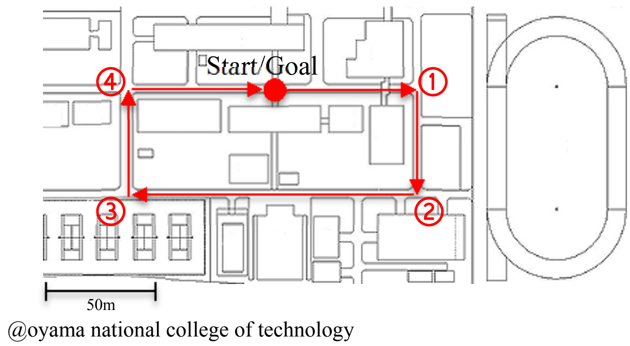

Fig. 8. Travel path.

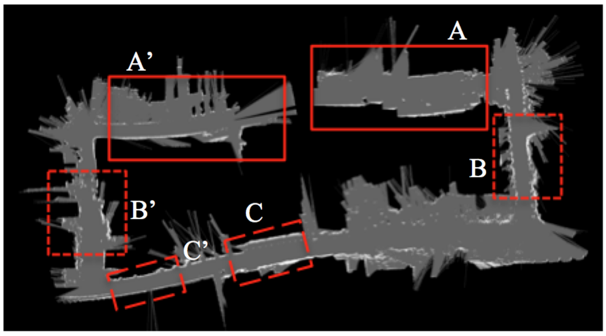

Fig. 9. Grid map.

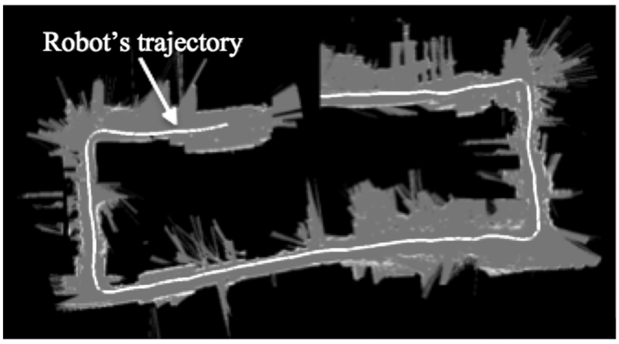

Fig. 10. Navigation result.

5. Evaluation Experiment

5.1. Robustness Test

Before the final run of the RWRC2013, the proposed method was tested several times in various situations on our campus. In this section, we present an evaluation experiment that was conducted in an environment on our campus (see **Fig. 8**). The purpose of this experiment was to show the robustness of the proposed method against physical changes in the environment. We made some changes to the environment by replacing parts A, B, and C with parts A', B', and C' on the grid map shown in **Fig. 9**. We left the magnetic database unchanged since the magnetic field is not strongly affected by physical changes in the environment. The mobile robot then used the altered grid map and the magnetic database to navigate the course. **Fig. 10** shows the grid map after being altered as

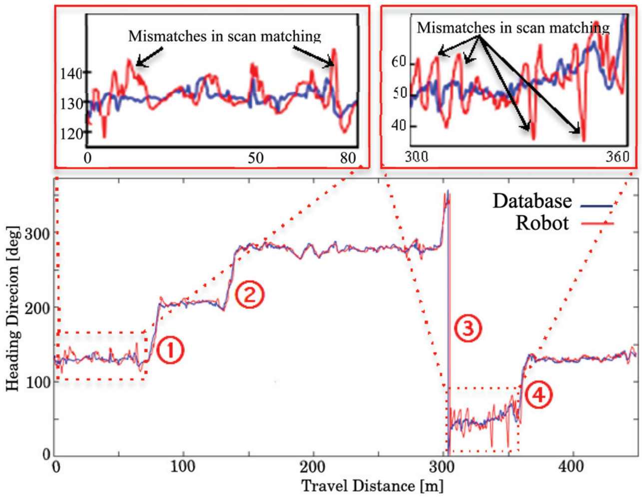

Fig. 11. Heading direction.

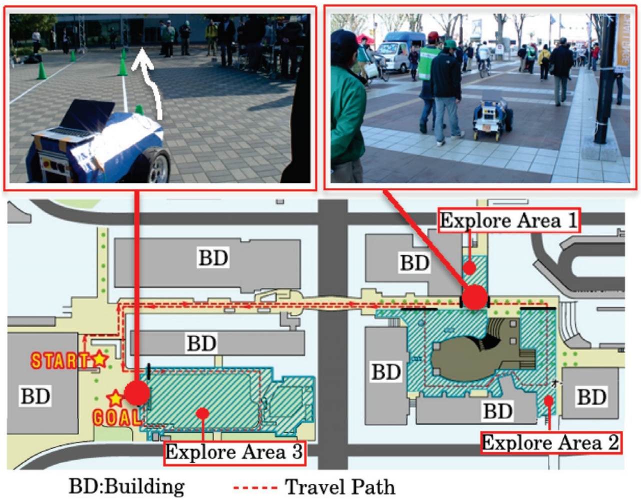

Fig. 12. Travel path of RWRC2013.

well as the results of the experiment. **Fig. 11** compares the heading direction of the mobile robot during the navigation to that in the database, where to refer to the distances at the corners shown in **Fig. 8**. The lower number of errors in the heading direction seen in **Fig. 11** indicates that the path-following that the mobile robot performed during the navigation was more accurate. The top parts of **Fig. 11** are two enlarged views of when the mobile robot was steering widely due to mismatches in the scan matching. However, the robot was brought back to the heading direction from the database by the Mag-Navi. As a result, even though mismatches occurred due to changes in the environment, the mobile robot still successfully completed the course. This proves that the proposed method is robust against dynamic changes in the environment.

5.2. Test in RWRC2013

The proposed method was also tested in the RWRC2013. In the final run, which was made on November 17, our mobile robot was one of the four that successfully reached the goal area without being preprogrammed to carry out any specified navigation methods in any specified areas. **Fig. 12** shows the course of the RWRC2013 and two snapshots taken during the final run. The right snapshot shows the navigation in exploration area 1, where our mobile robot successfully dealt with crowds. The left snapshot shows our mobile robot navigating the goal area, where it avoided a road cone and then went straight ahead, passing to the right of the goal. This was because there was a mismatch in scan matching due to changes in the positions of tents just before obstacle avoidance was activated. The Mag-Navi then worked fine, pulling the mobile robot back to its correct direction, but it was too late. **Fig. 13** shows the comparison B_z of the mobile robot and that of the database, which were used in localization. As we can see at the top of **Fig. 13**, the errors in the mobile robot's travel distance were completely corrected after the mobile robot localized using the peak-to-peak matching method. **Fig. 14** is a comparison of the heading direction of the mobile robot and that in the database. It also shows the accuracy of the mobile robot in following the trajectory it was taught.

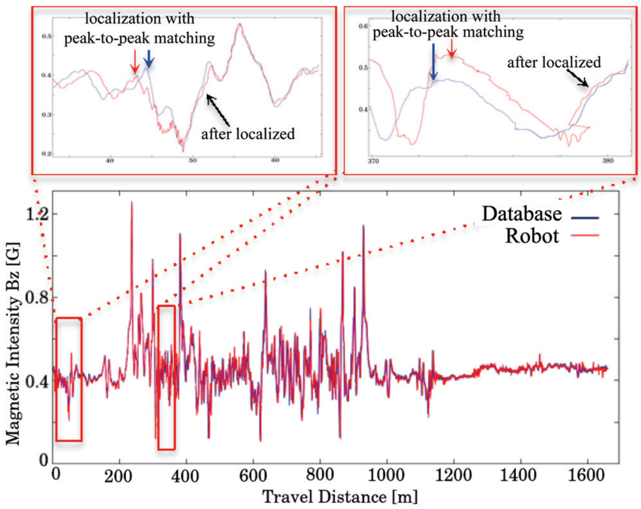

Fig. 13. Magnetic field B_z.

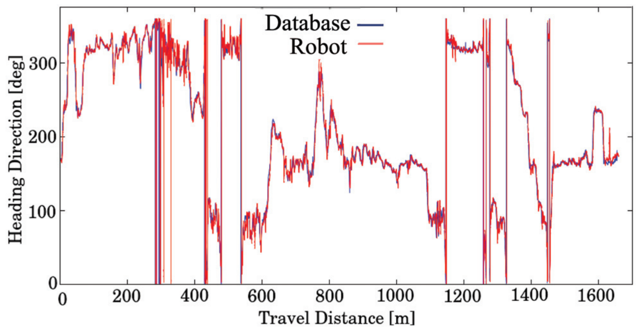

Fig. 14. Heading direction.

6. Conclusion and Future Work

This paper has described a robust navigation method that uses a 3-axis magnetic sensor and a laser range scanner. The two points of interest of the proposed method are that it uses a low-cost magnetic sensor and it has a laser range scanner installed at an extremely low position. In the evaluation experiment, we proved that the proposed method was robust against changes in the environment, as the mobile robot was able to complete the full course of the environment after we had altered the grid map. Moreover, the proposed method was also tested in the RWRC2013, and the mobile robot employing the proposed method successfully navigated a distance of 1.6 km. These results were good enough to prove that the proposed method was sufficiently robust to enable mobile robots to navigate in a real-world environment.

However, the robot's failure at the goal of the RWRC showed us that we still have to make the proposed method even more robust. In the future, we plan to filter the data from the laser range scanner before it is used for scan matching in order to lower the mismatch rate.

Acknowledgements

This research is supported by JSPS Grants-in-Aid for Young Scientists B (25730162).

References:

[1] T. Yoshida, K. Irie, E. Koyanagi, and T. Masahiro, "3d laser scanner with gazing ability," in IEEE Int. Conf. on Robotics and Automation, Shanghai, pp. 3098-3103, 2011.

[2] K. Okamura, T. Ishita, and A. Oya, "The Activity Towards the RWRC 2009: FUJISOFT-Univ. of Tsukuba Joint Team," J. of the Society of Instrument and Control Engineers, Vol.49, No.9, pp. 604-607, 2010.

[3] S. A. Rahok, Y. Shikanai, and K. Ozaki, "Navigation Using an Environmental Magnetic Field for Outdoor Autonomous Mobile Robots," Adv. Robotics, Vol.25, No.13-14, pp. 1751-1771, 2011.

[4] S. Yuta, M. Mizukawa, H. Hashimoto, H. Tashiro, and T. Okubo, "Tsukuba Challenge 2009 – Towards Robots Working in the Real World: Records in 2009 –," J. of Robotics and Mechatronics, Vol.23, No.2, pp. 201-206, 2011.

[5] S. A. Rahok, K. Inoue, and K. Ozaki, "Development of a Mobile Robot to Run in Tsukuba Challenge 2010," Adv. Robotics, Vol.26, No.14, pp. 1555-1575, 2012.

[6] M. Shinohara, S. A. Rahok, K. Inoue, and K. Ozaki, "Development of Localization Method Using Magnetic Sensor and LIDAR," J. of the Society of Instrument and Control Engineers, Vol.49, No.8, pp. 795-801, 2013.

[7] S. Y. Cho, "Enhanced Tilt Compensation Method for Biaxial Magnetic Compass," Electronics Letters, Vol.41, No.24, pp. 1323-1325, 2005.

[8] S. Y. Cho and C. G. Park, "A Calibration Technique for a Two-Axis Magnetic Compass in Telematics Devices," ETRI J., Vol.27, No.3, pp. 280-288, 2005.

[9] T. Higuchi, "Particle Filter," J. of The Institute of Electronics, Information and Communication Engineers, Vol.88, No.12, pp. 989-994, 2005.

[10] M. Yokozuka, Y. Suzuki, T. Takei, N. Hashimoto, and O. Matsumoto, "Auxiliary Particle Filter Localization for Intelligent Wheelchair Systems in Urban Environments," J. of Robotics and Mechatronics, Vol.22, No.6, pp. 758-766, 2010.

[11] J. Eguchi and K. Ozaki, "Development of Method Using a Combination of DGPS and Scan Matching for the Making of Occupancy Grid Maps for Localization," J. of Robotics and Mechatronics, Vol.25, No.3, pp. 506-514, 2013.

Supporting Online Materials:

[a] Aichi Micro Intelligent Corporation, AMI603 Datasheet:
http://www.aichi-mi.com/e-compass/pdf/ami603-datasheet-e.pdf
[Accessed December 5, 2013]

Name:
Sam Ann Rahok

Affiliation:
Assistant Professor, Department of Innovative Electrical and Electronic Engineering, Oyama National College of Technology

Address:
771 Nakakuki, Oyama, Tochigi 323-0806, Japan

Brief Biographical History:
2011- Postdoctoral Researcher, Utsunomiya University
2012- Assistant Professor, Oyama National College of Technology

Main Works:
- "Application of Localization Based on DC Magnetic Field Occurred in the Environment on Wheel Type Mobile Agricultural Robots," Adv. Robotics, Vol.25, No.6-7, pp. 923-939, 2011.
- "Navigation Using Environmental Magnetic Field for Outdoor Autonomous Mobile Robots," Adv. Robotics, Vol.25, No.13-14, pp. 1751-1771, 2011.

Membership in Academic Societies:
- The Robotics Society of Japan (RSJ)
- The Society of Instrument and Control Engineers (SICE)

Name:
Hirohisa Oneda

Affiliation:
Associate Professor, Department of Electronic Mechanical Engineering, Yuge National College of Maritime Technology

Address:
1000 Yuge, Kamijima, Ehime 794-2593, Japan

Brief Biographical History:
2012- Assistant Professor, Yuge National College of Maritime Technology
2013- Associate Professor, Yuge National College of Maritime Technology

Main Works:
- "The Time-evolution of Dynamic Behavior in a Cutting Model using Pullback," Int. Symposium on Stochastic System Theory and its Applications, pp. 13-18, 2007.
- "Development of a Motivational Material Using Visual Feedback to Bring Technical College Students Closer to Control Engineering," Asian Conf. on Information System, pp. 143-146, 2012.

Membership in Academic Societies:
- The Japan Society of Mechanical Engineers (JSME)
- The Japan Society for Precision Engineering (JSPE)
- The Japanese Society for Engineering Education (JSEE)

Name:
Akio Tanaka

Affiliation:
Associate Professor, Department of Innovative Electrical and Electronic Engineering, Oyama National College of Technology

Address:
771 Nakakuki, Oyama, Tochigi 323-0806, Japan

Brief Biographical History:

1992- Assistant Professor, Oyama National College of Technology
2008- Associate Professor, Oyama National College of Technology

Main Works:

- "Trial of Creativity Training in a Robot Contest," Engineering Education, Vol.51, No.1, pp. 143-146, 2003.
- "Trajectory Tracking Method Using Low Cost Magnetic Sensors," IEEE/SICE Int. symposium on System Integration, pp. 270-275, 2013.

Membership in Academic Societies:

- The Robotics Society of Japan (RSJ)
- The Institute of Electrical Engineers of Japan (IEEJ)
- The Japanese Society for Engineering Education (JSEE)

Name:
Koichi Ozaki

Affiliation:
Professor, Department of Mechanical Systems Engineering, Utsunomiya University

Address:
721 Yoto, Utsunomiya, Tochigi 321-8585, Japan

Brief Biographical History:

1996- Assistant Professor, Utsunomiya University
2001-2002 Visit Researcher, Helsinki University of Technology
2003- Associate Professor, Utsunomiya University
2011- Professor, Utsunomiya University

Main Works:

- "Development of a Mobile Robot to Run in Tsukuba Challenge 2010," Adv. Robotics, Vol.26, No.14, pp. 1555-1575, 2012.
- "Implementation of a Long-Distance Navigation Method of Low Cost Structure That Combines a Localization Using Magnetic Information and a Lateral Position Compensation," Trans. of the JSME, Vol.79, No.799, pp. 681-690, 2013.

Membership in Academic Societies:

- The Robotics Society of Japan (RSJ)
- The Japan Society of Mechanical Engineers (JSME)
- The Japan Society for Precision Engineering (JSPE)