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Uncertainty estimation in magnetic field inference

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Many physical problems are governed by Laplace's equation, to which there exists a unique solution when boundary constraints are fully defined. However, given only partial knowledge or discrete observation along a boundary, statistical methods are required to construct uncertainty estimates and likelihoods for possible solutions.
Within magnetism, obtaining the magnetic field or the magnetic scalar potential, $\Delta\phi = 0$, from incomplete boundary information is of fundamental interest for instance in robotics navigation and geophysics when estimating the geomagnetic field on the Earth's surface.

Here we propose and demonstrate new statistical methods for estimating the magnetic scalar potential from an incomplete boundary-value problem: (1) By using Gaussian Processes (GP) or (2) by an ensemble of physics-informed neural networks (PINNs). Using either we obtain statistical information for the complete boundary. This information is then used to efficiently construct the statistical solutions using a basis of harmonic functions for the magnetic scalar potential, such that this is guaranteed to be physically correct, i.e. obey Maxwell' s equations.

We show that the obtained uncertainty estimates using the above two methods compare well to the ones obtained from Hamiltonian Monte Carlo (HMC) simulations, which extensively investigate the target probability distribution for all valid magnetic scalar potential matching given knowledge.
Further, we qualitatively verify that the uncertainty estimates are correct, i.e., being confident where boundary values are given while being uncertain far away from observations points.
This allows for improved subsequent decision-making with the found statistical solutions to Laplace's equation, e.g., where to measure next when only limited amount of resources is available.

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