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Modular Spherical Magnetic Field Sensor Array

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Abstract

The characterization of magnetic field properties is an important task in magnetic imaging modalities. Emerging multi-coil field generator topologies, generating the gradient field in magnetic particle imaging, pose new challenges. If multiple coils are active, obtaining the current to field relation is not trivial, due to cross-coupling and cross-saturation effects. Singular measurements at certain operating points are not sufficient for a full system description in these non-linear systems. In this work, an adaptable measurement prototype which utilizes multiple magnetic field sensors is presented. The developed device consists of three-axis Hall-sensor ICs located on a spherical surface. Utilizing the solid spherical harmonic expansions the field inside the sphere can be approximated. The combination of high measurement accuracy, straightforward measurement procedures, and modularity enables rapid and reliable measurements.

I. Introduction

Characterizing the selection and focus field generator (SeFo) is crucial to avoid artifacts in image reconstruction. Especially in systems like a multi-coil SeFo, which are currently being implemented, this is a challenging task [1]. Such multi-coil iron core systems face challenges due to coil coupling, cross magnetization, and cross saturation [2]. Non-linearities in the current to field relation and field distortions from manufacturing tolerances or saturation effects can cause discrepancies between simulated and actual field. A comprehensive set of measurements at various operating points is needed to fully characterize this multi-coil SeFo. This in-depth field characterization can be used as prior knowledge for image artifact reduction [3]. Utilizing the solid spherical harmonic expansions, a reliable and fast modular three dimensional spherical magnetic field sensor array prototype was build [4]. A first non modular spherical sensor using the same principle was previously shown [5].

II. Methods and materials

The small scale prototype consists of 37 three-axis Hall-sensors (TMAG5170A2, Texas Instruments Inc., USA), which offer a measurement range of up to 300 mT. 36 of these sensors, fitted on corresponding circuit boards, are placed on a spherical surface in a t-design (t=8) [4]. The 37th sensor, located in the centre of the sphere, enables verification by comparing the measured to the approximated field value. A mount for the sensor boards with corresponding recesses was developed and additively

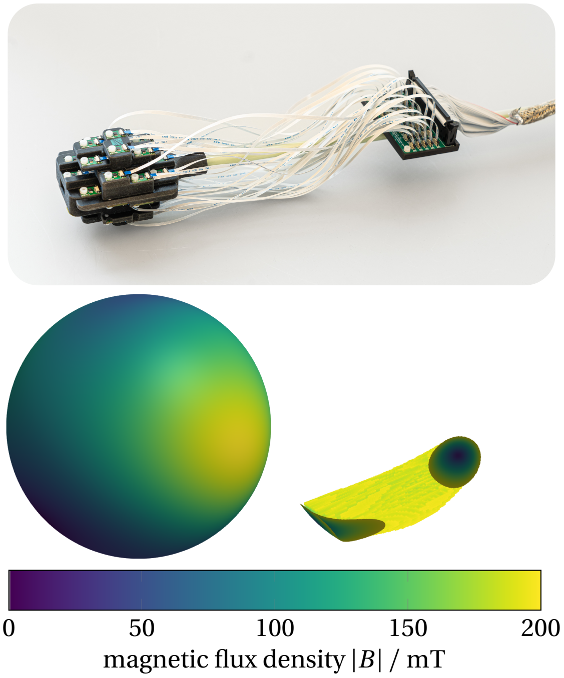

Figure 1: Manufactured sensor array (top), approximated magnetic flux density on the surface of the spherical sensor (left) and FFL with a flux density below 20mT (right).

manufactured featuring a maximum outer diameter of 82 mm, see Figure 1. Each sensor has a maximum displacement of 0.6 mm [6]. The communication with the sensors is realised by using a microcontroller board (Arduino Due, Arduino s.r.l., IT). The host computer can communicate with the Arduino via a serial interface. A Julia script was developed to initialize the device, verify each sensor, perform the measurement as well as store and show the measured field data.

III. Experiments

Preliminary tests of the used sensors include measurement and correction of magnetic offsets, linearity measurements and accuracy comparison to a commercial Hall-probe in a Helmholtz coil setup. The influence of temperature change and also repeatability of measurement was verified via recurring tests. The speed-up of the measurement process was evaluated by comparison with a conventional three-axis robot approach, which moves a Hall-probe mechanically to the 36 positions on a sphere. The full sensor array was tested by comparing the measured field of the central sensor with the approximated field inside of a Field Free Line (FFL) demonstrator. For this measurement the sensor array was positioned off-centred to the FFL.

IV. Results and Discussion

The tests demonstrated the full functionality of the measuring device and the accuracy of the approximated fields. Noticeable deviations occurred only in the comparison with the Hall-probe, likely due to positioning errors between the sensor IC and the probe. The sensor IC is mounted on a 3D-printed structure, while the probe was held manually, leading to location inaccuracies. The approximated field values are illustrated in Figure 1 (left), with a distinct approximation of the FFL for field values below 20 mT depicted in Figure 1 (right). The absolute discrepancy between the approximated value and the value measured by the central sensor in the FFL demonstrator is 0.855 mT (1.51 %).
The proposed measurement device achieved a measurement speed of approximately ~0.8 s, a considerable improvement over the 258 s required by the conventional setup.

V. Conclusion

The presented modular sensor array is able to approximate the magnetic flux density inside its spherical surface by using the solid spherical harmonics expansions at a much higher rate than the conventional setup. The FFL of the demonstrator device was successfully reconstructed and verified by the additional sensor located in the middle of the sphere. To measure a comprehensive dataset for modelling SeFo behaviour a higher readout speed is still desirable. The modularity enables expansion to various sizes, but also allows for designs with a higher count of sensors for an approximation with higher accuracy.

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Author's statement

Conflict of interest: Authors state no conflict of interest.

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