

Mobile Robot Localization using an Electronic Compass for Corridor Environment

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Abstract

This paper proposes a simple method for localization using an electronic compass. Electronic compasses are often used to detect the heading of mobile robots. However, electronic compasses have one drawback when used inside a building: they can easily be disturbed by electromagnetic sources (e.g., power lines) or large ferro-magnetic structures (e.g., bookshelves). However, this paper introduces another indoor application of electronic compasses. We take advantage of the magnetic field disturbances by using them as distinctive place recognition signatures. We first gather information about the changing heading as our robot travels along the hallway outside the lab, and then store this information. As the robot traverses the hallway, it gathers the information from the electronic compass and matches it with the pre-stored data. If a match is found, the robot can determine its current position. We use a sequential least-squares approximation approach for matching the signature. The simulation results will show that the robot can distinguish its location by using these signatures.

1 Introduction

Odometry is the most widely used method for determining the position of a mobile robot. HelpMate is a mobile robot that is used to carry meals, medical records, diagnostic samples, and other loads in hospitals [1]. Odometry is the only dead-reckoning system available on HelpMate. Slippage and irregularities of the floor surface cause errors in its odometry readings. Moreover, the errors continuously accumulate. Therefore, the odometry needs to be reset from time to time. To overcome this problem, robust and accurate localization of the robot is needed. There are many research labs that use vision for natural

landmark recognition [2][3]. Those techniques often require high-performance onboard computers and expensive cameras as well as computational overhead.

Electronic compasses are often used to detect headings of mobile robots in an outdoor environment [4]. However, electronic compasses have one drawback when used inside a building: they can easily be disturbed by electromagnetic sources (e.g., power lines) or large ferro-magnetic structures (e.g., metal bookshelves). This makes it impossible to use electronic compasses as reliable heading devices for indoor applications.

Inspiration for this investigation arose when we tried to investigate error readings of an electronic compass caused by electromagnetic sources or large ferro-magnetic structures from the hallway outside our lab. We found that reading errors for each particular position have a unique signature. As Baker [5] stated, any distinctive-environment feature that is specific to a particular area can be used in location-based navigation, e.g., a table, a sound, a magnetic abnormality, etc. The magnetic interference along the hallway caused by specific objects has its own characteristics. We, therefore, introduced a simple method for localization using an electronic compass in the detection of any magnetic anomaly for corridor navigation. We took advantage of the magnetic field disturbances by using them as recognition signatures to localize distinctive places [6]. The purpose of this paper is to investigate how these signatures can be used in localization.

The paper is organized as follows: Section 2 describes how to build compass signatures. Section 3 presents a matching technique using Sequential Least Squares. Section 4 shows the results of the experimental data and Section 5 provides conclusions and suggests future research to improve this method.

2 Building Compass Signatures

The electronic compass from Precision Navigation Inc., Vector2X, is used in our experiment. It gives an output from 0° to 360° , going from North (0°) to East (90°) to South (180°) to West (270°). The V2X is a 2-axis magnetometer that measures the magnetic field in a single plane. This plane is created by its two sensors (X-axis, Y-axis) which are perpendicular to each other on the board. The modules have an accuracy of 2° RMS with resolution of 1° . Interfacing the V2X with a computer, the V2X is set into a slave mode, which needs an external clock and special control signals, so a microcontroller called the Basic Stamp II, a product of Parallax Inc., is used for this purpose. The electronic compass is mounted on the top of HelpMate and is extended by a pole to minimize any interference from HelpMate itself as shown in Figure 1.

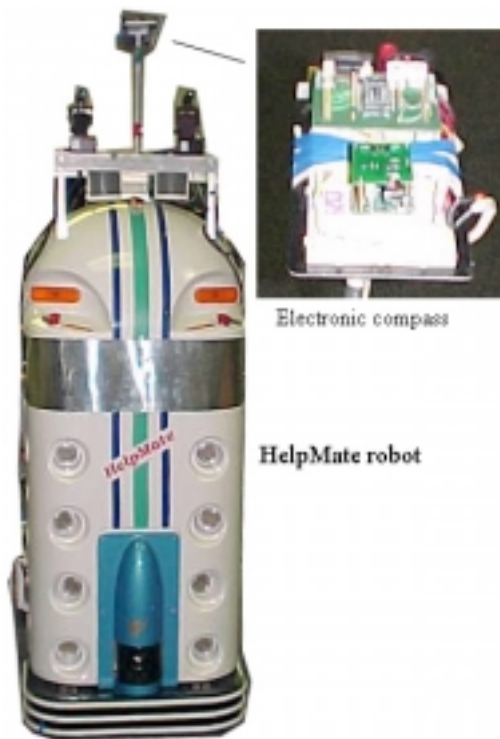


Figure 1: Electronic compass mounted on top of HelpMate

We require an algorithm to be able to recognize a location at any starting place (or after resetting the base drive), i.e., HelpMate does not need to start the localization process at the same place. Therefore, compass readings do not need to be a function of odometry,

but instead we use odometry as a reference for getting data from the electronic compass. The compass readings are collected every time that HelpMate travels d mm.

In our experiment, d is equal to 200 mm., which is chosen arbitrarily. With this technique, HelpMate can start at any place and begin to sense the series of compass readings for the matching process. To make it simple for gathering compass data, we will assume that the reading of the base drive heading is correct at all times, and errors from reading x, y positions are small for a short distance (~ 1 meter). For data accuracy, HelpMate's speed is approximately constant and slow (40mm/s), and its position is maintained on the center of hallways all the time.

Figure 2 shows the experimental environment of the hallway. First we divide the hallway into three parts for each side of the hallway. HelpMate is commanded to move forward and stay on the center of the hallway at all times, while compass information is gathered every 200 mm. The information from each side of the hallway is gathered separately to minimize an odometry error. The data are combined together in memory.

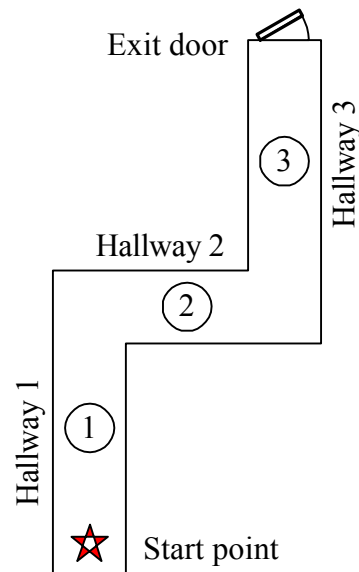


Figure 2: Hallway Environmental Experiment

When HelpMate travels along the hallway, we assume that its heading may only slightly change from the center (not more than 5°). This change can affect the compass reading. To compensate for this effect, the compass reading can be adjusted by monitoring the change from the center of the base drive heading

using equation (1).

$$h_{dh,n} = \begin{cases} 360 - h_{ct,m} - h_{cp,n} & ; h_{ct,m} - h_{cp,n} > 180 \\ 360 + h_{ct,m} - h_{cp,n} & ; h_{ct,m} - h_{cp,n} < -180 \\ h_{ct,m} - h_{cp,n} & ; \text{elsewhere} \end{cases} \quad (1)$$

where $h_{dh,n}$ is the deviation of HelpMate's heading from center, $h_{ct,m}$ is the center of HelpMate's heading (parallel to a hallway), $h_{cp,n}$ is the compass readings. Compensating for the compass readings is given by

$$h'_{cp,n} = h_{cp,n} - h_{dh} \quad (2)$$

We still may experience a minor problem for collecting the compass signature. The problem will occur when HelpMate is heading North or near to North. The compass readings can be shifted from 0° to 360° or vice versa, which will cause error in the signatures. To compensate for the bouncing back and forth of data, the compass reading should be adjusted by using equation (3).

$$h''_{cp,n} = \begin{cases} h'_{cp,n-1} + h'_{cp,n} & ; h'_{cp,n-1} - h'_{cp,n} > 360 - k \\ 360 + h'_{cp,n} & ; h'_{cp,n-1} - h'_{cp,n} < k \\ h'_{cp,n} & ; \text{elsewhere} \end{cases} \quad (3)$$

where $h'_{cp,n}$ is the current compass readings, $h'_{cp,n-1}$ is the previous compass readings, and k is an angle that can be chosen from 0° or 360° .

Note that k is arbitrarily chosen. The criterion to select the number is based on the strength of the disturbance sources and normal headings between two adjacent hallways as well as that it does not change the rest of the signatures. For our environment, we set $k = 15$. Figure 3 shows the result of this compensation.

The last step for preparing the compass signatures is to smooth out the compass reading. To do so, a simple *3-point running averager* is used [7], i.e.,

$$h'''_{cp,n} = \frac{1}{3} \left(\sum_{k=0}^2 h''_{cp,n-k} \right) \quad (4)$$

where $h'''_{cp,n}$ is the smoothing compass readings.

Figure 4 shows results of compass signatures of the three hallways. The signatures from the same hallway gathered from opposite directions are different in direction and values as shown in Figure 5. This information gives us the direction of HelpMate's heading.

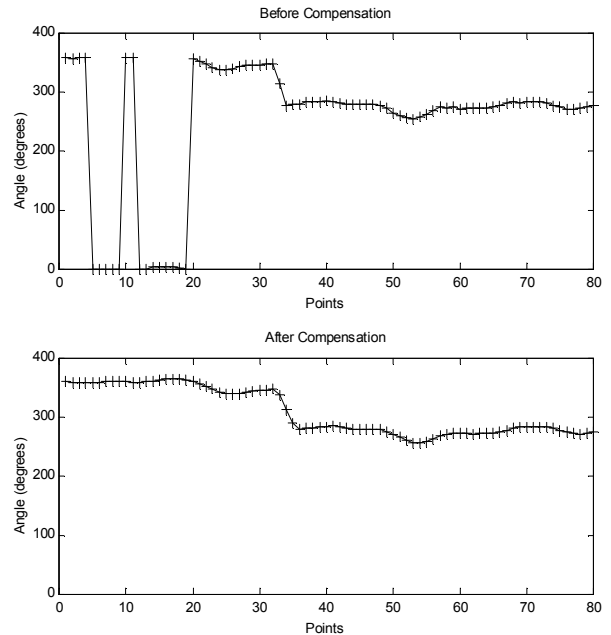


Figure 3: Compass compensation when Helpmate is heading to North

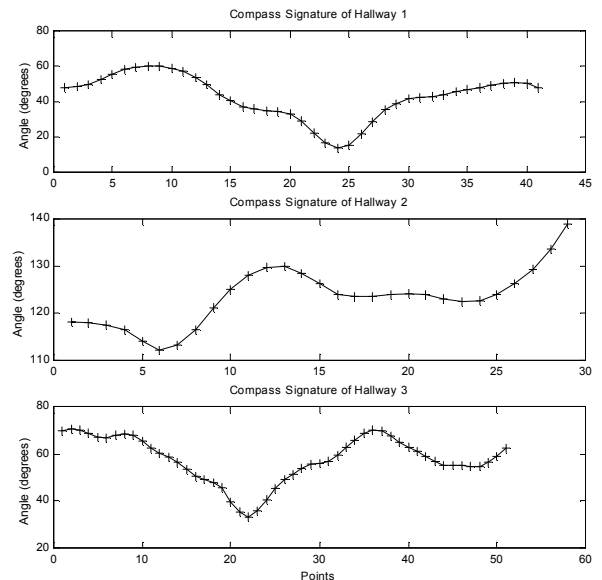


Figure 4: Three compass signatures of the hallways

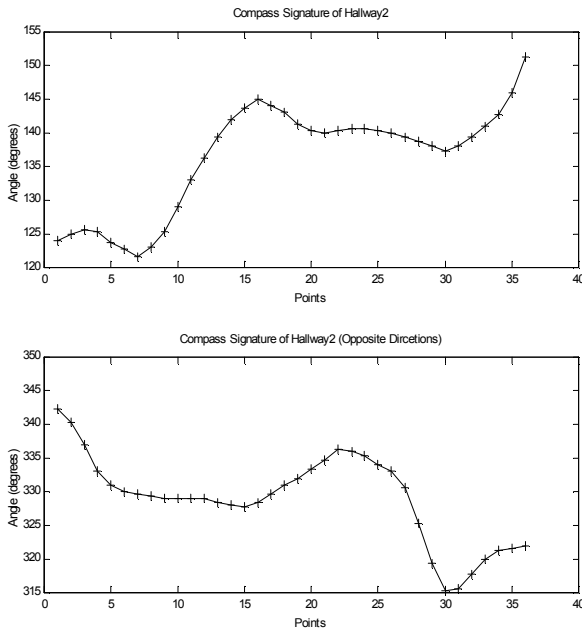


Figure 5: Signatures gathered from opposite directions (hallway2)

3 Signature Extraction

To approximate signatures, a discrete least square polynomial model is given by equation (5) [8].

$$\sum_{k=0}^n a_k \sum_{i=1}^m x_i^{j+k} = \sum_{i=1}^m y_i x_i^j, \quad (5)$$

$$j = 0, 1, \dots, n$$

where $\{x_i^j, y_i\}$ is a set of data with unknown coefficients a_k .

The discrete least squares method needs a series of m data to compute $n + 1$ coefficients of least-square polynomial of degree n . The least-square polynomials of degree n represent all m data. In our case, we need the algorithm to be used in real-time computation, i.e., HelpMate has to recognize a location while approaching it. Thus, we will not use all the compass readings from start up to the present position. Only the present data and selected previous data are used to represent a distinctive signature. The numbers of m and n are depended on how close the least-square approximation can match the pre-stored data. For our experiment, we use the least-square polynomial of

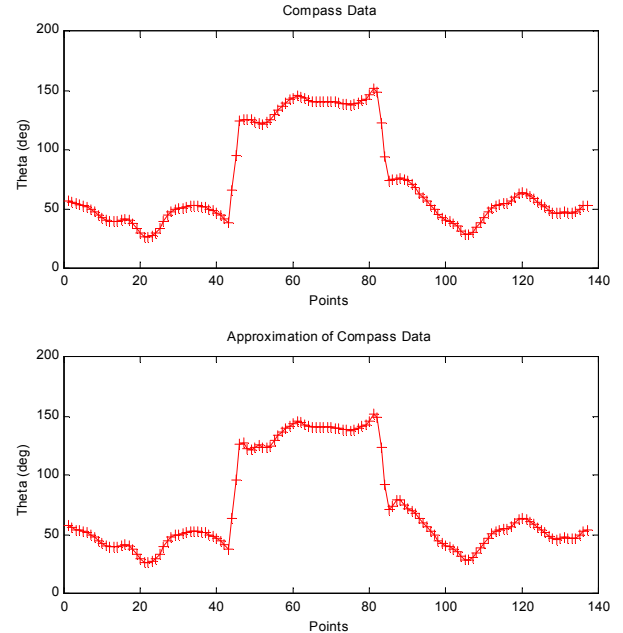


Figure 6: The comparison of pre-stored data and the least-square polynomial degree of 4

degree 4 with 10 data points, nine data from previous readings and one from a current reading as shown in Figure 6. While HelpMate is running, a reading is taken from the electronic compass, one data every 200 mm traversed. Together with the previous data stored in memory, the present data is computed using the discrete least square. The result is compared to the pre-stored data. Using the least matching error, and if the error is less than a threshold, then HelpMate can determine its current position. The threshold is the maximum of previously observed least matching errors. On the next loop, when new data arrives, the tenth data from the last computation is ejected, and the remaining data is shifted and passed to the next computation, thus we call this process a *sequential discrete least squares* solution.

After a series of least-square coefficients for whole data are obtained, the next step is to define distinctive signatures that represent specific locations, and store the location in memory for future use. Criteria for selecting a distinctive signature are as follows:

- A distinctive signature lies in the m -data points only
- A signature should include minimum/maximum

point(s) or both

- Do not select the points where mobile robots have to turn, e.g., intersections
- Do not use a flat signature
- Other features that make a signature distinguishable from others

We do not need to cover all these criteria, but try to meet most of them. Figure 7 shows signatures chosen from the whole signature to be distinctive signatures, e.g., each signature for each hallway. These signatures are stored in memory and used for localization.

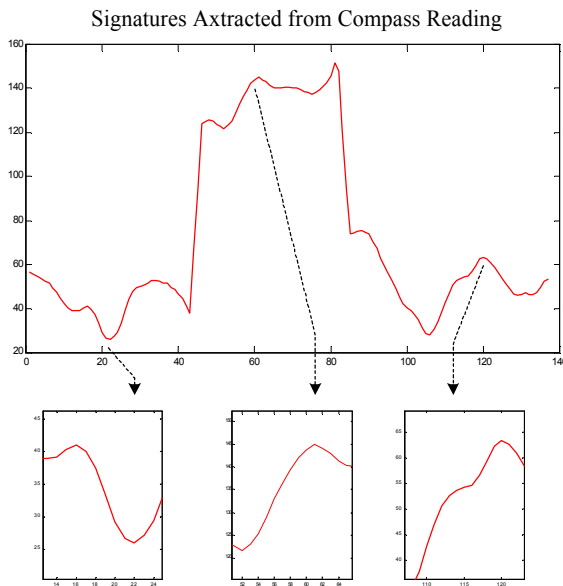


Figure 7: Signatures Atracted from Compass Reading

4 Performance Evaluation

This experiment was performed under Intelligent Machine Architecture [9] Version 2 (IMA2) developed at the Intelligent Robotics Laboratory (IRL), Vanderbilt University. This system runs on the Windows NT 4.0 environment and programs are written in Visual Basic 6.0. Performance evaluation is divided into two parts. First, HelpMate is commanded to navigate from Hallway1 to Hallway3 with the localization algorithm for recognizing those three locations.

HelpMate begins at a starting point in Hallway1. It proceeds and locates a known position (by magnetic signature) in Hallway1, HelpMate then proceeds to Hallway2, turns right and goes to a point in Hallway3. HelpMate then backtracks to return to the starting point. The results are shown as the following series:

```

====Matched at item 1 =====
error: 3.76115952110274
I found Hallway1_and_Head_to_Hallway2
====Matched at item 2 =====
error: 3.00977046446288
I found Hallway2_and_Head_to_Hallway3
====Matched at item 3 =====
error: 3.54400289451662
I found Hallway3_and_Head_to_ExitDoor
====Matched at item 4 =====
error: 2.60573578752889
I found Hallway3_and_Head_to_Hallway2
====Matched at item 5 =====
error: 4.18853376066538
I found Hallway2_and_Head_to_Hallway1
====Matched at item 6 =====
error: 1.96515553955517
I found Hallway1_and_Head_to_StartPoint
    
```

During our next experiment, HelpMate is placed at arbitrary locations in the hallways and turned on. HelpMate moves forward to recognize the place. If HelpMate can find its position using localization, it will set its current position with respect to the recognized location. Experiments are successful. HelpMate recognizes all places when it arrives to distinctive places.

5 Conclusion

The experiment was successful. HelpMate was able to recognize all places while travelling to the goal. The computation time was very rapid, and memory space used in consumption is very small. The goal of this paper was to investigate the possibility of using an electronic compass in localization, and the results showed that it is acceptable. This technique can be used with a topological map or odometry itself as an external reference. For other locations that do or do not have magnetic disturbances, we can make artificial magnetic interferes by placing magnetic materials or sources at certain positions to be distinctive places.

However, the current application of this technique is limited to corridor-like environments. For future work we explore ways to adapt this technique for other environments.

References

- [1] K. Kawamura, R. T. Pack, M. Bishay, and M. Iskarous, "Design philosophy for service robots," *Journal of Robotics and Autonomous Systems*, vol. 18, pp. 109–116, 1996.
- [2] O. Wijk and H. I. Christensen, "Localization and navigation of a mobile robot using natural landmarks extracted from sonar data," *Robotics and Autonomous Systems*, vol. 31, pp. 31–42, 2000.
- [3] Y. Matsumoto, K. Ikeda, M. Inaba, and H. Inoue, "Exploration and map acquisition for view-based navigation in corridor environment," in *Proceedings of the International Conference on Field and Service Robotics*, Pittsburgh, Pennsylvania, August 29-31 1999, pp. 341–346.
- [4] V. D. Hardt, P. Arnould, D. Wolf, and M. Dufaut, "Method of mobile robot localisation by fusion of odometric and magnetometric data," *International Journal of Advanced Manufacturing Technology*, vol. 9, no. 1, pp. 65–69, 1994.
- [5] R. Baker, *Human Navigation and the Sixth Sense*, Simon and Schuster, New York, 1981.
- [6] B. J. Kuipers and Y. T. Byun, "A robot exploration and mapping strategy based on a semantic hierarchy of spatial representations," *Journal of Robotics and Autonomous Systems*, pp. 47–63, 1991.
- [7] J. H. McClellan, R. W. Schafer, and M. A. Yoder, *DSP First : A Multimedia Approach*, Prentice-Hall, Englewood Cliffs, 1998.
- [8] R. L. Burden and J. D. Faires, *Numerical Analysis*, Brooks/Cole Publishing Company, CA, 6th edition, 1997.
- [9] R.T. Pack, D. M. Wilkes, and K. Kawamura, "A software architecture for integrated service robot development," in *Proceedings of the IEEE International Conference on Systems, Man, and Cybernetics*, Orlando, September 1997, pp. 3774–3779.