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Real-time Characterization of Inductive Position Sensors

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Summary:
We propose a fast method to characterize inductive position sensors with zero physical prototypes. The technique is based on an in-house developed electromagnetic simulation tool which shows three orders of magnitude improvement with respect to the most widely used commercial software. This simulation software is used for producing synthetic data for training a machine learning surrogate model based on a neural network. In this way the characterization of a sensor takes just milliseconds.

Keywords: encoders, resolvers, inductive position sensors, electromagnetic simulation, machine learning

Introduction

Inductive position sensors (IPS) perform linear or angular position measurements [1-2]. Being contactless, low cost and immune to external magnetic field, dust and liquids they are preferred in those applications where the position measurements are performed in harsh environment. Furthermore, since the measured position derives from a ratiometric measurement they can operate in different thermal conditions.

An IPS consists of a transmitter (TX) coil (see Fig. 1) which, being driven by an alternate current, establishes a variable magnetic field inside the sensor. In this region two receiver coils RXsin and RXcos (see Fig. 1) measure induced voltages U_RXsin and U_RXcos.

When a conductive target is positioned above the sensor, eddy currents are generated inside it. These eddy currents shield the magnetic flux in such a way that the induced voltage on the RX coils depend on the target position with a sine and cosine spatial variation. The position of the target can be determined thanks the following formula

$$\theta_{mis} = atan\left(\frac{U_{rxsin}(\theta)}{U_{rxcos}(\theta)}\right). \quad (1)$$

The main drawback of this type of sensors is that the linearity error in many cases can be too high. Hence, the prediction of this error by means of a simulation tool is of paramount importance for its characterization. In fact, in this way the linearity error can be estimated without realizing a physical prototype at all, saving time and resources.

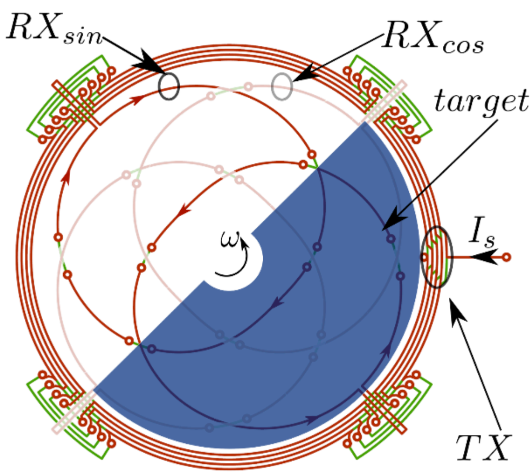

Fig. 1. An example of rotary inductive position sensor. The target is represented in blue.

Simulation tool

For the virtual prototyping of the sensor, there is the need to solve many eddy current problems by varying the position of the target (see Fig. 2). If Finite Elements tools are used, as implemented in most commercial software, the simulation speed is poor. In particular, when the target is moved, both the mesh and the simulation have to be recomputed from scratch.

A different strategy for IPS simulation uses the *surface integral method*. The main advantage of such a method is that only the conductors are meshed, whereas the insulators are not. Thus, this method is very efficient especially for modeling eddy currents with moving conductors since the remeshing is not needed.

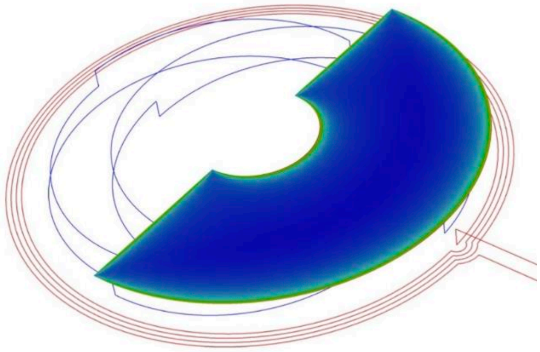

Fig. 2. Example of the simulated sensor with the surface integral method.

The surface integral method is not widely used because the produced matrix is full and its entries are difficult to compute accurately because their computation involves the evaluation of a singular integral. The use of surface integral method for inductive position sensors has been introduced in [3-4].

In this paper we propose a new method called SUPERO, which builds around novel basis functions recently introduced in [5] for a volume integral method. In place of using the standard Rao-Wilton-Glisson (RWG) or Raviart-Thomas basis functions, we designed new basis functions tailored for the surface integral method, which enable a very efficient and accurate construction of the system matrix. Moreover, the full matrix can be sparsified obtaining unprecedented simulation speed.

The results provided by SUPERO are very accurate and can be obtained 2500 faster than the most widely used commercial software.

Surrogate model

With the new tool SUPERO, the simulation of 101 positions of an inductive position sensor can be performed in about 30 seconds, in place of roughly 24 hours needed with a FEM software. Still, 30 seconds to assess the linearity error of a sensor are not acceptable for many applications we have in mind.

For this reason, we exploit the fast simulation tool SUPERO to produce many artificial data to be used for training a supervised machine learning method. The aim is to obtain a surrogate model which can estimate the error of a configuration in milliseconds.

Three methods to build the surrogate model will be compared:

1. Support vector machine (SVM);
2. Gaussian processes regression (GPR);
3. Neural network (NN).

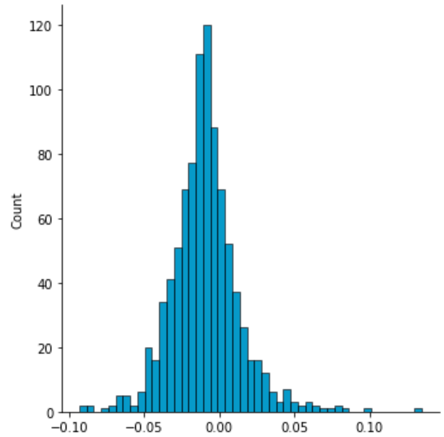

Fig. 3. Distribution of the discrepancy between the sensor linearity error provided by the simulation and the simulation error provided by the surrogate model based on a 3-layer neural network.

Results

We used 5 design variables: maximal radius of the TX coil, minimum and maximum radius of the RX coils, minimum and maximum radius of the target. 3000 designs have been used for training and 1000 for testing. The method that provides the best results both in terms of training and prediction time and forecasting accuracy is the neural network model (see Fig. 3).

Conclusions

By using the surrogate model, the characterization of the error of an inductive position sensor can be performed in milliseconds. This opens new possibilities of devising novel design support systems to guide the user in the design of the sensor.

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