Source Reconstruction of Electromagnetic Fields Employing Modern Evolutionary Algorithms

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***Abstract*—**This work aims at description of possible processes which lead to estimation of electromagnetic fields in near field based on source reconstruction. This is a specific kind of an inverse problem where the known measured values are the far field intensities of electric and magnetic fields. Application of this work can help in localization of hot spots in a black box containing some emitters and thus for example help designers to appropriately modify the design or to use an interference suppression. That can be a reason why this work may be also important in the field of electromagnetic compatibility.

***Keywords*—**electromagnetic field, evolutionary algorithm, inverse problem, source reconstruction

I. INTRODUCTION

This work is a preliminary study considering the topic of the author's dissertation *Estimation of Electromagnetic Fields in Near Field Based on Source Reconstruction*. The author needs a specific instruments which will help with the backward reconstruction. Evolutionary algorithms can be used right for this purpose, to estimate the original sources from given results of measurement in far field (or at the end of the near field zone) [8], [9].

From the simpler point of view, in this case, the evolutionary algorithms would not serve as optimization tools which improve a structure, geometry, composition or anything else to get better results (better in a desired attribute or behavior like airflow, energy consumption or transmission coefficients). The evolutionary algorithms could be used as a technique for estimation of values of design variables which influence the results of the process of propagation of electromagnetic waves. In this kind of optimization the difference between measured values of intensity of electric and magnetic fields and computed values is optimized, minimized. Therefore this problem can be considered more as a reconstruction problem than the optimization one.

The problem of transformation from far to near fields is very actual in the field of electromagnetic compatibility. In this domain this kind of transformation could provide very useful information about positions of disturbing sources. This technique is usually named as searching for hotspots on an electromagnetic appliance and helps designers to examine a specific device or a component and provides information which helps designers to change the design and/or whether to use an interference suppression.

II. PROBLEM SPECIFICATION

The problem to be solved in this work is a problem of backward reconstruction.

Let us have a simple model situation where there is a small black box containing an emitter (a dipole for instance) of unknown position and orientation (and thus layout of the electric and magnetic fields in the near field on the box). The submission would be to get information about the fields on the small black box.

The only information which is provided at the beginning is the measured intensities of the electric and magnetic components of electromagnetic filed for multiple points (which are defined in coordinate system) in a more distant near field zone, but not a far field yet (far field is an area which is in distance of more than several multiples of wave-lengths; we can imagine a bigger box surrounding the smaller black box).

Then, the goal is to estimate the correct values of intensities of the electric (E) and magnetic (H) components of electromagnetic filed for multiple points (a layout) on the smaller black box. Fig. 1 presents a box with the direction of x, y, z components of E and H fields. Therefore this is for example a little bit different situation in comparison with [10] where the electric field at the near field radiating is measured by electrostatic discharges.

The boundary of near field area is usually defined as [8], [9] in Eq. (1):

$$R_{nf} = \frac{D^2}{4\lambda} \tag{1}$$

where

- R_{nf} is the extent of near field
- D is diameter of antenna
- λ is the wavelength

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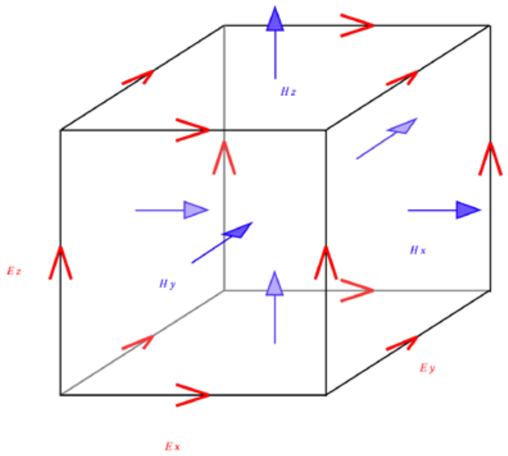

Fig. 1 components (*x*, *y*, *z*) of electric (*E*) and magnetic (*H*) fields on a cube [1]

In our experiment, the dimensions of the inner and outer box, the properties of the emitter in the inner black box are the following:

- Dimensions of the inner (smaller) black box: 0.3 m x 0.3 m x 0.3 m
- Dimensions of the outer (bigger) box: 1.0 m x 1.0 m x 1.0 m
- Type of the emitter in the inner box: dipole
- The working frequency: 300.0 MHz
- The length of the dipole: 0.1 m
- The value of current in the dipole: 1.0 A
- Number of measured points on each face of the outer box (rows x columns): 11 x 11
- Number of points to be computed on each face of the inner box (rows x columns): 11 x 11

From the settings above, the dimensionality of the problem can be computed in the way presented in Table 1.

Table 1 the dimensionality of the simple model problem

Number of points per face:	*NPPF = 121*
Number of faces:	*NFA = 6*
Number of fields:	*NFI = 2*
Number of field components:	*NFC = 3*
Number of design variables:	*Dimensionality = NPPF * NFA * NFI * NFC = 4356*

With respect to such a high dimensionality of this problem (4356 dimensions) the optimal solution could be very difficult to find.

The situation is modelled in Fig. 2. The unknown values (to be estimated) are the values of *x*, *y*, *z* components *E'* and *H'* fields on the inner cube.

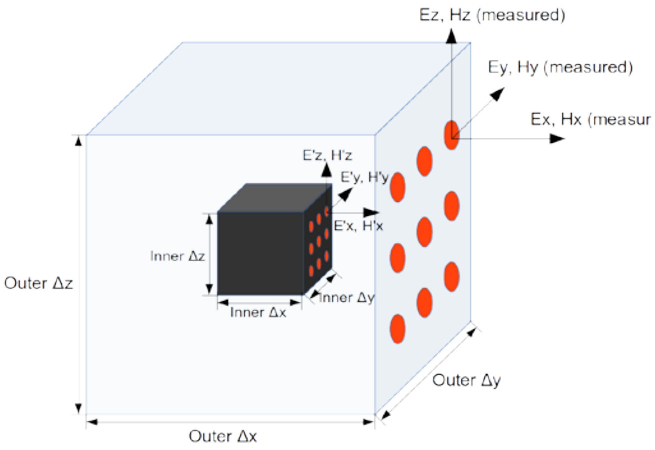

Fig. 2 illustration of a simplified problem containing only 9 points per face (only right face is visualized in this figure)

III. UTILIZATION OF EVOLUTIONARY ALGORITHMS

For the specified problem, there is a need of a fast and robust computational instrument which is capable of a multi-parameter optimization. As presented in introduction, the evolutionary algorithms, like Genetic Algorithm [3], [4], Particle Swarm Optimization [5], [6] and Self-Organizing Migrating Algorithm [7], can do the job (also including local optimization algorithms like Levenberg-Marquardt or the method of Conjugate Gradients).

In the following sections, specified problem is structured into an individual and an objective function which serves as a basis for further design and implementation.

A. *Design of an Individual*

In this reconstruction problem an individual is a representative of values of components of electromagnetic fields on the inner cube. Thus, such an individual contains *x*, *y*, *z* components of electric and magnetic fields of all desired points on all cube faces (11 x 11 points per face).

Content of an individual:

- Electric components: E{x,y,z}_face{1:6}_point{1:11}.{1:11} what relates to the total number of 2178 (3*6*11*11)
- Magnetic components: H{x,y,z}_face{1:6}_point{1:11}.{1:11} what relates to the total number of 2178 (3*6*11*11)

B. *Initial Values*

The initial values of design variables are set to the measured values on the outer cube. This approach is considered as the simplest way.

C. *Objective Function*

Our problem is a minimization problem in which the effort is to zero the difference between measured values and computed values of intensity of electric and magnetic field from an individual.

The objective function computes the intensity of electric and magnetic fields of all *x*, *y*, *z* components of all points on the outer cube and then the output is compared to the measured values and the root mean square is returned as a result (cost). The computation is based on an individual which is representing the input data (intensities of electric and magnetic fields of all *x*, *y*, *z* components of all points on all faces of the inner cube).

The objective function uses the Huygens principle [2] (surface equivalence theorem, for 2D planar source) to transform the input near field data (on the inner cube) to the more distant near field data (on the outer cube). The difference defines the fitness value of each individual.

The objective function which defines the fitness of an individual could be written in the following pseudocode:

```
function cost = ObjectiveFunction(
        individual,
        emitterParameters,
        innerCubeDimensions,
        outerCubeDimensions,
        measuredValuesOnOuterCube)

    % Transform the individual
    % from near field to distant
    % outer near field
    computedValuesOnOuterCube =
        TransformNF2DNF(
        individual,
        emitterParameters,
        innerCubeDimensions,
        outerCubeDimensions);

    % Compute the root mean square
    cost = RMS(
        measuredValuesOnOuterCube,
        computedValuesOnOuterCube);

return cost;
```

Typical computed values of electric field of component *z* are shown in Fig. 3 (simple dipole in the center of the inner box, therefore the symmetry of the intensities can be seen in the figure).

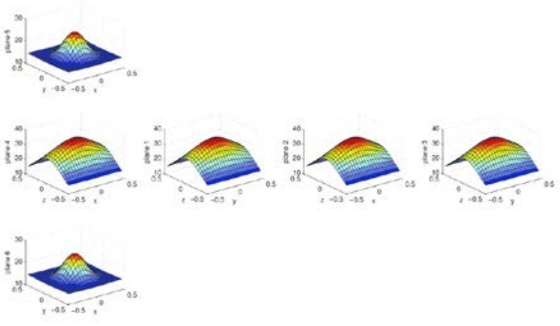

Fig. 3 visualization of computed component E_z on the faces of the outer cube (plane 1 is the right face, 2 is back, 3 is left, 4 is front, 5 is top and plane 6 is the bottom face)

D. *Current Implementation*

This project is now already implemented in Matlab employing the Levenberg-Marquardt local optimization technique where all the core functions are rewritten into C, optimized and compiled into MEX files which makes the processing approximately twice faster. The details about the acceleration is mentioned in Table 2. The numbers in the table were computed simply in the following manner: the original M-file was run one million times and also the MEX file was run one million times, then the time consumption was compared.

Table 2 the acceleration of the core functions rewritten to C and compiled into MEX files (speed comparison against the original M-files)

Function	Speed up Factor
convcasp.c (converts Cartesian co-ordinates [x,y,z] into spherical ones [r,th,phi])	*3.2x*
convtoca.c (transforms spherical co-ordinates [r,th,phi] to the Cartesian ones [x,y,z]	*2.6x*
convtosp.c (transforms to spherical co-ordinates [r,th,phi]	*2.7x*
huygens_fast_approx.c (Huygens principle -- surface equivalence principle for 2D planar source	*2.7x*

IV. REAL MEASUREMENTS

The possibilities of contemporary technologies have been taken into account when choosing the sensors, ways of signal transmission and the system of further data postprocessing. The signal processing chain is based on the needs of this study and on the requirements of connection of particular subsystems in this work.

A. *Signal Processing Chain*

Fig. 4 illustrates a schema of the signal processing chain. On the top there is the object of interest representing the black box we would like to inspect. Sensor senses the intensities of electric (*E*) and/or magnetic (*H*) components of electromagnetic field around the object of interest. The sensor is connected to a Vector Network Analyzer (VNA) which measures the intensities from sensor, collects the data and send them to a PC. There is also a need to know the precise position of the sensor by each point of measurement. The information about actual position must be also sent to the PC where this should be synchronized and collected together with the data of intensities of *E* and/or *H*.

B. *Sensor*

Sensor represents one of the most important devices in this measurement set.

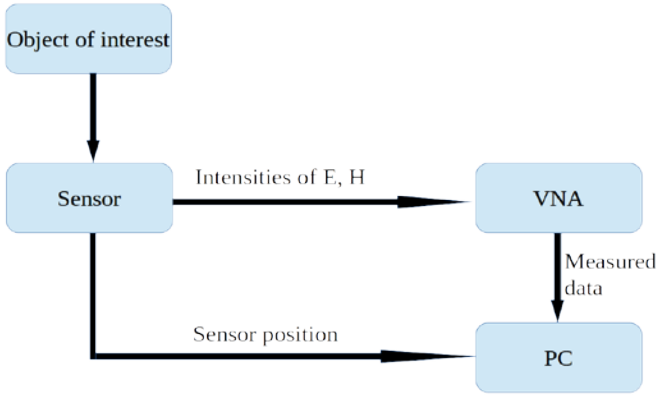

Fig. 4 the signal processing chain

This block consists of two subsystems. One of them is a measuring probe which measures the electric component of the electromagnetic field. The second subsystem is a sensor of position of the mentioned measuring probe

The reason for measuring only the electric component is that we do not discriminate the electric (*E*) and the magnetic (*H*) components when being in far field. It is enough to measure just one of the components when measuring in far field. The missing (not measured) component can be computed from the following equation [11]:

$$H = E/377\ \Omega \qquad (2)$$

Both components (the electric and the magnetic one) must be measured when the measurement takes place in the near field zone. Their relation differs by 377 Ω.

The borders of near field are described in Eq. (1) in the section of Problem Specification.

The antenna could consist of a row of antennas with an appropriate net of connections and a fast switching unit. The antennas could be simple field antennas (patches) with output for all the three planes of polarization E_x, E_y, E_z or a dual output E_{xtan}, E_{ytan}. If there is only one dipole the three planes of polarizations will be measured separately.

The frequency band lies between 30 MHz and 6 GHz. This range is usually used for measurement of electromagnetic emission, interference from electronic appliances. For example there is a standard for measurement of appliances used in information technology (information telecommunication equipment, CISPR22).

The sampling rate relates to the highest possible measured frequency. By the sampling theorem the position deviation should be less than 2.5 mm (to be able to reconstruct a continuous signal the sampling frequency must be at least twice as much as the highest harmonic frequency in the signal to be sampled, therefore we have to use the sampling frequency 12 GHz, then the corresponding wavelength is 25 mm and the deviation should be one tenth at maximum what is 2.5 mm).

Table 3 differences in measurement of electric and magnetic components in lower and higher frequencies.

	0 — Tens of Hz	*Higher frequency*
Electric component	A dipole antenna could not be used	A small unipole antenna
Magnetic component	A loop of more threads with a low noise amplifier or Hall probe with a low noise amplifier	A loop of one thread, without amplifier

The measurement of position of the antenna could be done in the two following ways:

- Using a passive stereoscopy (the antenna must have three important points, markers)
- Using a laser emitter connected to the antenna which emits a grating of the laser light on a projection plane. An optical camera records this scene and performs a specific transformation by the deformation of the grating

C. *Utilization of Other Electronic Appliances*

The signal from the measuring probe is sent to a Vector Network Analyzer (VNA which measures the incoming voltage, what could be for instance ZVB20 from the company of Rohde&Schwarz, measurement will be done on the second port). The data from VNA are subsequently postprocessed in a PC.

The position and rotation of the measuring probe in three dimensional space is also sent to a PC which collects all these data (position coordinates S_x, S_y, S_z along with the angles th_x, th_y, th_z).

When we put all the information together we have a set of positions of the measuring probe connected with voltages for all three planes of polarization.

D. *Postprocessing*

The postprocessing is needed to correct the values measured by the VNA (voltages in three axes per position of measurement) by the specific antenna factor (AF_{el}). There is a need to interpolate the measured data file of E_x, E_y, E_z which are not measured uniformly to get the correct equidistant values.

The next step is to compute the magnetic components H_x, H_y, H_z using a combined antenna factor (AF_{eh}) and thus the complete information about the electromagnetic field at the specific position.

The measured intensities must be also well assigned to the right position.

E. *Output Data*

At the end of the signal processing chain there is a complete information of a matrix of points covering all the planes of the measured black box finalized by a computer.

The output data could be formatted as following in a simple text file, one point per one row (time, position in three dimensions: x, y, z, intensity of the electric and magnetic component of the electromagnetic field also in all three planes of polarization: x, y, z):

$time[s]\ P_x[m]\ P_y[m]\ P_z[m]\ E_x[Vm^{-1}]\ E_y[Vm^{-1}]\ E_z[Vm^{-1}]\ H_x[Vm^{-1}]\ H_y[Vm^{-1}]\ H_z[Vm^{-1}]$

V. CONCLUSION

Ideas contained in this work describe the preliminary insight into the problematic of estimation of electromagnetic fields in near field based on source reconstruction.

This is the right place for modern evolutionary algorithms (or possibly also for local optimization techniques) to help to find a close solution of the specified problem of backward reconstruction.

Along with the description of this problem of backward reconstruction also the process of measurement with the design of signal processing chain was presented and particular sensors and electrical appliances were proposed from a higher abstraction level of point of view.

With respect to the very high dimensionality of this problem possibilities of application of some approximation must be taken into account in the further work along with the use of programming techniques aimed at speeding up the code. Nevertheless the second point is now rather subsidiary reflecting the current situation where the functions have been already optimized and rewritten into C language and compiled into MEX files.

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