Fast, Accurate and Reliable Identification of Hidden Conductive Objects with Deterministic and Stochastic Methods

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Abstract. The identification of a conductive object known in shape but hidden by low- or non-conductive material is a special application of non-destructive eddy current testing.
To find the positioning and orientation parameters of an object from the magnetic flux densities measured in a distance of several centimeters, a non-linear inverse problem has to be solved. This can be done by deterministic as well as stochastic optimization methods in principle. In order to fulfill all demands on the identification process, that are high accuracy, reliability and low computation time, a combination of a deterministic and a stochastic method is useful and was therefore applied to the problem at hand.

1 Introduction

Figure 1 shows the principle of the configuration for measuring eddy current effects at an object to sensor distance in the range of 3 cm. A time harmonic excitation field is produced by two opposed saddle coils. The device under test is a copper ring, whose position (*x, y* and *z*) and orientation (angles ϑ and φ) have to be identified. Giant magneto resistance (GMR) sensors are used to measure the magnetic flux densities in some field points. 8 GMR sensors are positioned on a circularly shaped circuit board inside the saddle coil configuration. To improve the spatial resolution, three sensors layers are positioned along the y-axis.

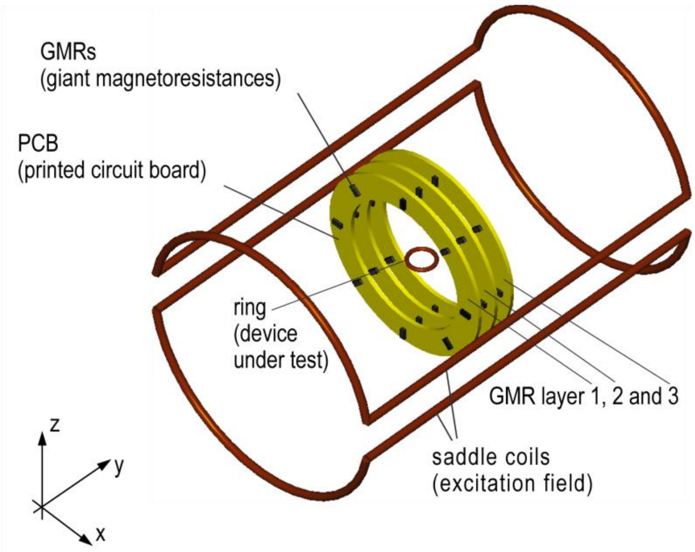

Figure 1: Measurement Configuration.

The forward problem is solved numerically using a 3D finite element model and applying the $\mathbf{A}, V - \phi$ formulation [1].

2 Inverse Problem

Solving the inverse problem of the eddy current application at hand means to find the positioning and angle parameters **p** of the object by measuring the magnetic flux densities

B in some field points. Therefore, the residual between the noisy measurement data vector $\mathbf{B}^{\delta}$ and the forward problem solution vector **B**(**p**) for a certain parameter configuration **p** has to be minimized. Deterministic as well as stochastic methods can be used in principle. While deterministic methods are commonly faster, stochastic methods work more globally and reliable. Since a fast, accurate and reliable algorithm is required, the advantages of both methods can be combined or the disadvantages eliminated, respectively, by applying a hybrid optimization method.

An appropriate **deterministic method** to solve a non-linear, ill-posed inverse problem is the Iteratively Regularized Gauss-Newton (IRGN) algorithm [2]. The IRGN method was applied to the problem at hand and it was found out that the method is fast and accurate but not reliable (10-20% fail to converge to the true solution) .

Another possibility to solve an inverse problem is to apply a **stochastic method**, e.g. a $(\mu/\rho, \lambda)$ Evolution Strategy (ES) [3]. With this method a reliable and accurate solution is reachable but the convergence speed is very low.

Therefore, a **hybrid algorithm** was found to eliminate the drawback of each method. Since starting values which are far away from the true values are the main reason for failure using the IRGN, a pre-Evolution Strategy (pre-ES) is performed first to provide good initial values for the very fast and accurate IRGN. In very few cases the angle parameters are not well identified within the IRGN sequence (the angle sensitivities are much smaller), thus, a post-ES is started to improve these results. 100% of all tested samples (different parameter configurations to be identified) were identified with this hybrid method. Figure 2 shows the characteristic parameter behaviour of the most frequent sequence "pre-ES – IRGN" of the hybrid identification method.

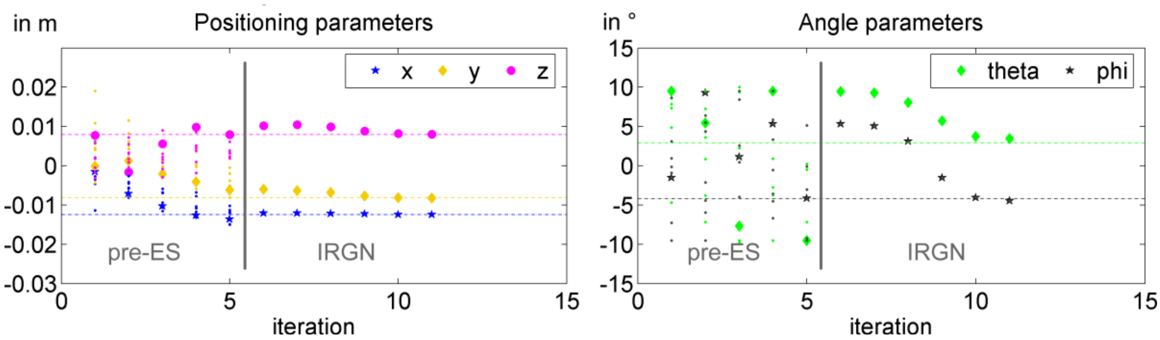

Figure 2: Characteristic Parameter Behaviour of the Hybrid Identification Method. A post-ES was not needed in this case since the residual level was reached within the "pre-ES – IRGN" sequence.

3 Conclusion

A hybrid method, combining stochastic and deterministic optimization algorithms, was developed to solve the current inverse problem, i.e. identifying a hidden conductive 3D object. First results show that it is possible to identify the positioning and angle parameters of the object precisely, reliable and with a sufficient small number of function calls.

References

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