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THE USE OF MAGNETIC FIELD AND MAGNETOMETERS IN SUPPORTING THE AIR NAVIGATION

ABSTRACT

At present, the Earth's magnetic field (geomagnetic field) undergoes considerable variations. The use of towers measuring areal variations in magnetic intensity may provide additional support for aircraft navigation. This paper presents the idea of using magnetometers for supporting GNSS as well as for creating a landing system based on magnetic field variations.

Keywords:
magnetic field, air navigation, landing system.

INTRODUCTION

The concept of using magnetic field for navigation without GPS assistance has already been presented at several conferences. Nevertheless, due to the constant and significant variations in the magnetic intensity and the location of the Earth's magnetic poles, as well as numerous magnetic perturbations, so far it has been possible to create a navigation system operating only indoors, using unchanging (in time) values of magnetic intensity. Although WMM (World

Magnetic Model) and IGRF (International Geomagnetic Reference Field) are extremely useful tools for determining the position using the Earth's magnetic field, creating a similar system operating in an outdoor environment is much more complicated because of the much larger surface area to be mapped with regard to local magnetic anomalies.

Extremely important with this respect are the effects of the work performed by I. Shockley and J. F. Racquet from the Air Force Institute of Technology [Shockley and Racquet, 2014]. The effect of their work was the determination of the position using the previously mapped path created by collecting the data from a three axis magnetometer in points with known positions, located at a constant distance. An unquestionable advantage of this type of mapping is excluding velocity as a factor in determining the accuracy of navigation. Making the map in the manner described above reducing the demand for computer memory space taken by the map in relation to the demand for memory space taken by a map made with the standard method. After completing the measurements, the research team started to determine what system would be used to find the locations on the magnetic map. Three methods were implemented, related to the imposition of a filter randomly generating particles (measurements) at a distance of 50 meters from the true position. That was subsequently followed by the determination of the probability of associating the recorded point with the real position. The purpose of that particle filter was to provide divergence required to supplement the map of the magnetic field.

The accuracy of the results which were recorded in the field with the established navigation system were dependent on the technique used for determining the probability and the type of vehicle, terrain, and measurements. For navigation in low-density urban areas RMS error is in the range of 0 to 50m and it is not greater than 20 m throughout 70% of the measurements, whereas the maximum error is 50 m [Shockley and Racquet, 2014]. For illustration purposes, scans of error graphs and the maps indicating the real position of the vehicle and the results of magnetic positioning are presented in Figures 1 and 2.

The results are very promising and they are an inspiration to continue the research into the use of magnetic navigation in aviation. The comparison of error values obtained during the measurements performed in the suburbs of urban areas with those performed within urban areas points to the overwhelming dominance of the latter. Conclusion: shorter distances between the glide path and any buildings mean more magnetic perturbations and will result in greater positioning errors. This means, however, that if a similar system is used for airport ground navigation and the landing approach, these errors will be greatly lower because of the distance between the glide path itself and its vicinity and tall buildings.

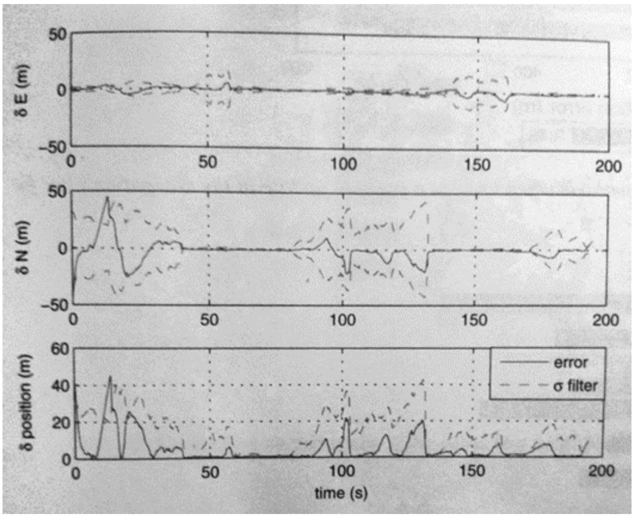

Fig. 1. MagNavigate position errors as compared with the actual vehicle position using the AFIT map [Shockley and Racquet, 2014]

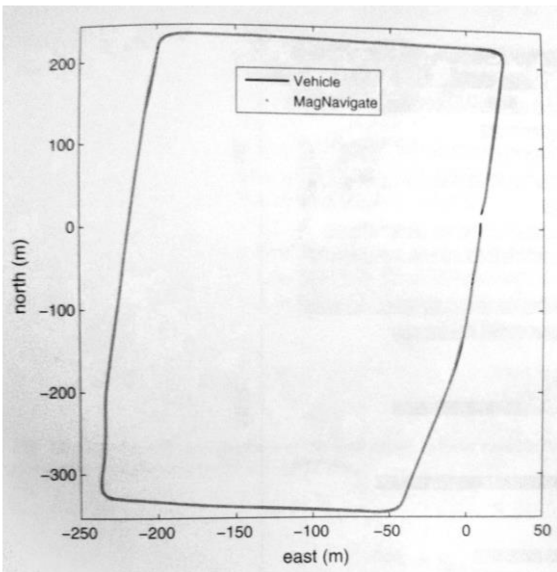

Fig. 2. AFIT map navigation using 1m distance separated magnetometer measurements in the navigation filter [Shockley and Racquet, 2014]

THEORETICAL FOUNDATIONS

Research and mapping of the magnetic field are now common, and various types of magnetometers are used in the mapping. The system which is the simplest, cheapest, and most rapidly becoming widespread is by far the Indooratlas [https://www.indooratlas.com]. This system allows users who have a smartphone application to navigate indoors and it provides positioning accuracy in the range of 2 m to 10 cm using pre-prepared maps of the magnetic field and its perturbations. The user's position on the map obtained from the system is determined by calculations using data received from the magnetometer and the compass in the smartphone. The example described is very accurate in terms of illustrating the point of the article, it relates, nevertheless, to navigation indoors, where weather conditions have virtually no impact on the nature of the magnetic field as opposed to conditions in outdoor environments. Mapping and imaging the magnetic field near the ground accurately reflecting magnetic perturbations by means of both scalar and vector values is also popular and increasingly used not only to conduct research studies, but also, e.g. to detect underground burials, ruins of buildings or other objects.

An interesting example is the study and creation of land characteristics using Overhauser gradiometer (GSM-19T) [http://www.gemsys.ca]. This method is very interesting, as it allows to detect very minor alterations in magnetic field strength. A sample map is presented below.

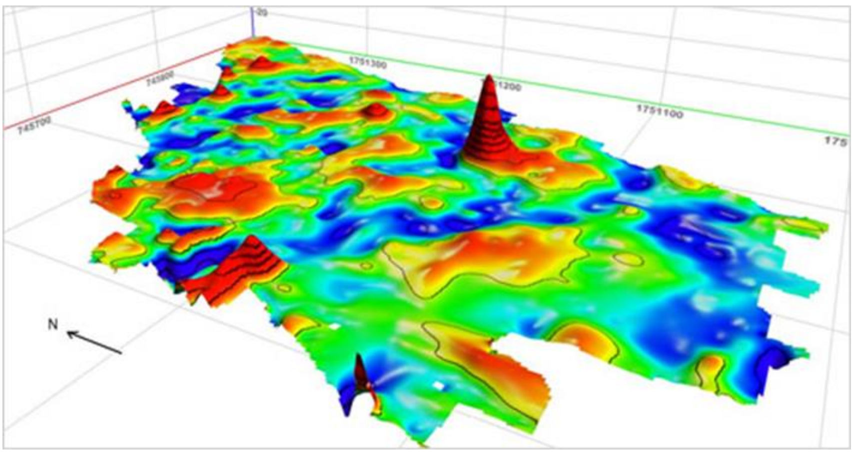

Fig. 3. Map of magnetic anomalies [http://www.gemsys.ca]

Such a map is made by carrying the above-mentioned gradiometer recording the data and with a GPS logger that allows for positioning the data collected, since both the GPS logger and the measuring equipment have defined sampling frequencies. This method, although it is worth basing on, is not the essence of the idea presented in this article but only a part of it.

For use in aviation, it is required to create a three dimensional scalar and vector model of magnetic field pertaining to different altitude ranges. Additionally, one should consider the fact that the measurements and the final appearance of such maps are affected by such weather conditions as humidity, wind and, most of all, ambient temperature because these conditions influence the measuring equipment. Apart from the factors listed, the sense of the current data update at various points is also explained by the presence of storms and lightning, the influence of the atmospheric dynamo and solar wind. Precise and active area navigation for aircraft will be possible after including these factors into the model at the current rate (2–50 Hz).

ASSISTING THE LANDING WITH MAGNETIC NAVIGATION

Currently, three axis magnetometers are relatively cheap and very common, therefore, they can be used to create a system supporting and complementing satellite navigation even at the landing approach. The reason for seeking other means of navigation is the fact that the present systems, ILS, MLS or TACAN are very expensive. It has already been proven that the GPS system with the support of the EGNOS can provide accuracy meeting CAT III ILS requirements [EASA No. 01/2005], [Ogórek, 2014] with regard to a two-phase glide path. Fog and other factors affecting the propagation of radio waves and reducing the positioning accuracy, as well as a large interval between obtaining subsequent positions (1 second) pose a serious problem with regard to assisting the landing with the GPS system. The work of the American researchers, however, presented a different approach to magnetic navigation. It turned out that the accuracy achieved by the creation of one track and supplementing it with a mathematical model allows for effective navigation in outdoor environments. The idea of this section is to propose a study on setting up a system which would assist landing approaches using magnetic field measurements supplemented with the GPS system.

The main issue concerning the creation of such a system is mapping the magnetic field both at the airport and approximately 4 kilometres along the glide path. Taking into consideration the runway width (assumed to be 60 m) and the assumed width of the initial part of the glide path being 200 m, and assuming that the runway length is 2 km, it is necessary to collect magnetic data from the area of 0.64 km^2 (it should be pointed out that the values given above are proposed). It should be noted that in this way the magnetic field will be mapped only near the ground surface. In order to obtain a three-dimensional model of the magnetic field, it is necessary to perform measurements also at a certain height above the ground. As a consequence, drones (UAVs) with measuring equipment may be used in order to perform the initial mapping (under different conditions), and the data should be collected from 6 different altitude levels. This is reasonable due to the lack of knowledge and information on the principles and algorithms governing the magnetic field distribution in the airspace over the certain area.

This solution will allow for processing and updating the current model depending on external factors which could affect the positioning accuracy. Also in this case, it is important that magnetometers should be placed at different altitudes, but only within the glide path. The proposed equipment layout is shown in Figure 4. However, the precision of the model supplemented by the equipment should be examined in order to adjust the distances *a*, *b*, the distance between magnetometers hung on lines, and their positioning in height, taking into account both ergonomics and economics. During system operation, data will be collected from the measuring equipment, and then implemented into the model, where the appropriate corrections will be computed.

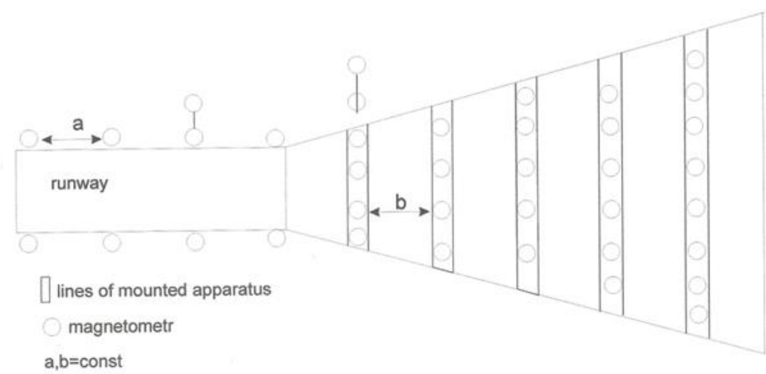

Fig. 4. Schematic layout of the measuring equipment of the system

It is a truism that the system would be too expensive for the data to be transmitted and processed on-board the aircraft. This issue is addressed through equipping airports with software and equipment, allowing for the data processing. In this case, the only requirements for the aircraft manufacturer will be equipping the aircraft with a three-axis magnetometer, and the instruments enabling the reception of the pre-prepared information on the bearings.

The scheme of the system operation is as follows: data collected from the measuring equipment with the frequency established during the tests are sent to the airport system and are subject to the ongoing processing. The aircraft sends the data from its magnetometer and the GNSS device to the system located at the airport and receives assistance in the form of bearings ready to use during the landing. To simplify the calculations and narrow the range of the processed data, the software must take into account the velocity and position of the aircraft, obtained by the implementation of data from the GPS receiver.

An important argument in favour of the validity of using this type of solution is the fact that the aircraft navigation would be conducted on the basis of the environment spatial data (in this case based on the intensity of the Earth's magnetic field and its local perturbations). It should also be noted that the data processed and generated on the basis of the complete model will be both scalar and vector, which will be an additional support in determining the position of the aircraft. The obvious issue is the need to calibrate the three-axis magnetometers in order to reduce possible measurement errors caused by electromagnetic effects generated by other electrical equipment on-board the aircraft and by the aircraft.

Attention should also be paid to the manoeuvre of entering the glide path. When executing this manoeuvre, the distance from the runway threshold, at which the aircraft will begin to receive signals from the vertical beacon, depends to a large extent on the pilot. It should, therefore, be concluded that high precision of positioning is not required for the execution of that manoeuvre. Consequently, it is reasonable to use points with known geographical coordinates for calculating the distance and bearings to these points using data obtained directly from the GNSS receiver. The algorithm for calculating the aforementioned values [Ogórek, 2013] is very complicated and it is suitable for using and processing by additional software applications for on-board computers of an aircraft. Thus, the operation of the described system will be complete, with the current procedures for approach to landing, easy to use by flight crews, and the GNSS system will be used to support and complement the magnetic navigation system, in the execution of both landing approach and landing, and during airport ground navigation.

CONCLUSIONS

The solutions proposed by Shockley and Raquet are interesting for aviation. They set new research directions to create new systems supporting landing under difficult flight conditions. The measurements performed (in 3D) showed that each airport has its own specific characteristics of the magnetic field. The fundamental problem is a thorough examination and developing a map of the magnetic field. The research shows that the results obtained with regard to the accuracy of the glide path, complemented by a mathematical model, allow navigating on the glide path. Linking the magnetic field with the GNSS system will allow the creation of a new system supporting the landing.

To sum up, the research commenced became an inspiration to seek new solutions with the aim of supporting the landing approach by measuring the intensity of the magnetic field in conjunction with GNSS.

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STRESZCZENIE

Pole magnetyczne Ziemi (pole geomagnetyczne) podlega znacznym fluktuacjom. Autorzy założyli, że użycie wież mierzących powierzchniowe zmiany intensywności pola magnetycznego w pobliżu lotniska może dostarczyć dodatkowego wsparcia w nawigacji lotniczej. W artykule przedstawiono nowatorski pomysł zastosowania magnetometrów dla wspierania pomiarów GNSS, jak również dla stworzenia systemu wspomagającego lądowanie opartego na sensorach zmian parametrów pola magnetycznego.