Disambiguating Robot Positioning Using Laser and Geomagnetic Signatures

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Abstract. This article proposes a technique for position disambiguating of mobile robots using laser and geomagnetic signatures in indoor terrains. Referring to the geomagnetic signature, magnetic field disturbances are used as unique recognition signatures. First, we gather information about the magnetic heading and the laser mapping as our robot traverses a path between start and goal points of the workplace using the vector mapping paradigm (VMP) [1]. Second, we employ a spectral analysis, based on the discrete cosine transform (DCT), to code and to compress geomagnetic and laser signatures, and then store this information. Finally, as the robot traverses a vector, it gathers the information from the compass and the laser scanner, converts it into DCT form and matches it with the pre-stored data. If a match is found, the robot can deduce its current position. The results show how the robot can distinguish accurately its position using these signatures.

1 Introduction

Pose tracking is a key subject in robotics. Mobile robot pose tracking is the process of deducing a robots pose (location, heading) relative to its environment from its sensor data. Therefore, it has been referred to as the most fundamental methodology for providing a mobile robot with autonomous capabilities. Using odometry encoders is the most widely used method for determining the position of a mobile robot. Unfortunately, the acquisition of odometric data is associated with different types of noise e.g. non-linear noise (backlash, hysteresis, toggle, threshold, saturation, damping and friction), time based noise (accumulation effect) and white noise. Another form of odometric errors is generated by the mechanical system from rotation or due to slippage and drifting. Consequently, the odometry needs to be corrected from time to time. To overcome this problem, robust and accurate localization of the robot is needed. A variety of algorithms has been used to solve the problem of robot localization, e.g. expectation maximization, maximum likelihood, probabilistic approach (Markov, MCL) and simultaneous localization and mapping (SLAM, Kalman) [6, 4, 5, 7]. Also, There are many researchers, who adopted vision systems for the recognition of natural or artificial landmarks. Those techniques often require high-performance on-board computers and expensive vision systems as well as computational overhead. Moreover, those systems incorporate a lot of instability, complexity and noise. This study introduces a technique to estimate the pose based on the spectral analysis of laser and geomagnetic signatures. This technique relies mainly upon the frequency analysis of signatures, using the DCT algorithm. Compared with the spatial domain analysis, prevalent in signature matching and robot localisation, the frequency domain provides more stability for dealing with pattern recognition subjects, especially in the presence of phase shift and scaling errors. Consequently, matching of signatures in the spectral domain facilitates pose estimation, even if signatures are partially distorted or in the presence of limited changes due to rotation or displacement. The DCT pertains to a group of algorithms (e.g. DFT, FFT, DST, wavelet, Gabor, etc.) used for the frequency analysis of patterns. Furthermore, the DCT has a compression capability which speeds up matching of thousands of patterns.

The remainder of the paper is organized as follows. Section (2) presents employing the magnetic compass to serve as a heading device. Section (3) illustrates the basic formulation of the DCT algorithm. Section (4) demonstrates laser mapping and dynamic pose tracking. Section (5) shows the results of the presented framework.

2 Geomagnetic Signatures

2.1 Natural Magnetic Field

The Earth acts like a great spherical magnet, in that it is surrounded by a magnetic field. The Earth's magnetic field resembles, in general, the field generated by a dipole magnet (i.e., a straight magnet with a north and south pole) located at the centre of the Earth. The axis of the dipole is offset from the axis of the Earth's rotation by 11° This means that the north and south geographic poles and the north and south magnetic poles are not located in the same place. At any point, the Earth's magnetic field is characterized by a direction and intensity which can be measured. To measure the Earth's magnetism in any place, we must measure the direction and intensity of the field. The Earth's magnetic field is described by seven parameters, see figure (1): D is the declination, X indicates north, Y indicates east, I is the inclination, Z is the vertical intensity, H is the horizontal intensity and F is the total intensity.

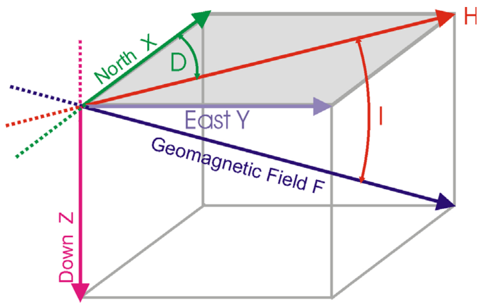


Figure 1: Magnetic field elements

2.2 Deviation Sources

The error due to magnetic interferences is the most distracting one. The source of such interferences can be natural or artificial causes. The erroneous compass data, generated by the mentioned interferences, are positively considered as a natural signature by which a certain terrain can be depicted (self localization). The magnetic interference sources can be classified as the following; (**1**) Natural sources such as; magnetized rocks, cosmic fields, electric currents following in the earth's crust, ocean current and wind effects. (**2**) Artificial sources such as; ferro-magnetic structures, internal electrical components, mechanical vibration and power lines [10, 8].

2.3 Fluxgate Compasses

The compass best suited for use with mobile robot applications is the fluxgate compass. When maintained in a level attitude, the fluxgate compass will measure the horizontal component of the earth's magnetic field, with the advantages of low power consumption, no moving parts, tolerance to shock and vibration, rapid start-up, and relatively low cost. If the vehicle is expected to operate over uneven terrain, the sensor coil should be gimbal-mounted and mechanically dampened to prevent serious errors introduced by the vertical component of the geomagnetic field [10, 8]. We used a KVH C100 compass mounted on two RWI-B21 robot platforms (Colin and Robin) to survey the geomagnetic signature of our workspace.

2.4 Compass

Electronic compasses are often used to detect headings of mobile robots in an outdoor terrain. In essence, electronic compasses have one drawback when used inside a building: they can easily be disturbed by electromagnetic sources (e.g. power lines, electromagnetic fields of robot internal components, fields of external instruments or large ferro-magnetic structures). This makes it impossible to rely on electronic compasses as reliable heading devices for indoor applications. It is found that reading errors for each particular position have a unique signature [8, 10]. In general, any distinctive-environment feature that is specific to a particular area can be used to recognize its own characteristics, natural landmarks. This article, therefore, introduces a method for pose deduction using an electronic compass to detect geomagnetic anomalies for VMP based navigation in collaboration with the analysis of laser signatures [1], see figure (3). The advantage of the magnetic field disturbances is taken by using them as recognition signatures to localize distinctive places. In figure (2) we define some special marks (denoted from 1 to 8). The disturbances of the geomagnetic measurements at positions (3,4,6,7,8) are due to the presence of ferro-magnetic structures (frames of glass doors), at positions (1, 5) they are due to the electromagnetic radiation of a wireless LAN transceiver, while the disturbances at position (2) have no obvious cause.

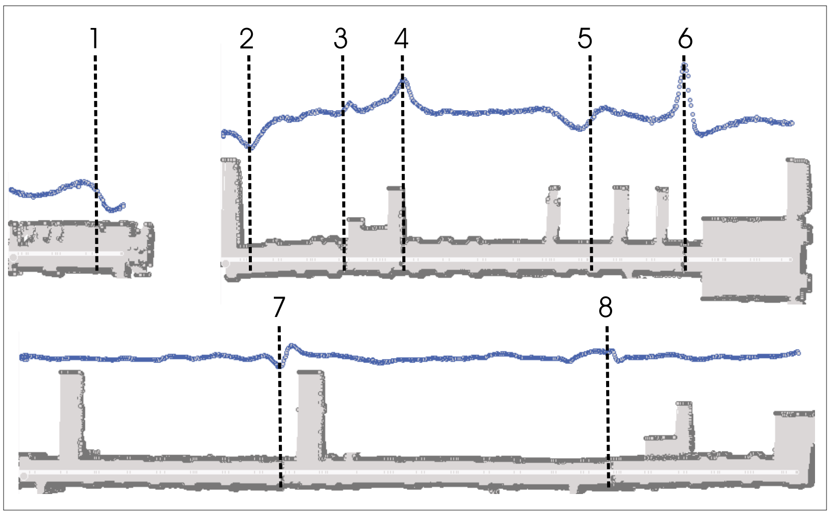


Figure 2: Laser and geomagnetic mapping

3 Spectral Analysis of Signatures

The DCT transforms a signal from a spatial representation into a frequency representation. Lower frequencies contribute more to a signal than higher frequencies, so if we transform a signature into its frequency components and throw away data about higher frequencies we can reduce the amount of data needed to describe those signatures without sacrificing too much signature quality. The DCT transform can be accomplished as follows;

$$y_i = \Lambda_i \sum_{j=1}^{N} x_j \cos \frac{\pi(2j-1)(i-1)}{2N}, i = 1, ..., F \tag{1}$$

where, x_i is the data series, at time t_i, $x_i \in R^n, i = 1, ..., N$, F is the number of DCT coefficients, y_i is the DCT coefficients and N is the signature length.

$$\Lambda_i = \begin{cases} \frac{1}{\sqrt{N}} & for\ i{=}1 \\ \sqrt{\frac{2}{N}} & for\ 2{\le}i{\le}F \end{cases} \tag{2}$$

For all frequencies ($F = N$), i varies from 1 to N, there is no compression. To compress the signature (by omitting high frequencies), i varies from 1 to fl ($F = fl$), where fl is the frequency limiter or called the number of DCT coefficients. The inverse DCT can restore the original signature using a limited number of DCT coefficients, see figure (3).

$$x_i = \sum_{j=1}^{F} \Lambda_j y_j \cos \frac{\pi(2i-1)(j-1)}{2N}, \quad i = 1, ..., N \ \ and \ \ j = 1, ..., F \tag{3}$$

4 Laser Signatures

4.1 Laser Mapping

To gather the odometric data of an environment, the laser scanner returns a set of points corresponding to the intersection points of the laser beam with the obstacles. The laser beam rotates in a horizontal plane and emanates from a scanner mounted on the robot. The scan is a 2D slice of the environment. We used a SICK LMS 200 laser scanner mounted on our B21 robot ”Colin”. The 2D laser scanners have many advantages, like high speed, high precision, high angular resolution and easy data interpretation. The laser scanner has also several disadvantages, like high cost, high weight (4.5 kg), 2D plane scanning limitation, high power consumption and problems with glass doors, mirroring objects and dark black materials. In figure (4) we define some special marks (denoted from 1 to 6). The marks 1, 5 and 6 are used to sign the position of the glass doors. The laser scanner failed to detect them due to their transparency. The area marked by 2 is the downward stairs and should not be entered with the B21 platform. The horizontal plane laser scanner is not able to detect downward stairs. The area marked by 3 is a table and the laser scanner was able to identify just the legs of the table but the table itself wasn’t recognized. The object marked by 4 is a dynamic object (door) and the presented location is not permanent.

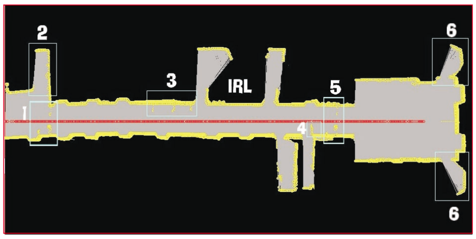
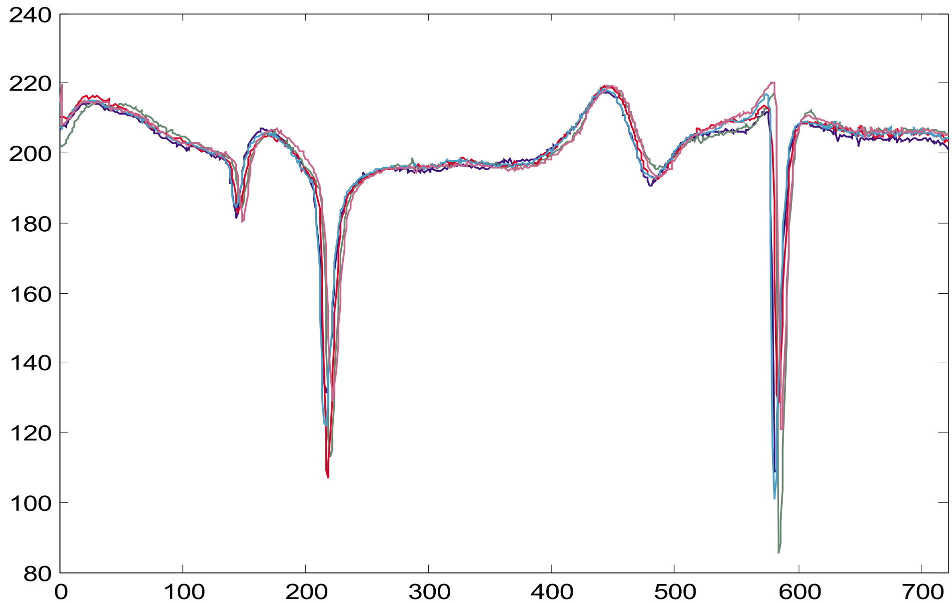
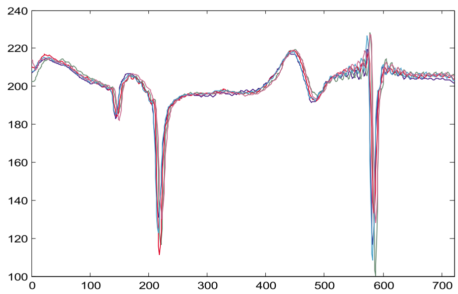


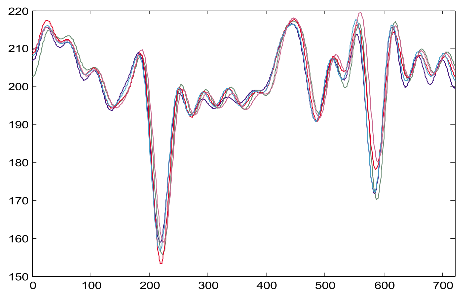
Figure 4: 2D laser mapping



(a) Original signature



(b) Signature reconstruct with 140 DCT coefficients (20%)



(c) Signature reconstruct with 35 DCT coefficients (5%)

Figure 3: DCT based spectral analysis for signal reconstruct purposes

4.2 Vector Mapping Paradigm

Several mapping paradigms have been investigated to model the robot's workspace. The most widely used methods are the occupancy grid, the topological graph and maps integrating both. Each of these methods has its characteristics, advantages and disadvantages. Throughout this work the vector mapping paradigm has been used. This technique is usable for robots equiped with a laser scanner. The vector mapping is originally based on the occupancy grid with a reduced map size. The main idea of the vector mapping is to determine empty space as a region of cells between the laser scanner (robot's position) and the detected obstacles. In other words, these empty cells will be represented by end points of the laser rays (vectors) and the position of the laser scanner. The measurements of the vector mapping are given in a polar coordinate system whose origin is the position of the scanner (robot), while the end of the vectors is the obstacle boundaries. This map reduces both computational burden and memory requirements. In this method, it is required to record just the start (once per scan) and the end of the vectors so the region in between is considered free space that will preserve the consistency of the maps. The laser scanner sends out 180 laser rays per scan with 1° angular resolution. The resolution of the vector mapping can be controlled using either hardware or software techniques.

The vector mapping technique can be easily converted into the traditional maps. As example, the occupancy grid can be generated by marking all cells included in the vector region as empty and the remainder cells as occupied. Also the topological graph and integrated form can be estimated through the occupancy grid. Based on vector mapping a contour-graph can be generated. This graph includes the contours of the existing obstacles. This graph is used later in the path planning and navigation based on the SLN-algorithm. Enlarging the obstacle's boundaries is used to generate the contour graph. Figure (5.a) presents two different models based on vector mapping: the first one has been built using 500 measurement points and the second using only 10 points. The difference in precision between the two models seems not too much although the map size difference is clearly large: the second map (figure (5.b)) size is about 2% of the first map size (5.a). This sort of mapping has a flexible resolution format depending on the required precision and the computational power of the system. Adjusting the number of the central measurement points can control the resolution of the map. The vector mapping has the advantages of the traditional mapping techniques: precision, consistency and efficiency with a low storage size.

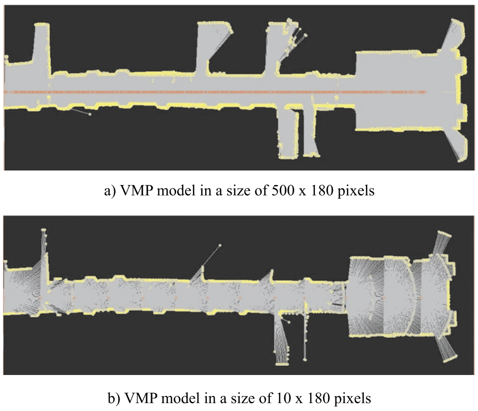


Figure 5: Mapping using the laser scanner

4.3 Laser Pose Matching

Generally, laser signatures are used effectively to deduce pose and heading of mobile robots, see figure (6). To match signatures, different techniques have been used, e.g. the probabilistic approach, absolute correlation and least mean squares [3, 9, 2]. Throughout this framework the spectral analysis of signatures has been used to match laser scans. The spectral analysis has some advantages when applied to pose deduction; first, it can match the signature even in the presence of noise or if the signature is partially distorted. Besides, it can detect signature scaling and rotation.

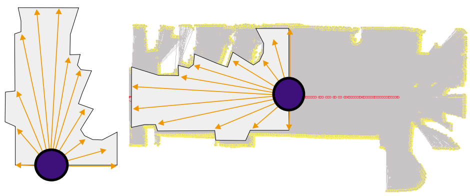
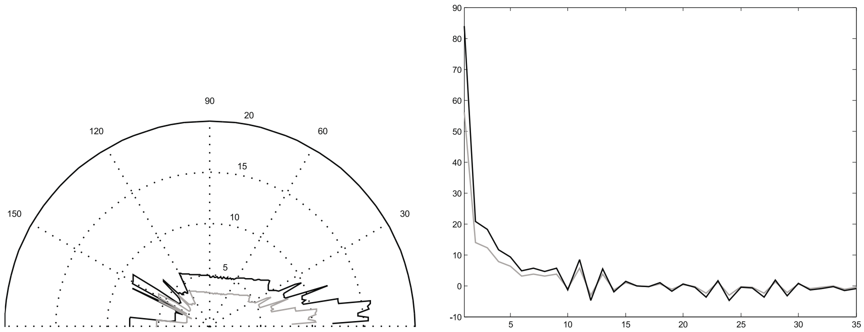


Figure 6: Laser signature matching

- Scaling property:
  The spectral analysis has the capability to detect scaling. So, If $f(t) \Leftrightarrow F(\omega)$, then $f(at) \Leftrightarrow \frac{1}{|a|} F\left(\frac{\omega}{a}\right)$. The value $|a| > 1$ compresses the time axis and expands the frequency axis, while the value $|a| < 1$ expands the time axis and compresses the frequency axis, ω is the frequency, t is the time and a t_o are constants. Figure (7) shows the scaling effect on the spatial and spectral representation.

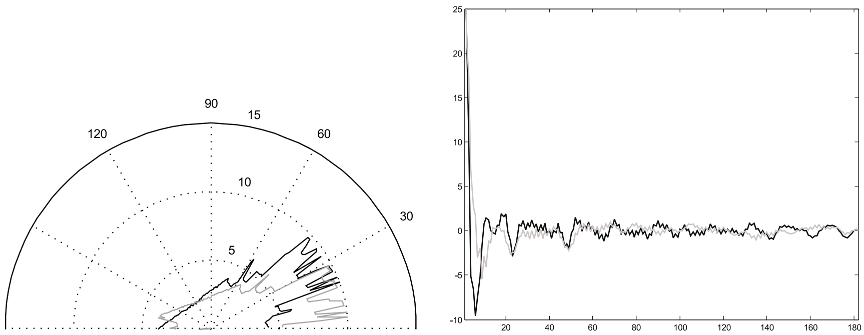
- Phase shift property:
  Spectral analysis can counteract the influence of limited rotation or displacement. Figure



(a) Signature scaling (b) Signature DCT coefficients

Figure 7: DCT based spectral analysis with scaling

(8) shows the effect of rotation on the spatial and spectral representation of a signature.



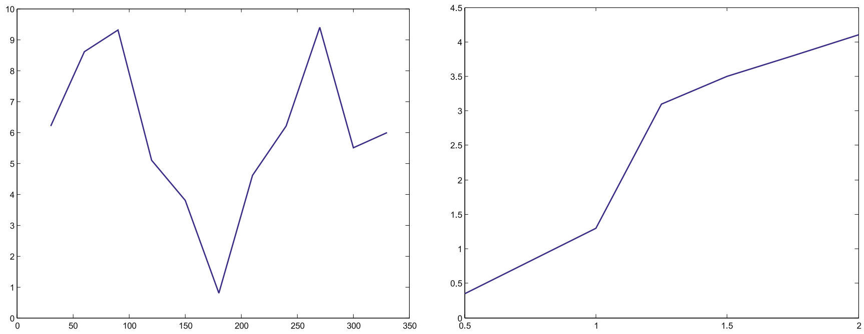
(a) Laser signature rotation (b) Signature DCT coefficients

Figure 8: DCT based spectral analysis under phase shift (rotation)

Figures (9.a) and (9.b) show the robustness of the DCT with respect to signature phase shift and translation, respectively. On the left we show how we can find the best match and heading of the robot at the global minimum although the robot is one meter apart from its home location. The right graph shows the change in match error due to this translation.

5 Conclusion

The major contributions of this article are the formulation of a new approach, spectral analysis, to the modelling and identification of laser and compass features that provide improved computational efficiency in the positioning techniques. By manipulating the manner in which feature information of both laser and geomagnetic signatures is incorporated into the model, it can be shown that significant improvements in the performance of the algorithm can be realised. Moreover, the simplicity and the efficiency of dynamic pose tracking techniques succeeded to improve the robot pose estimation process.



(a) Pose tracking w.r.t. rotation (b) Pose tracking w.r.t. displacement

Figure 9: DCT based pose tracking

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