Traceable and Reproducible 3D Magnetic Field Mapping for Data-Driven Magnetic Drug Targeting

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Abstract

Background: Magnetic Drug Targeting (MDT) aims to localise drugs while minimising systemic toxicity in vascular disease, localised tumours, and site-specific inflammatory conditions. MDT safety and efficacy depend on accurate three-dimensional magnetic-field distributions and gradients governing particle transport, capture efficiency, and off-target exposure. Automated three-dimensional field mapping is often affected by motion-related uncertainties—such as scale errors, drift, misalignment, and load effects—leading to non-deterministic datasets and biased gradients that limit data reuse, interoperability, and reproducibility. *Objective*: To develop and describe an automated three-dimensional magnetic-field mapping infrastructure serving as a data acquisition and quality-assurance layer for MDT medical informatics workflows, delivering traceable, reproducible, analysis-ready magnetic-field inputs integrable into computational modelling, digital twin frameworks, and data-driven decision support systems. *Methods*: The workflow implements controlled, high-accuracy three-dimensional magnetic-field acquisition through coordinated motion control, optical referencing, and calibration under operational load. Laser-assisted positioning establishes repeatable spatial registration between the magnetic source and the field sensor, while automated motion execution ensures deterministic sampling over a predefined grid. Motion integrity is monitored through closed-loop feedback to detect scale deviations, tracking errors, and mechanical drift. Prior to acquisition, axis scaling and alignment are calibrated using optical reference markers to compensate for load-dependent uncertainties. Magnetic-field values are acquired at each sampling node via automated optical digitisation of a calibrated digital teslameter, followed by confidence scoring, unit normalisation, and structured logging to ensure traceability. *Results*: The workflow produces consistent, reproducible volumetric magnetic-field datasets enriched with provenance metadata and systematic quality-control indicators at acquisition. These datasets are suitable for downstream computational analysis and modelling. *Conclusions*: Data derived from the mapping infrastructure enable the training of deep learning surrogate models that approximate the relationships between magnet position, orientation, and magnetic-field distribution. Such proxy predictors reduce the need for repeated measurement campaigns, supporting efficient estimation of magnetic-field distributions and gradients for data-driven MDT applications.

Keywords: Medical informatics; Magnetic drug targeting; Reproducible measurements; Magnetic field mapping; Data quality; Experimental standardization.