DOI 10.5162/SMSI2020/A1.1

Analytic Method for Magnetic Position System Calibration

Michael Ortner[1], Perla Malagò[1], Stefano Lumetti[1], Dietmar Spitzer[2], Sigmund Zaruba [3]
[1] Silicon Austria Labs, Europastraße 12, 9500 Villach, Austria
[2] Infineon Technologies Austria, Siemensstraße 2, 9500 Villach, Austria
[3] Infineon Technologies AG, Am Campeon 1-15, 85579 Neubiberg, Deutschland
michael.ortner@silicon-austria.com

Summary:

The greatest shortcoming of magnetic position sensor systems is their sensitivity to fabrication tolerances. In this work, we propose a novel calibration scheme based on evolutionary optimization and the analytic solution for the magnetic field. This method allows us to calibrate more than 10 degrees of freedom in the course of seconds with little computation requirements, and realize a complex, novel position system by simple means.

Keywords: Magnetic system design, analytic method, magnetic position sensor systems

Introduction and Background

Magnetic position sensor systems are based on the relative motion of a permanent magnet with respect to a magnetic field sensor. Such systems are widely used for industrial applications due to their excellent properties [1]. In the automotive sector alone there are more than 100 applications that include gear position, steering wheel, gas- and brake pedals, wheel speed, window lifter and many others [2].

Recently, a novel magnetic system was proposed for the detection of the motion of a 3-axis joystick by means of a single sensor and a single magnet only [3]. This highly cost-efficient implementation is now called "MJ113". A realization with 5 discrete tilt states is displayed in Fig.1(a). In Fig.1(b) the magnetic field at the sensor position is shown for a 360° rotation for each tilt. In this implementation, the circular paths in the magnetic space are well-separated from each other by >10 mT.

Problem and Motivation

The major drawback of all magnetic position systems is their difficulty to deal with fabrication tolerances. In this respect the MJ113 is no exception as revealed by the experimental analysis shown in Fig.2, where the sensor outputs of 15 similar systems (colored dots) are displayed together with the corresponding theoretical predictions (solid lines).

A precision fabrication of the MJ113 would nullify the cost-efficiency which is its main advantage. In this work we show that it is possible to realize such a system by relying on simple experimental means and on a novel calibration scheme based on analytical methods.

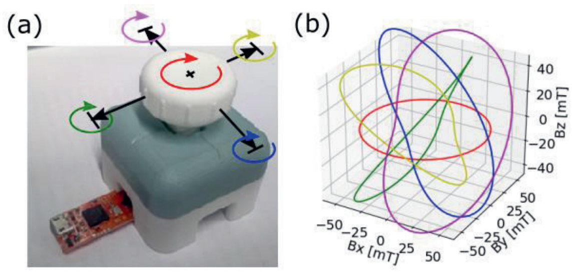

Fig. 1. Mechanical 3-axis motion and resulting field at the sensor.

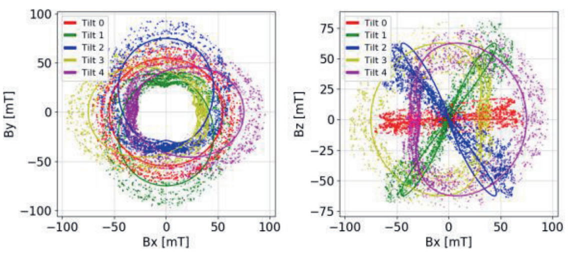

Fig. 2. Experimental analysis of 15 similar systems.

Experimental Setup

The experimental implementation is based on cost-efficient 3D-printing technology. The final device, shown in Fig.1(a), includes a test board of the Infineon XMC 2Go type endowed with a TLE493D 3D-magnetic field sensor. In our implementation choice, a Neodymium (Br~1T) cubical permanent magnet with 4-mm sides is embedded at the bottom of the joystick's rod. The airgap is 2 mm, the distance from the center of tilt is 7 mm and the magnet sideways displacement is 2 mm in accordance with [3].

The experimental data in Fig.2 is obtained by tracking the sensor output while rotating the joystick knob in the five discrete tilt positions, as indicated in Fig.1(a).

Calibration Scheme

State-of-the-art systems approximate the field in a simple manner, e.g. by an arctangent function, and compensate for the tolerances in an end-of-the-line process. This method is limited by the simple form of the field approximation and cannot account for multiple tolerances in a complex system like the MJ113.

Instead, we propose to use the full solution for the magnetic field and perform the calibration as a multivariate optimization problem which includes all relevant system tolerances. Such an optimization is impossible when slow numerical methods are used for field computation.

We have shown that the analytic solution provides an excellent approximation in this case, with errors below 0.1 % [4]. Specifically, for special geometries like cuboids the formulas are simple and compute in microseconds on common CPUs [5].

For the computation of the magnetic field we use the Magpylib package [5] and for the optimization we apply a differential evolution algorithm [6]. This combination is very synergetic as the vectorized code of Magpylib employs SIMD operations while the differential evolution algorithm parallelizes the computation of each generation. Thereby, 13 co-dependent calibration variables can be determined in only a few seconds on a mobile CPU (i5-8365U). The chosen tolerances include the sensor position, the magnet position and magnetization as well as the individual tilt end-point angles.

As input data of the calibration procedure we use only four points on each circle and minimize the square of their distance to the theoretical circles by variation of the tolerances. The calibration points can be obtained experimentally by a user with little effort.

Results and Discussion

The result of the calibration procedure is shown in Fig.3. For each tilt, 50 random positions on the circles are chosen, and their distance to the designated theoretical values are displayed in units of LSB (~0.1mT). The circular markers show the calibrated states while the crosses correspond to the uncalibrated ones. The orange region outlines the nearest false tilt states, while the gray region corresponds to the best possible result from a full calibration which includes all 5x50 experimental data points.

Clearly, the system is unusable in its uncalibrated state (bad tilt circles are closer than the designated ones) while the 4-point calibration makes an identification of the correct tilt state possible. Still it seems that the calibrated states can be quite far from their designated circles, see e.g. yellow peaks. However, this is a result of the cheap mechanics and the user moving the joystick by hand to collect the data, as can also be seen by looking at the full calibration where all data points are used in the calibration. From that point of view, the 4-point calibration is surprisingly efficient as the best possible result is mostly achieved.

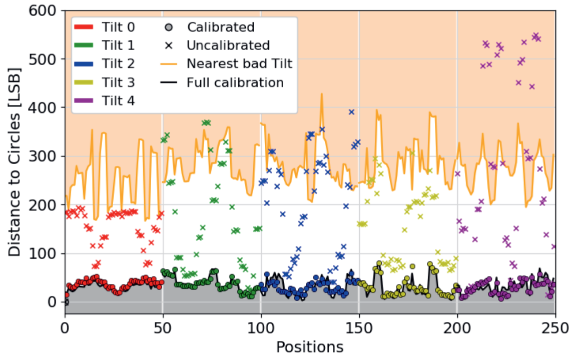

Fig. 3. Results of the 4-point calibration procedure.

Conclusion and Outlook

We have proposed a novel calibration method that makes it possible to deal with multiple fabrication tolerances in magnetic systems within short time frames and with little computation effort. For demonstration, the algorithm was applied for the calibration of a novel magnetic joystick realized by cost-efficient 3D printing.

Ongoing work is dedicated to study the potential of this method for calibration and design of arbitrary magnetic systems.

References

[1] Treutler, C. P. O. "Magnetic sensors for automotive applications." Sensors and Actuators A: Physical 91.1-2 (2001): 2-6.

[2] Infineon Technologies AG, “XENSIV – Sensing the world”, Product catalog, B142-I0675-V2-7600-EU-EC-P, 06, (2019)

[3] Ermakova, A. et al. "Analytical Development of a Four-Axis Magnetic Multimedia Control Element." IEEE Sensors Journal 18.19 (2018): 7819-7825.

[4] Malagò, P. et al. “Magnetic system design by analytic computation”, in preparation, 2020.

[5] Ortner, M. et al. “Magpylib – A free Python package for computation of magnetic fields”, submitted to SoftwareX, Elsevier, 01/2020.

[6] Storn, R. "On the usage of differential evolution for function optimization." Proceedings of North American Fuzzy Information Processing. IEEE, 1996.