

Magnetic Tensor Sensor and Way-Finding Method Based on Geomagnetic Field Effects for Visually Impaired Users

Ranjitha.S¹, Savitha.S², Shiny Mercy Angelin.D³, Vasundhara.S⁴, Subhash.J⁵

UG Scholar, Department of ECE, Adhiyamaan College of Engineering, Hosur, Tamilnadu, India^{1,2,3,4}

Assistant Professor, Department of ECE, Adhiyamaan College of Engineering, Hosur, Tamilnadu, India⁵

ABSTRACT: This paper presents a method utilizing geomagnetic field effects commonly found in nature to help the visually impaired persons (VIPs) navigate safely and efficiently; both indoor and outdoor applications are considered. Magnetic information indicating special locations can be incorporated as waypoints on a map to provide a basis to help the user follow a map that amalgamates the waypoints into spatial information. Along with a magnetic tensor sensor (MTS), a navigation system for helping VIPs more effectively comprehend their surroundings is presented. With the waypoint enhanced map and an improved dynamic-time-warping algorithm, this system estimates the user's locations from real-time measured magnetic data. Methods using image data to enhance waypoints at dangerous locations are discussed. The MTS-enhanced method can be integrated into existing personal mobile devices (with built-in sound, image, video, and vibration alert capabilities) to take advantages of the rapidly developing internet, global positioning systems, and computing technologies to overcome several shortcomings of blind assistive devices. A prototype MTS-enhanced system for indoor/outdoor navigation has been developed and demonstrated experimentally. Although the MTS and algorithm are presented in the context of way-finding for a VIP, the findings presented here provide a basis for a wide range of applications where geomagnetic field effects offer an advantage.

KEYWORDS: Blind, geographic information system, navigation, perception, visually impaired, way-finding.

I. INTRODUCTION

For people who lost the optical ability to interpret their surroundings, way-finding that requires the person to navigate indoor or outdoor to the destination is often a daunting task. Recent advances in personal mobile devices capable of computing, communication and control, digital imaging, and global positioning, which are widely available at affordable cost and offer potentials to enhance the global perception of the user's surrounds. However, these technologies are generally ineffective for uses by blind people, particularly in close-range navigation. Inspired by the ability of some biological organisms to detect geomagnetic (earth magnetic) fields as an orientation cue during migration or homing, this paper explores the use of geomagnetic field effects to extend the capability of personal devices to help blind people overcome some problems encountered in daily way-finding.

Traditionally, visually impaired persons (VIPs) without residual vision rely on white canes or guide dogs for close range navigation. White canes are most widely used because they are inexpensive, lightweight and small, and can reliably detect sufficiently large obstacles (such as steps and uneven surface) near ground/floor level, but the users require to continuously scan the small area ahead of them. While guide dogs are effective travel aids, they themselves are difficult to be taken care of by the VIP. Fully trained guide dogs are very expensive and useful only for five years. As a result, it was estimated that only 1% of the two million VIPs have guide dogs. Many technologies have been applied to way-finding; for example, where auditory feedback was proposed as a navigation aid for the visually impaired. Methods for indoor/outdoor navigation can be broadly divided into three categories based on existing human-made signals, predeployed infrastructures and nature-generated physical fields. The first category utilizes signals such as wireless fidelity, FM radio,

television, and phone signals. As these signals were originally developed for transferring voice and/or picture information, their accuracy is generally less than desired for positioning. The second category relies on predeployed infrastructures that use technologies such as ultra wideband, radio frequency identification, ultrasound, and infrared for navigation. The latter two, ultrasound and infrared sensors, provide proximity information but offers no physics-based information about the object, and thus require infrastructures with embedded data for location information. Predeployed infrastructures are costly and have limited area coverage. More recently, global positioning systems (GPS) are widely used for outdoor navigation. However, GPS cannot operate well in areas inaccessible to good-quality satellite signals, and their resolution (typically 10 m) are inadequate to avoid dangers in way-finding applications. The third category takes advantages of some nature-generated physical parameters or signals (such as thermal infrared, acceleration, and optical field) for positioning. These natural or passive signal-based technologies offer a low-cost solution. Methods on obstacle avoidance can be classified into humangenerated (active) and nature-generated (passive) signals with advantages and limitations similar to the above mentioned second and third categories for navigation, respectively. Active signal methods, which requires an emitter/receiver pair to generate/detect signals (like ultrasonic and sonar) to determine the existence of the obstacles and their locations, are less sensitive to environmental influences but have limited range of operation. Passive-signal methods (for example, the uses of thermal infrared or optical fields naturally emitted/reflected from the obstacles to estimate the obstacle information), in general, have a potential to offer a low-cost solution.

High-resolution vision systems and algorithms are now widely available at relatively low cost. Video information can be internet-transferred using personal digital assistant without relying on predeployed or dedicated infrastructures. The VIP can share images/videos captured by a wearable camera through internet, which permit a remote sighted guide to navigate the VIP in the immediate travel environment. More recently, rapid developing social networks (such as Twitter, Face book and RSS), which act essentially as a “social sensor,” can further enhance the global perception of the surrounding environments. However, these technologies are generally ineffective for close range way-finding by a VIP. Magnetic sensing technology, inheriting many advantages of magnetic fields (such as great penetration, fast response, and well-defined theory), has been applied to help VIPs, such as reaching ferrous objects and transmitting images via retinal stimulation. The observations of geomagnetic distortion or anomalies in the presence of magnetic objects have led some researchers to develop geomagnetic-based methods to help the VIPs navigate; for example, guide walking direction with a magnetic compass and localization utilizing the magnetic flux density (MFD). However, several barriers must be overcome for effective use of geomagnetic fields for way finding.

- 1) Sensor range for geomagnetic anomaly is limited.
- 2) Non magnetic objects cannot be detected.
- 3) Accurate survey of magnetic fields in 3-D space is difficult to obtain.
- 4) Efficient algorithms for mapping localization with survey data remain lacking. To overcome the aforementioned shortcomings of the passive methods that derive information from signals in nature, this paper presents a method based on geomagnetic field anomalies around ferrous objects for indoor/outdoor navigation. This method can be integrated into the existing devices (such as a VIP white cane) and/or embedded in a personal mobile device (generally built with sound, image, video, and vibration alert capabilities) to take advantages of the rapidly developing internet, GPS and digital imaging technologies; for example, camera-based assistive label reading for blind persons. When complemented with imaging processing and GPS, the method presented here will have significant potentials to

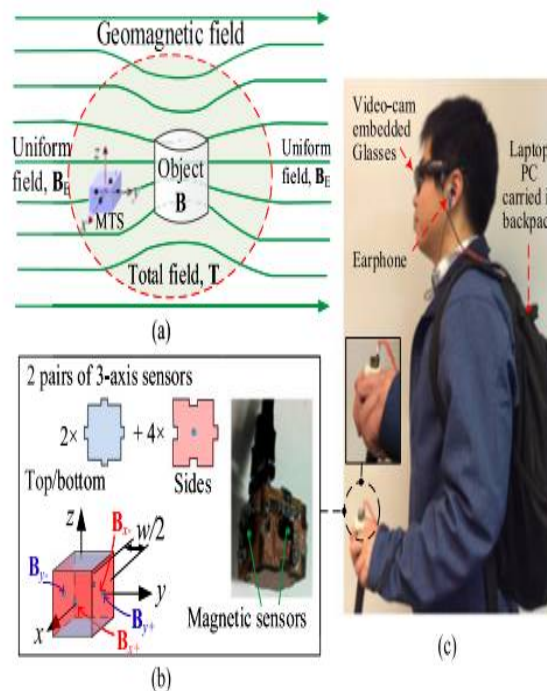


Fig. 1. Schematics illustrating MTS-based navigation system. (a) Magnetic object in geomagnetic field. (b) MTS. (c) Navigation system for visually impaired.

enhance the navigation experience of a VIP in both indoor and outdoor environments. The remainder of this paper offers the following.

- 1) A magnetic tensor sensor (MTS) is introduced to enhance closed-range way-finding. The MTS utilizes direction dependent geomagnetic-field effects to detect magnetic anomalies due to the presence of magnetic objects or current-carrying equipment. Magnetic anomalies exist almost everywhere and can be commonly found in modern buildings. Unlike traditional sensors that rely on direct MFD measurements, the MTS simultaneously measures the magnetic tensor G and MFD to determine the closeness and motion status of the magnetic object.
- 2) Methods to incorporate geomagnetic effects and optical information as waypoints to define special locations (like pole, stair, gate, and corner along a corridor) on a map are discussed, which provides a basis to estimate locations from the real-time measurements relative to the map.
- 3) A navigation algorithm based on improved dynamic time-warping (DTW) of magnetic data is presented. This new method which requires only 1-D magnetic map greatly simplifies data collection. As will be shown, this method does not need the whole magnetic map after collecting the samples, and thus reduces sample sizes and search area.
- 4) A prototype navigation system (that includes an MTS and takes advantages of existing vision and GPS technologies) has been experimentally evaluated; both indoor and outdoor applications are considered. This paper focuses on assisting VIPs who obtain no visual information by themselves. Thus, this sensing method is applicable to a VIP who has residual vision as well as a healthy people.

II. BLOCK DIAGRAM

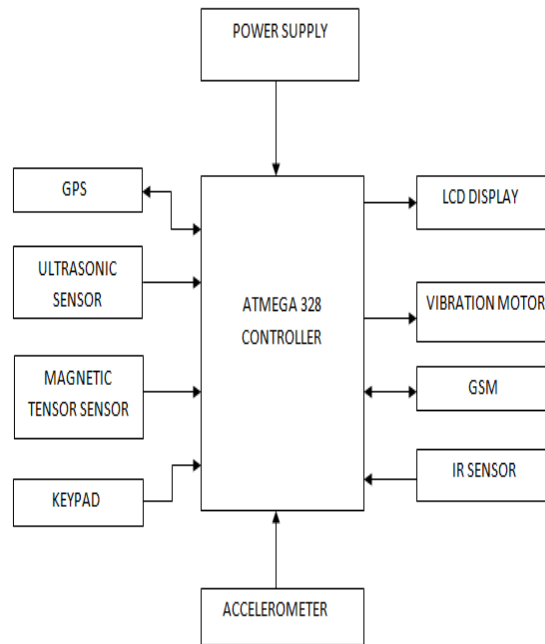


Fig 2: Block Diagram

III.GEOMAGNETIC-FIELD MTS

Fig. 1 illustrates the design concept of an MTS for guiding VIP. When a magnetic object is in space, the earth-magnetic

TABLE I
SENSOR PARAMETERS

Three-axis magnetic sensor Model: BMC050		Wearable digital video camera Model: POV ACG-20	
Size (mm)	3 × 3 × 0.95 h	Resolution (pixels)	1280 × 1024 (image) 640 × 480 (video)
Range (μT)	±1000	Frame rate	30 frames/s
Resolution (μT)	0.3 (at 20 Hz)	Connection	Mini USB
Output noise (μT)	0.3		

(or geomagnetic) field around it is “distorted” as illustrated in Fig. 1(a). This distorted field can be used to derive information in the immediate surroundings of the VIP. However, the geomagnetic anomaly is difficult to be evaluated using direct MFD measurements. Thereby, the magnetic tensor \mathbf{G} is utilized to interpret the geomagnetic effects. In addition, magnetic sensors in digital format are chosen to minimize the noise effect. Fig.

1(b) shows a prototype MTS consisting of two orthogonal pairs of digital three-axis magnetic field sensors (BMC050) mounted at $\pm w/2$ (where $w = 10$ mm) from the x - and y -axes of the sensor local coordinate system. Packaged in a small footprint, BMC050 [25] has a relatively large measurement range, high resolution, low output noise, and low energy consumption; see Table I. In operation, the MTS communicates with a laptop PC through an inter-integrated circuit (I2C) bus and a USB adaptor, where the MTS output signals are filtered using 1-D median filter to remove noise. As will be shown, the MTS can effectively supplement image-based information to improve the indoor/outdoor navigation of the visually impaired user. Carried in a backpack by the VIP as shown in Fig. 1(c), the MTS measurements (with data from GPS and wearable camera) provide the user with surrounding information (by means of an earphone and/or stimulator).

IV. MAGNETIC MAP-FOLLOWING FOR INDOOR NAVIGATION

Fig. 3 shows the emergency excavation route of an office building and the magnetic map for a VIP to follow, which provides the environment for the indoor navigation experiment to evaluate the prototype MTS and the location algorithm. The symbols 1 to 8 indicating the waypoints [red numbers in Fig.3(a)], which are specified landmarks and alert critical and dangerous locations along the path from Room 474 (red star) to the stair (red dot), are defined in Table II and Fig. 3(c), (d).

A. GEOMAGNETIC WAYPOINTS:

Table II illustrates three different types of geomagnetic waypoints which are defined before data collection: The first type is characterized by magnetic property in an object or a structure, which may be general steel or embedded components such as reinforced bars in a concrete pillar or column. The second type exists by virtue of its current induced magnetic anomaly; the electrical closet 2 where power lines, electrical equipment and network switches are housed is a good example. The third type is caused by the changes in sensor orientation relative to the uniform geomagnetic field without a magnetic anomaly (because geomagnetic field effects are directional); for example, the corner along the corridor 4 is a nonmagnetic waypoint which helps locate the direction change. Unlike the first or second type waypoint at which the specified location is defined, Waypoint 4 has little anomalies in the area but can be detected by the sensor after an actual geographical change in direction has taken place. For simplicity, only the MFD components along the route are shown here on the magnetic map in Fig.3(b) which shows several significant MFD changes due to the magnetic waypoints marked in the pink shaded window. The field changes at 4 and 6 are caused by the changes in sensor orientation relative to the uniform geomagnetic field, and that in 1 to 3 and 5 are due to magnetic objects. With the magnetic map, the localization algorithm described in Section II-B was utilized to estimate the actual location using measured \mathbf{T} and \mathbf{G} . The concept feasibility of the MTS guided indoor navigation is evaluated by computing the errors of the estimated locations with respect to the actual locations. Based on four datasets collected along the route, the mean errors and their ranges at the eight waypoints are plotted in Fig. 4, the standard deviation of all experimental data is 81 mm; and the position errors at stair-waypoint 8 are within ± 0.075 m.

V. OUTDOOR NAVIGATION

The MTS and its way-finding algorithm can be integrated into a VIP white cane and embedded in a personal mobile device to take advantages of the rapidly developing internet, GPS, and digital imaging technologies to enhance the outdoor navigation experience of a VIP. To avoid repetition, experimental results of two practical applications are discussed here: The first analyzes the magnetic anomalies due to commonly seen objects along a typical outdoor walkway, where the experimental results also serve as a basis for validating the observations. The second illustrates some dangerous waypoints in the context of street crossing.

VI. TECHNOLOGY ENHANCEMENT

GPS are widely available in personal devices for outdoor navigation but their resolutions (<10 m) are inadequate to help VIPs avoid obstacles along the path; for examples, signposts and moving vehicles are not on the map. While these obstacles can be easily avoided by healthy people, they cannot be seen by the VIPs.

VII. APPLICATIONS AND EXPERIMENTAL RESULTS

The performance of the prototype MTS [see Fig. 1(b)] and navigation system [see Fig. 1(c)] has been experimentally evaluated involving both indoor and outdoor applications. The flowchart shows the relations among the magnetic map, magnetic/vision data collection, and localization algorithms for the indoor (E1) and outdoor (E2) navigation examples. In E1, vision images are utilized to predict and identify an upcoming critical waypoint (such as a stair) or danger whereas in E2, vision images are introduced to extract and locate moving vehicles and zebra crossings. In both indoor and outdoor experiments, the MTS is attached to the VIP (at a height approximately 0.6 m from the floor/ground); and the MTS coordinate system is defined such that its yaxis points to the moving direction. As will be shown, when coupled with information derived from images, magnetic information can significantly improve the safety of the blind user.

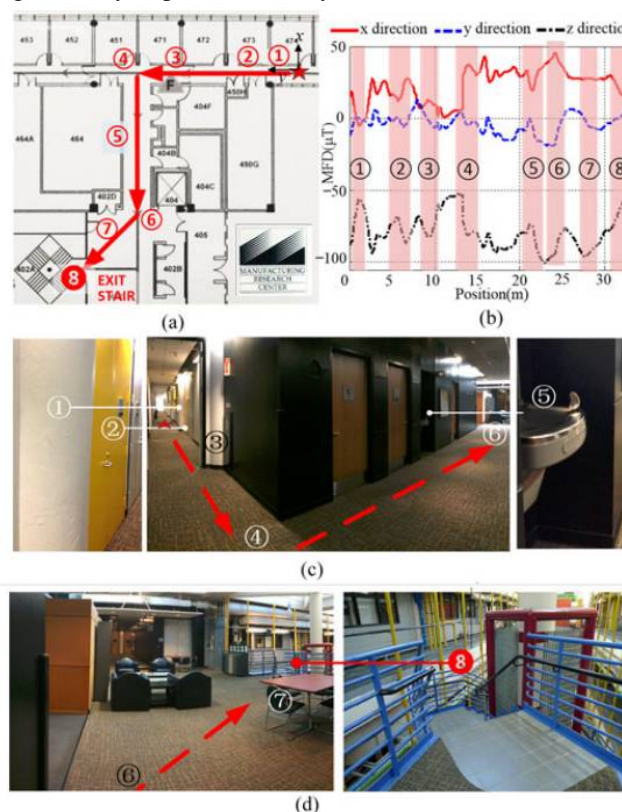


Fig. 3. Schematics showing path/waypoints for indoor experiments. (a) Floor plan for emergency evacuation route. (b) MFD along the route. (c) Objects along the route: pillars 1, 3, electrical closet 2 and dispenser 5. (d) Critical waypoint along the route: stair 8.

TABLE II
DESCRIPTION OF WAYPOINTS

① Pillar	② Electrical closet
③ Pillar/Steel door frame	④ Corner along the corridor
⑤ Water dispenser	⑥ End of corridor (elevator with first-aid box)
⑦ Table and chairs	⑧ Stair with steel handrails

VIII. CONCLUSION

A navigation method utilizing geomagnetic field effects to guide the VIPs has been presented. Through this method, magnetic information (indicating special locations like stair, gate, and corner along a corridor) can be incorporated as waypoints on a floor map, which provides a basis to help the VIP follow a 1-D map that amalgamates magnetic waypoints into spatial information using the improved DTW method. Along with a prototype MTS, a navigation system that combines the advantages of the geomagnetic field effects commonly found in nature and the rapidly developing (internet, GPS, digital video imaging, and computing) technologies has been developed, which enables the user more effectively comprehending their surroundings. As compared to other navigation methods, the proposed method is low cost because it bases on nature generated physical fields. Meanwhile, the magnetic fields have favorable properties (such as great penetration, fast response, and insensitive to environments) which make this method robust and effective. When complemented with imaging processing and GPS, the disadvantages of the magnetic field-based sensors, which include limited sensing-range and disability to detect nonmagnetic objects, can be cost-effectively overcome, and the method presented here will have significant potentials to detect and avoid obstacles for both indoor and outdoor navigation. Both numerical and experimental results show that the orientation-insensitive tensor-based parameter Q is a useful indicator to gauge the closeness of a magnetic object; and when simultaneously measuring the MFD and its time rate, the MTS can be used to determine the motion status of the moving magnetic object (such as a vehicle) within a circular range of approximately 2 m radius. As compared to GPS resolution of 10 m, the MTS-enhanced navigation is capable of relatively accurate magnetic map-following (with a maximum mean position error of 0.21 and 0.08 m standard deviation). Results also show that when coupled with information derived from images, magnetic information can significantly enhance the navigation performance of a VIP, especially for areas with large magnetic anomalies and/or potentially dangerous waypoints.

REFERENCES

- [1] I. Ulrich and J. Borenstein, "The guidecane-applying mobile robot technologies to assist the visually impaired," *IEEE Trans. Syst., Man, Cybern. A, Syst. Humans*, vol. 31, no. 2, pp. 131–135, Mar. 2001.
- [2] R. Liu and Y.-X. Wang, "Auditory feedback and sensory substitution during tele-operated navigation," *IEEE/ASME Trans. Mechatronics*, vol. 17, no. 4, pp. 680–686, Aug. 2012.
- [3] B. Li, Y. Wang, H. K. Lee, A. Dempster, and C. Rizos, "Method for yielding a database of location fingerprints in WLAN," *IEE Proc. - Commun.*, vol. 152, pp. 580–586, 2005.
- [4] V. Moghtadaiee, A. G. Dempster, and S. Lim, "Indoor localization using FM radio signals: A fingerprinting approach," in *Proc. Int. Conf. Indoor Position. Indoor Navig.*, Sep. 21–23, 2011, pp. 1–7.
- [5] C. Ye, S. Hong, and A. Tamjidi, "6-DOF pose estimation of a robotic navigation aid by tracking visual and geometric features," *IEEE Trans. Autom. Sci. Eng.*, vol. 12, no. 4, pp. 1169–1180, Oct. 2015.
- [6] S. Gezici *et al.*, "Localization via ultra-wideband radios: A look at positioning aspects for future sensor networks," *IEEE Signal Process. Mag.*, vol. 22, no. 4, pp. 70–84, Jul. 2005.
- [7] N. B. Priyantha, A. Chakraborty, and H. Balakrishnan, "The cricket location-support system," in *Proc. 6th Annu. Int. Conf. Mobile Comput. Netw.*, Boston, Massachusetts, USA, Aug. 2000, pp. 32–43.
- [8] R. Want, A. Hopper, V. Falcao, and J. Gibbons, "The active badge location system," *ACM Trans. Inf. Syst.* vol.10, pp. 91–102, 1992.
- [9] D. Hauschildt and N. Kirchof, "Improving indoor position estimation by combining active TDOA ultrasound and passive thermal infrared localization," in *Proc. 8th Workshop Position. Navig. Commun.*, Apr. 7–8, 2011, pp. 94–99.
- [10] B. Zhou, Q. Li, Q. Mao, W. Tu, and X. Zhang, "Activity sequence-based indoor pedestrian localization using smartphones," *IEEE Trans. Human-Mach. Syst.*, vol. 45, no. 5, pp. 562–574, Oct. 2015.