Three-axis Joystick as Stray Field Robust Magnetic Position System

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Summary: It was demonstrated that a specific arrangement of magnet and single 3D magnetic field sensor can effectively resolve the motion of a three-axis joystick. However, the proposed configuration lacks robustness against stray magnetic fields. Building on the original concept, this work explores the feasibility of achieving stray field immunity through differential measurement techniques. Our findings show that while a stray field robust design is attainable, it imposes stringent requirements on system design and sensor arrangement to ensure reliable operation under varying magnetic conditions.

Keywords: Magnetic position systems, Magnetic sensors, Magnetic field simulation, Magnetic system design,

Background, Motivation, and Objective

Magnetic position systems leverage magnetic fields from permanent magnets to translate relative physical position into electrical signals using magnetic field sensors [1]. Unlike mechanical or optical alternatives, magnetic systems operate contact-free and resist environmental factors like dirt and temperature variations, which enhances their reliability in industrial applications. [2]. Recent advancements include multidimensional sensing like three-axis joysticks [3] or six degrees of freedom systems [4].

In [3] Malagó et al. propose a design method for magnetic position systems based on geometric optimization, utilizing a differential evolution algorithm that relies on fast analytical solutions for magnetic field simulation. This method is applied to tracking three-axis joystick motion using only a single 3D magnetic field sensor. This solution provides a cost-effective, high-resolution option for three-axis joysticks and ball-joint motion tracking for applications that include gaming controls in simulators, steering in nautical and aerospace fields, robotic joint motion tracking, as well as mechanical systems like steering knuckles and multimedia control elements like the BMW iDrive.

However, the system proposed by Malagó et al. lacks stray field stability, meaning that small variations from external magnetic fields can lead to inaccurate position measurements. Robust designs, such as those in [5], ensure consistent performance, which is essential for safety and precision in industrial applications. The authors argue that a well-designed system can achieve a state separation of more than 1 mT per degree, offering significant robustness. However, industry standards like ISO 26262 [6] account for stray fields as high as 5 mT, posing a considerable challenge for maintaining measurement ac-curacy in compliant systems.

In this work, we build upon the system and simulation methods developed in [2] to design a stray-field-stable three-axis joystick by applying a differential measurement principle.

Methodology

Stray field robustness through differential measurement uses pairs of strategically positioned sensors to cancel a homogeneous external magnetic field by measuring the difference in their readings. This approach isolates the target magnetic signal, focusing on variations caused by the magnet rather than environmental interference, thus enhancing accuracy without complex shielding.

Analytical solutions are crucial to the magnetic system design approach proposed in [3], as they provide extremely fast computations of magnetic fields of permanent magnets. This allows the application of genetic algorithms in design spaces with dozens of variables, facilitating the discovery of novel solutions and optimal layouts. This design approach is implemented using the Magpylib Python package [7], which provides vectorized analytical solutions for rapid and efficient magnetic field computations.

The chosen system design parameters include the position and orientation of the magnet mounted on the joystick axis, as well as the position and orientation of the sensor with an airgap of 2 mm. Off-the shelf magnet sizes and cubical geometries with sides between 2 mm and 5 mm are chosen, with typical rare earth material with a polarization of 1 T. The sensor itself contains two 3D sensing elements (pixels) spaced realistically between 1 mm and 3 mm apart to allow integration of the differential sensing principle within a single sensor unit. For practical reasons related to PCB fabrication, two layout types are selected:
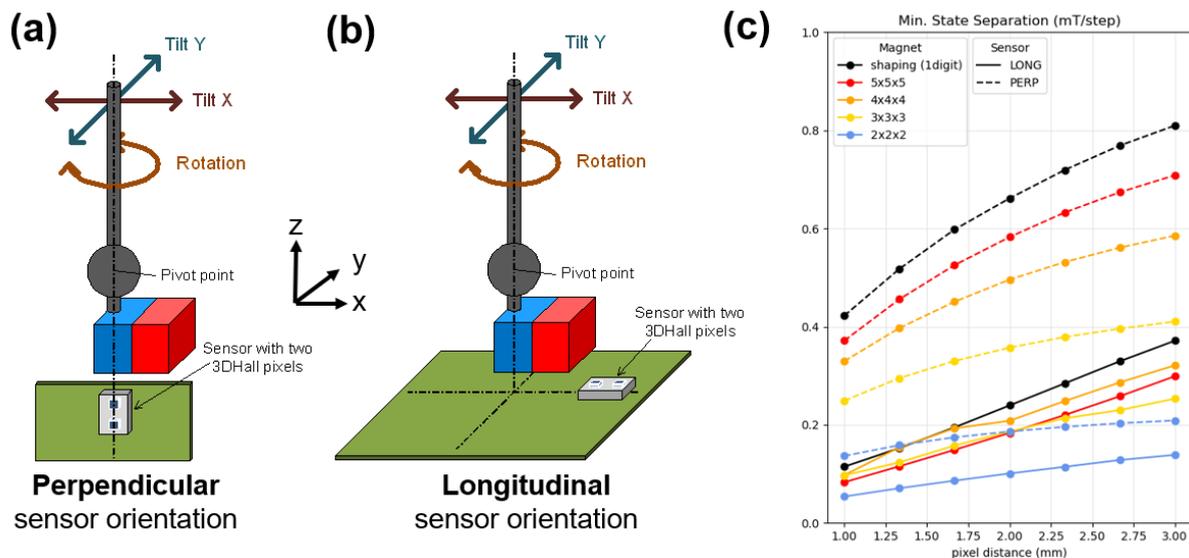
Fig. 1: Design layouts satisfying the design constraints (a) and (b). Simulation results (c).

the perpendicular layout, where the sensor pixels are aligned along the z-axis (Fig. 1a), and the longitudinal layout, where the two sensor pixels lie in the same x-y plane (Fig. 1b).

Results

Simulations confirm that a differential setup is possible for the three-axis joystick. As with the original single-pixel design, strict design constraints apply: the magnet must be mounted on the axis with an offset from the center, and its magnetization must be oriented perpendicular to both the displacement and the axis.

The perpendicular configuration is most effective when the sensor is positioned directly on the z-axis. Here, the second pixel is placed at a larger air gap, receiving significantly less magnetic field from the magnet and thus primarily serving to "measure the stray field". The longitudinal setup, however, is more challenging to implement. This setup requires the sensor to be laterally displaced beyond the magnet itself, with the pixels aligned radially. The two schemes are sketched in Fig. 1 (a) and (b).

Simulation results for optimal designs are presented in Fig. 1 (c), showing the minimum state separation in millitesla per degree of joystick tilt/rotation (step) for various magnet sizes and tilt angles up to 20°. As anticipated, state separation improves with greater inter-pixel distance. Perpendicular setups demonstrate significantly larger state separation, suggesting they are better suited for sensing applications.

Conclusion and Outlook

We have demonstrated that stray-field-stable magnetic detection of three-axis joystick motion is feasible using magnetic field sensors with dual 3D sensing elements. Simulations reveal that achieving a one-to-one correspondence between magnetic field states and joystick degrees of freedom imposes strict requirements on magnet and sensor arrangement, with perpendicular alignment generally yielding better results. The sensor-magnet configurations developed in this work are patented by Infineon Technologies AG.

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