

Simulation-Driven Machine Learning for Position Estimation in Novel PCB-Based Tilt-Inductive Position Sensors

Antonino Vacalebri
DPIA, EMCLab
University of Udine
Udine, Italy
vacalebri.antonino@spes.uniud.it

Francesco Campagna
DPIA, EMCLab
University of Udine
Udine, Italy
campagna.francesco@spes.uniud.it

Ruben Specogna
DPIA, EMCLab
University of Udine
Udine, Italy
ruben.specogna@uniud.it

Abstract—PCB-based Inductive Position Sensors (IPS) are advantageous with respect to resistive, capacitive or Hall-effect alternatives since they allow for contactless sensors that are immune to stray fields and robust to temperature changes, all while being easy to manufacture by using conventional PCB fabrication techniques. In this work we present a novel IPS design for measuring the angle of a target conductor with respect to the sensing coils, and the distance between them. Simulations are used to build a dataset for training a neural network to solve the inverse problem of estimating tilt and airgap from the measured voltages. The trained network is tested against experimental data measured from a physical prototype.

Index Terms—inductive position sensors, surface integral method, neural networks, eddy currents, PCB

I. INTRODUCTION

PCB-based Inductive Position Sensors allow for contactless sensor designs, immune to stray fields and robust to temperature changes [1]. Being based on printed coils also allows for ease of manufacturing via standard PCB fabrication techniques. This makes them suited, for example, for the automotive industry [2], [3].

In this work we present a sensor design that allows for the measurement of the tilt angle between the sensor coils and a conductive target and their distance, that we will call *airgap*. The design of the coil shapes of this sensor was made by means of simulations through an in-house solver that uses a surface integral method for fast solving eddy current problems [4]. This formulation has two main advantages with respect to standard Finite Element (FE) approaches: only the conductor regions need to be meshed (i.e. the target), and there is no need to re-mesh the domain for different target positions. This results in orders of magnitude improvement in computation time.

The idea presented in this paper is to use this fast simulator also to build a dataset to be used in the training of a machine learning algorithm for solving the inverse problem of estimating the real tilt and airgap from measurements taken

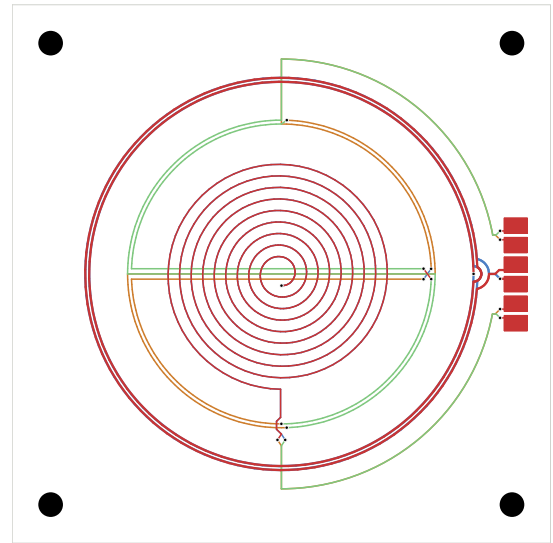


Fig. 1. Four layers PCB containing the TX coil (outermost red coil), RX1 coil (green and orange) and RX2 coil (innermost red coil).

from the sensor coils. This is much preferable to training with real data, for which a complex and costly automated measurement setup would be required.

The sensor design is then discussed in Section II, while in Section III simulation accuracy is evaluated with respect to a physical prototype, and the ML algorithm is trained and tested. Conclusions are then drawn in Section IV.

II. SENSOR DESIGN

The sensor consists of three coils: a transmitter (TX) coil and two receivers (RX) coils. The first receiver coil, RX1, has a *double-D* shape and is sensitive to tilt changes, while the second receiver coil RX2 is a spiral developed over two layers, more sensitive to the airgap. The final Printed Circuit Board (PCB) is shown in Fig. 1, where TX, RX1 and RX2 are respectively the outermost red, the green and orange, and the innermost red coil. More details on the design choices for the coils will be discussed in the full paper.

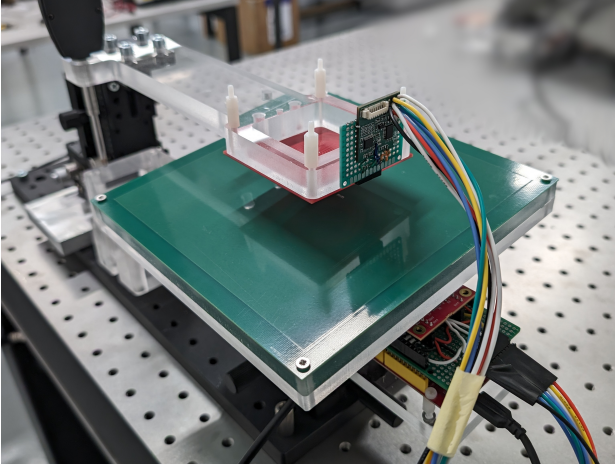


Fig. 2. Photo of the experimental setup. The sensor is connected to an IPS2550 chip, and measured through a ADS131M02. Reference data for tilt and airgap are obtained from a SCL3300 and digital micrometer, respectively.

III. EXPERIMENTAL RESULTS

The experimental setup consists of the tilt-IPS sensor and a target copper plate. The latter has dimensions $160 \text{ mm} \times 160 \text{ mm} \times 35 \mu\text{m}$. A Renesas IPS2550 chip is used for driving the TX coil and preconditioning of the RX coils signals, and a Texas Instruments ADS131M02 ADC is used for measuring these voltages. Reference values for tilt and airgap are obtained with a Murata SCL3300 inclinometer and digital micrometer, respectively. The setup is shown in Fig. 2.

The RX1 coil measurement presents a constant offset with respect to the simulation, equal to the difference between the measured and simulated voltage when no target is present. This can be easily compensated with a calibration step. Fig. 3 shows the compensated voltage measured across the RX1 coil as the target plate is tilted around the x -axis at different airgaps. A linear dependence is clearly visible, showing that for a fixed airgap, tilt estimation can be easily obtained through a simple calibration procedure. All other dependencies (i.e. RX1 voltage vs. airgap, RX2 voltage vs. airgap, RX2 voltage vs. tilt) will be discussed in details in the full paper.

A dataset of 4970 simulation points was built for airgaps in the 3 to 30 mm range, and tilt angles in the -10° to 10° range. This was used to train a fully connected neural network with four hidden layers, implemented using the *TensorFlow* Python library [5]. This neural network was then given as input the voltages measured from the experimental setup, resulting in the estimated positions in Fig. 4.

IV. CONCLUSION

The design shown in this digest allows for precise tilt and airgap estimation in a contactless way, as shown by the comparison between ML estimated and measured data. The full paper will discuss possible improvements in the modeling of the coils (in particular the spiral), and further discuss the dependence of each coil voltage to the tilt and airgap.

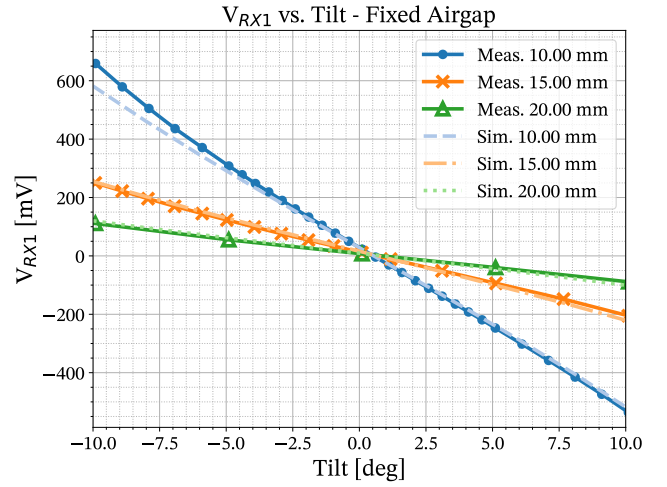


Fig. 3. Measurements (*Meas*) and simulation (*Sim*) results of the voltage across the RX1 coil as the tilt angle changes, at different airgaps. The measurement was adjusted with a constant offset given by the difference of the measured and simulated voltage when there is no target.

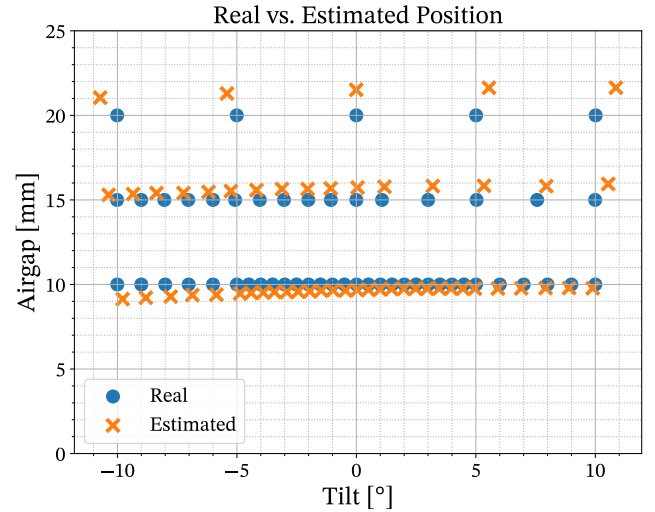


Fig. 4. Estimation of the tilt angle and airgap by the four-layered neural network.

Future developments are the introduction of another *double-D* coil rotated by 90° to obtain a 2-axis tilt estimation, and the use of topological optimization to minimize offsets and non-linearities.

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