Identification and Quantification of Metallic-Conductive Objects Using Low Frequency Magnetic Field

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***Abstract*—This paper presents a method to identify and quantify metallic-conductive objects in a non-metallic-conductive container using Low Frequency (LF) magnetic fields. The proposed method is a further development of the IndLoc system which has been developed at the Fraunhofer Institute for Integrated Circuits. It enables the materials' flow tracking in production and logistics sites.**

***Index Terms*—LF magnetic field, logistics, industry 4.0, quality check**

I. Introduction

Material flows in production and logistics remains not transparent [1]. Tracking them requires manual, potentially error-prone activities such as scanning on the one hand or tagging of items and containers on the other hand [2]. These processes require a high level of time and effort, and account for a significant share of total costs in intralogistics [3]. Therefore, automated material flow tracking offers significant potentials in terms of process reliability and overall efficiency.

In most production systems across a variety of industries, material flow monitoring and re-ordering are being carried out semi-automated or completely manually [4], thereby causing high efforts without creating the desired transparency. A typical example of semi-automation is the picking process, where the data collection requires human input, e.g. by confirming performed actions or entering quantities of picked goods. In order to create material flow transparency,, the IndLoc technology has been further developed at Fraunhofer Institute for Integrated Circuits (IIS). The IndLoc technology is based on low frequency magnetic induction [5].

The technology can be used in non-line-of-sight environments because its LF magnetic field is not affected by many non-metallic-conductive obstacles such as the human body.

The IndLoc system identifies pre-learned metallic-conductive objects by measuring the response of a primary LF magnetic field using receiving coils positioned below the box that contains the objects. The measured signals are then processed and compared with each object's pre-recorded fingerprint. The fingerprint includes information about the object and the quantity. The object is identified based on the minimum Euclidean distance.

The paper is structured as follows: Section II explains the process analysis and the scenario identification. Section III describes the IndLoc system and its components. Section IV explains the proposed identification method. Finally, Section V concludes the paper.

II. Process Analysis and Scenario Identification

The implementation of an automated identification and quantification technology for parts and materials can find application in different industrial use cases. Even if the performed core functions remain the same, different scenarios entail changes ranging from e.g. installation location over product, material and transport unit characteristics to transfer speed through the conductor loop.

In order to ensure transferable results, two representative application scenarios were identified as exemplary implementation cases based on literature research, expert interviews and process assessments with project partners from different industries. In a combined top-down and bottom-up approach, first, relevant action points along the logistics process chain were specifically queried with regard to their implementation in the various companies (top-down), then further potentials were openly collected with regard to advantageous technical framework conditions and urgent process needs expressed by the industrial partners.

With the examined logistical process chains reaching from goods receipt over warehouse, production, picking/packing to goods issue, pre-identified and targeted possible action points included automatic delivery note reconciliation, auto-entry for storage and retrieval in warehouse management, identification of assembly items in manufacturing as well as article verification for shipping readiness.
Thereby, frequently occurring and therefore particularly relevant characteristics of action points were determined, serving as application field for experimental investigations and process developments, ultimately resulting in two concrete implementation scenarios.

Scenario I is a regular picking process where the system should detect and quantify objects in separate, single-sort bins/shelves, display the current fill level and report the results to a warehouse management system (WMS) via a given middleware. Hereby, picked goods are detected by the system and the remaining quantity is updated.

Scenario II includes a picking cart with intelligent placing areas on which the picker puts parts according to the order. These parts are detected, quantified and matched with the pending order so that picking errors can be noticed and alerted.

III. System description

The IndLoc system has been further developed from what is described in [5] to suit the above mentioned Scenario II. Fig. 1 shows the newly developed system. The surface is divided into two compartments where two boxes containing objects can be put on each one to identify and quantify them. For each compartment there is a light indicator which blinks blue if there are no objects on top of the compartment area and blinks green when there are objects on top of the compartment which has been identified and quantified successfully.

Fig. 2 shows the inner components of the system which all are integrated in a compact plastic housing. It consists of a 100×45 cm rectangular magnetic field source known as the exciter loop and two pairs of receiving coils. Each coils pair consists of four 3×6 cm rectangular coils with 15 windings each. Additionally, there is a signal processing unit, the reader, which is the same size as a normal shoe box and it generates the primary magnetic field and processes the measured voltage values from the receiving coils.

An AC current I_{ex} flows in the exciter loop with a frequency that ranges from 30 kHz to 150 kHz . The exact frequency at any given time can be configured through the software and the reader unit. The exciter loop carries only one AC current at a specific frequency at any given moment. I_{ex} generates a primary magnetic field $\vec{H}_{ex}$. This field induces a voltage U_{obj} into the conductive objects' bodies. This results in a current flow in closed-paths in the objects bodies

Fig. 1: The newly developed IndLoc system demonstrator with the metallic-conductive objects identification and quantification features.

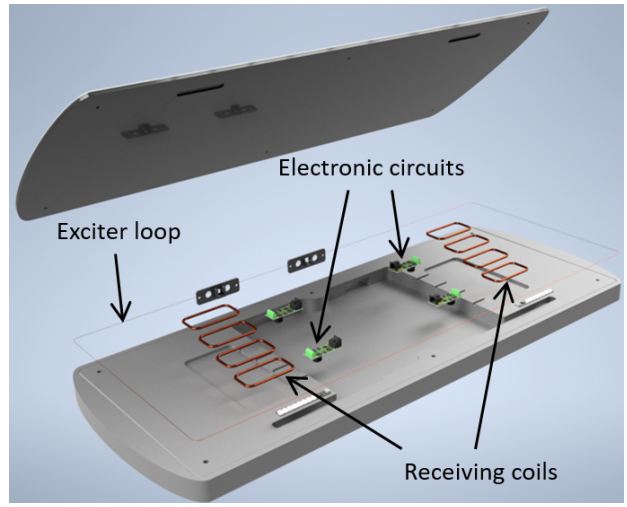


Fig. 2: The inner part of the system comprising a 100×45 cm exciter loop, electronic circuits and 8 receiving coils each has dimensions of 3×6 cm and 20 winding.

known as Eddy currents. These currents produce a secondary magnetic field $\vec{H}_s$ which induces voltages $\widetilde{U}_1, ..., \widetilde{U}_8$ in the eight receiving coils.

As shown in Fig. 3, the measured voltages are forwarded after sampling to the reader unit which filters, amplifies and process them. The reader sends the real and imaginary (Re, Im) components of the processed samples using User Datagram Protocol (UDP) to a personal computer (PC). At the PC, a fingerprinting comparison takes place to identify and quantify the objects using pre-recorded data of each object from a database or a lookup table.

IV. The proposed method

The proposed method performs a frequency sweep by varying the frequency of the I_{ex} current and measures the response of each individual frequency using the receiving coils. During each frequency sweep, the AC current that flows into the exciter loop is varied n times. Where n is the number of frequencies $f_1, ..., f_n$. In this paper we use $f_1 = 30$ kHz and $f_n = 140$ kHz with a step of 5000 Hz between each two consecutive frequencies. The proposed method consists of two

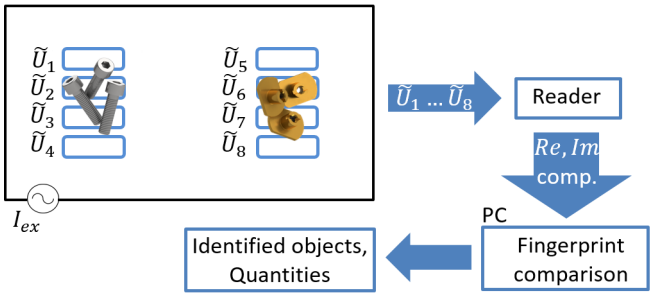


Fig. 3: A block diagram showing the different stages of the objects identification and quantification process using the measured voltages $\widetilde{U}_1, ..., \widetilde{U}_8$ from the metallic-conductive objects placed on top of the receiving coils. The (Re, Im) values are sent to a PC where the fingerprinting comparison takes place.

stages. The first one is to generate a fingerprinting database. The second consists of the identification and quantification processes.

A. Generating a fingerprinting database

In this database all the necessary features to successfully identify and quantify 15 different metallic-conductive objects are stored. Fig. 4 shows the objects under investigation throughout this paper. For each object a non-conductive 15×20 cm box must be filled with units of the same object. Afterwards, the box is placed on top and covers four receiving coils. A full frequency sweep process starts from f_1 and ends with f_n. For each f, the following must be calculated and appended to the database

$$\phi_f = \arctan \sum_{j=1}^{4} \widetilde{U}_j(Re, Im) \tag{1}$$

$$A_f = |\sum_{j=1}^{4} \widetilde{U}_j(Re, Im)| \tag{2}$$

where ϕ_f, A_f are the phase and the amplitude of the sum of the four receiving coils' voltages $\widetilde{U}_j$ at a frequency f, respectively. The resulting database is structured as shown in Table I.

TABLE I: The fingerprinting database structure

object number x	f_1		...		f_n	
1	ϕ_{11}	A_{11}	...	...	ϕ_{1n}	A_{1n}
2	ϕ_{21}	A_{21}	...	...	ϕ_{2n}	A_{2n}
...	...	...	...	...	...	...
m	ϕ_{m1}	A_{m1}	...	...	ϕ_{mn}	A_{mn}

B. Identification and quantification

To identify and quantify the objects which are placed on the surface of the receiving coils, a frequency sweep must be carried out. For each f, the measured (Re, Im) components from the corresponding 4 receiving coils are used to calculate

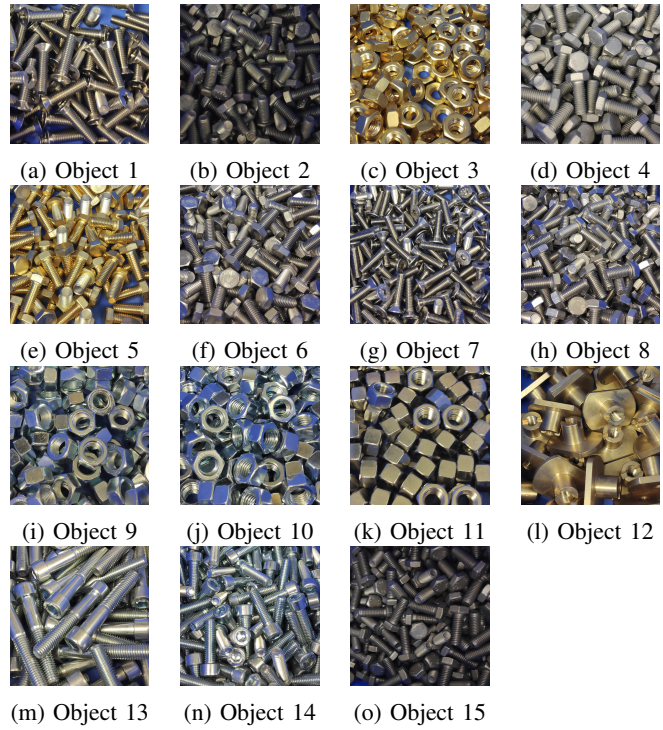


Fig. 4: The objects under investigation

Eq. (1). The phase of the objects from the database is used for identification due to its uniqueness. As shown in Fig. 5 each object has a different phase value for each frequency. We have split the phase curves of the objects under investigation into two separate plots for clarity. Please note that each plot in Fig. 5 has a different the y-axis scale for clarity.

The identification is carried out by comparing the measured resulting phase value from Eq. (1) with each entry from the database to find the best match. This is done by executing the following equation

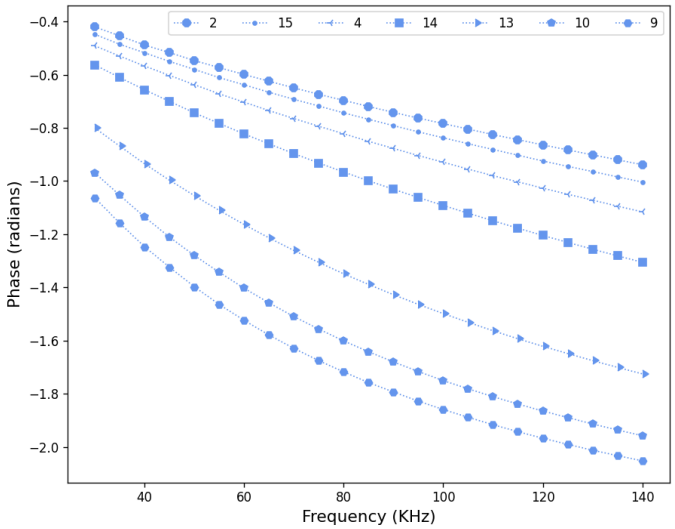
$$d_{\phi_i}(\widetilde{\phi}_1, ..., \widetilde{\phi}_m)^2 = \sum_{l=1}^{n} (\widetilde{\phi}_l - \phi_{i,l})^2 \tag{3}$$

where d_{ϕ_i} is the sum of the Euclidean distances between the measured phase values $\widetilde{\phi}_l$ and the database phase entries $\phi_{l,i}$. i, l are the the number of frequencies and the object number from the database, respectively. The identified object's number x can be found by

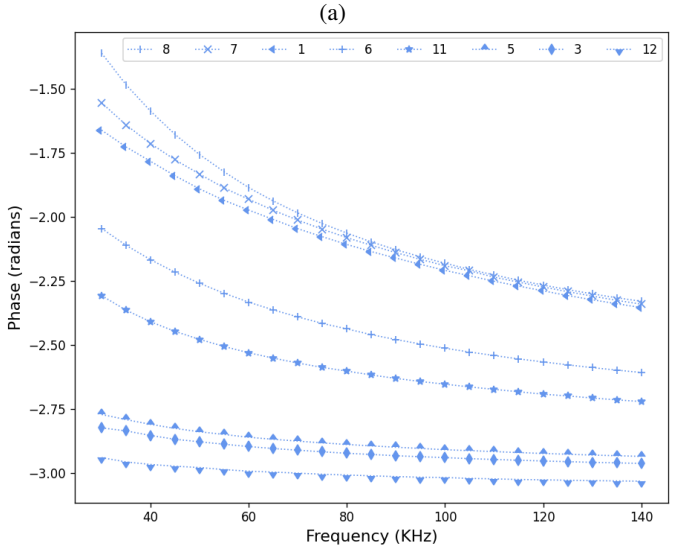
$$x = \underset{i}{\operatorname{argmin}}\, d_{\phi_i}(\widetilde{\phi}_1, ..., \widetilde{\phi}_m)^2 \tag{4}$$

and it corresponds to the database entry with the minimum distance.

The quantification process starts once the object has been identified. This is achieved by dividing the measured amplitude $\widetilde{A}_n$ at the highest frequency f_n with the identified object's amplitude from the database A_{xn}. The decision to use



(a)



(b)

Fig. 5: The phase values of the objects under investigation. Please note the different y-axis scaling. The objects' numbers in these two plots correspond to the objects' numbers in Fig. 4.

the amplitude of the highest frequency as an indicator for the quantity present in the box is related to the measured signals strength from the receiving coils. The measured signals are proportional to f and we want them to be higher than the noise level that the reader hardware has. This assures that even if there are only few objects in the box or the signals are weak due to the properties of the objects we will be able to quantify. The quantity percentage of the objects in the box q can be calculated as

$$q = \widetilde{A}_n / A_{xn} \times 100 \tag{5}$$

V. Conclusion

In this paper, we have presented a method to identify and quantify metallic-conductive objects in a non-metallic-conductive container using Low Frequency (LF) magnetic fields. To achieve that, the IndLoc technology has been extended with the frequency sweep functionality, new receiving coils and an updated software algorithm.

A group of 15 different metallic-conductive objects has been successfully identified and quantified using Euclidean distance comparison.

Future work will be focused on using modern Machine Learning classifiers to improve the identification and quantification accuracy and speed. Additionally, it will enable identifying more objects based on new features that might be present but currently not exploited in the presented method.

References

[1] G. Eason, B. Noble, and I. N. Sneddon. "On certain integrals of Lipschitz-Hankel type involving products of Bessel functions." *Phil. Trans. Roy. Soc. London*, vol. A247, pp. 529–551, April 1955.

[2] J. Clerk Maxwel. "A Treatise on Electricity and Magnetism, 3rd ed", vol. 2. Oxford: Clarendon, 1892, pp.68–73.

[3] I. S. Jacobs and C. P. Bean. "Fine particles, thin films and exchange anisotrop." in Magnetism *G. T. Rado and H. Suhl, Eds. New York: Academic*, vol. III, pp. 271–350, 1963.

[4] K. Elissa, "Title of paper if known," unpublished.

[5] I. Ibrahim, K. Rieger, T. Draeger, R. Psiuk. "Adaptive algorithm for estimating the position of a passive object in a picking shelf," in *International Conference on Indoor Positioning and Indoor Navigation*,30 Sept. - 3 Oct 2019.