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Measurement of Magnetic Azimuth by Magnetometer and Gyroscope with Implementation of Complementary Filter

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Annotation:
It is possible to measure magnetic azimuth relatively easily with the usage of one magnetometer. However, the precision of the measurement is limited by accuracy of calibration of the used sensor and the uncertainty of the very magnetometer. In order to achieve more precise results, the acquired data from magnetometer can be combined together with data from another sensor. For this purpose it is possible to use appropriate digital filter, e.g. complementary filter. The aim of this article is to introduce method of measuring magnetic azimuth by applying the complementary filter, which is able to improve the accuracy of measurement.

Anotace:
Magnetický azimut je poměrně jednoduché změřit prostřednictvím jednoho magnetometru, avšak přesnost takového měření je omezená přesností kalibrace daného senzoru a jeho nepřesností. Na dosáhnutí přesnějších výsledků měření je možné zkombinovat hodnoty magnetického azimutu z magnetometru s měřeními jiného senzoru, a to pomocí vhodného digitálního filtru. Takovým filtrem je například komplementární filtr. Cílem tohoto článku je proto uvést způsob měření magnetického azimutu s využitím komplementárního filtru, který umožňuje zlepšit přesnost výsledného měření.

INTRODUCTION

Magnetic azimuth can be typically evaluated from the output data of magnetometers. These sensors are able to estimate orientation of cardinal directions from which the tilt from north can be calculated. Their measurement contains errors caused by surrounding hard and soft magnetic materials. Their effect can be eliminated by appropriate calibration and therefore it is an important step in process of measuring magnetic azimuth which cannot be avoided. However, the result of measurement is even after calibration affected by uncertainty of magnetometer itself. Therefore, the output data have to be alternated with other means to achieve more precise results.
Gyroscopes bring solution for mentioned problem. They can measure azimuth that is relative to the starting point of measurement. It is impossible to detect tilt from north from this kind of azimuth by itself. Nevertheless, the measurement by gyroscope can accompany magnetic azimuth obtained by magnetometer and improve overall accuracy. An option how to combine these two azimuths lays within the field of digital filters. Especially useful for this case is linear complementary filter.

THE METHODS OF MEASUREMENT

The Calibration of Magnetometer

The calibration of magnetometer is crucial part of the process of measurement without which the results would not be interpreted correctly. It is necessary to initiate the calibration before the actual measurement. It contains calibration against the impact of hard and soft magnetic materials in the surroundings of the sensor.
During calibration in two-dimensional space, the sensor should be turned around its vertical axis at least 360° and sufficient number of samples need to be taken. If there are no magnetic materials near the sensor, which would interfere with magnetic field of earth, the result of the rotation around axis z has to be a circle with the centre in the origin of coordinate system [1]. Hard magnetic materials in the surroundings of magnetometer cause permanent offset presented as deviation of the circle from the origin. This offset must be quantified and subtracted from the measured data [2]. The soft magnetic materials cause the distortion and warp the circle, which is corrected by multiplication of samples with quantified distortion factor.

The Calibration of Gyroscope

The gyroscopes need to be calibrated before the start of measurement, similarly to magnetometers. When the gyroscope is laid still on the flat surface and no force is applied to it, the output value in every axis should be zero [2]. In reality, the output data provide some value of angular acceleration caused by offset in each of the axis. If this offset would not be removed during calibration, it would cause additional drift of the output data with time.

During calibration the gyroscope should be laid intact on the plain flat surface and sufficient number of data should be collected. The offset can be enumerated from values of the output data for each axis separately. To achieve calibrated output the offset of given axis has to be subtracted from new measured samples in that axis. The same process is applied to all other remaining axes.

The Measurement of Magnetic Azimuth

The magnetic azimuth was measured directly by one calibrated magnetometer. In order to identify the accuracy of measurement done by sensor, the following method of measurement was proposed. The designed device with implemented sensors was set in angles from 0° to 360° with 10° step. The output data was measured in each stop by given sensor. These measured data were mathematically processed and magnetic azimuth was acquired. The values of magnetic azimuth $azimuth_{mag}$ were than plotted depending on the set angle, marked as $azimuth_{set}$, as can be seen in the figure 1 depicted with blue colour.

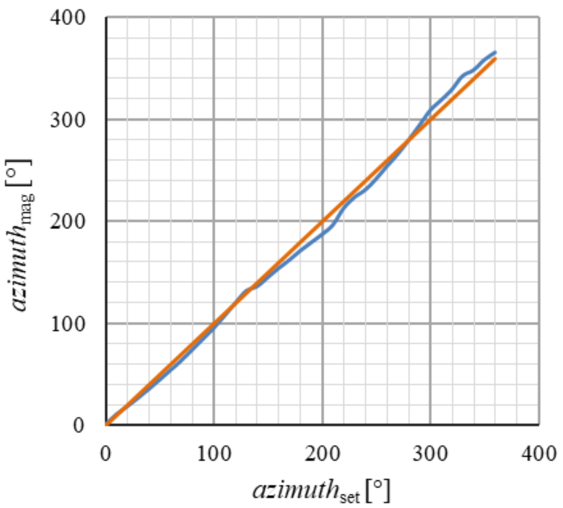

Fig. 1: The magnetic azimuth measured by magnetometer in relation to set angle

Measured magnetic azimuth was compared to ideal theoretical value shown in figure 1 with orange colour. This ideal theoretical value was aimed to be obtained by magnetometer. However, it is visible from the figure 1 that the measured magnetic azimuth $azimuth_{mag}$ deviates from the ideal angles of azimuth, especially in the higher range of set angles.
The measurement of magnetic azimuth can be improved using the measurement of azimuth done by gyroscope. The azimuth from gyroscope is relative to the staring point and does not reflect any relation to north on its own. Nevertheless, the linear complementary filter provides the solution for combining these two measurements.

THE COMPLEMENTARY FILTER

The complementary filter is a type of digital filter. Specifically useful for described type of measurement is linear complementary filter. This filter combines low pass and high pass filter in its structure. Therefore, it is convenient to apply it on sensors with complementary properties, such as magnetometer and gyroscope. Magnetometer has better response with slowly changing signals. On the other hand, gyroscopes tend to measure more precisely with quicker changes. Hence, they have complementary dynamic responses [3]. Mathematical structure of the filter is given as shown in equation 1.

$$\psi_{filt} = \alpha \cdot \psi_{gyro} + (1 - \alpha) \cdot \psi_{mag} \quad (1)$$

The sign ψ_{filt} represents magnetic azimuth acquired from the mathematical application of the filter, α is a weighting factor with value in the range <0; 1>, ψ_{gyro} is the angle of azimuth received from gyroscope and ψ_{mag} stands for magnetic azimuth measured by the magnetometer.
The measurement of magnetic azimuth after application of the linear complementary filter was executed the same way as in measuring with magnetometer alone. The device was set in angles from 0° to 360° with 10° steps in which the magnetic azimuth was obtained. The values of magnetic azimuth $azimuth_{filt}$ in relation to set azimuth, labeled $azimuth_{set}$, is displayed with blue colour in figure 2. The values shown with orange colour are again ideal theoretical values of magnetic azimuth, which were aimed to be obtained by the measurement.

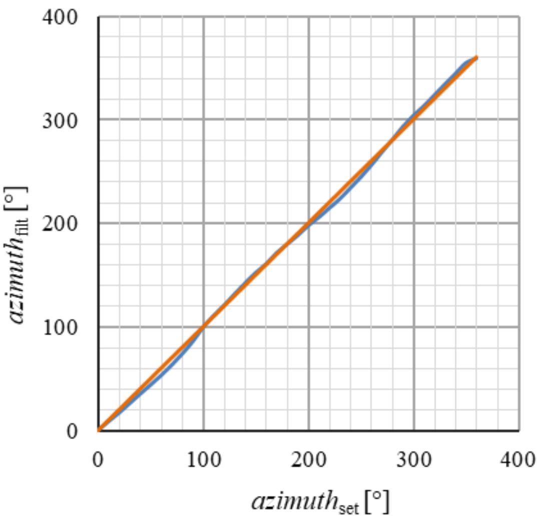

Fig. 2: The magnetic azimuth measured by magnetometer and gyroscope after application of the linear complementary filter in relation to set angle

It is evident from the figure 2 that values of measured magnetic azimuth after application of the filter follow closely ideal values. Overall, the magnetic azimuth values are similar to theoretical values and they repeatedly overlap. This can be compared to values of magnetic azimuth done by magnetometer alone from the figure 1. The angles of magnetic azimuth marked $azimuth_{mag}$ deviate from ideal azimuth by bigger differences. This proves that linear complementary filter improved the accuracy of the measurement of magnetic azimuth.

CONCLUSION

In conclusion, this paper proposed the different approach for measuring magnetic azimuth and an improvement of the accuracy of this kind of measurement. The magnetic azimuth can be simply measured using magnetometer alone, but the presented approach with the usage of complementary filter allows to obtain results that are closer to the theoretical magnetic azimuth. The application of linear complementary filter allows to improve accuracy of azimuth measurement by detecting slowly and also quickly changing signals. Therefore, the addition of output from gyroscope to the data gained from magnetometer helps to increase overall precision of measurement.

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