Prototype of EMC Expert system for optimal design of radio-electronic equipment

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Abstract. This paper presents the results of the development of a prototype EMC expert system for optimal design of radio-electronic equipment. The work outlines the general structure of the system and describes the development features of the interference signals database, the analytical report generation module, the ready-made solutions database, the shielding effectiveness module and the degradation trend module.

1. Introduction

Ensuring electromagnetic compatibility (EMC) is an important task in the development of radio-electronic equipment (REE). This task is usually associated with expensive and time-consuming measurements [1]. Also, it is worth noting that solving this class of problems requires design engineers to have deep expert knowledge and experience in this field. Therefore, it is advisable to consider EMC at the design stage by simulating it with specialized software [2]. Modern trends in software development in this area encourage software developers to introduce various analytical tools and elements of EMC expert systems (ES) into a software product.

The use of modern computer technologies makes it possible to develop ESs that contain a knowledge database (DB) of large data volumes with the possibility of their unlimited expansion and backup. In addition, when solving EMC problems, ESs rely only on embedded mathematical models, algorithms, and knowledge bases, which give more objective results, and therefore the possibility of errors is extremely small.

Some of the most notable results of the ES development are discussed below. In the paper [3], it is noted that compliance with EMC requirements can be a serious problem for engineers designing modern REE. Traditional approaches depend largely on the EMC design rules. Unfortunately, these rules are not based on specific EMC requirements for a particular device, and they usually do not take into account the specific purpose of the circuit or the design details that ultimately determine whether the device meets the requirements or not. The paper [4] proposes the approach based on the analytic hierarchy process of a three-dimensional model in solving the problem of multi-criteria optimization and optimal design of warships considering the EMC requirements. The three-dimensional model proposed by the authors consists of a cube, each axis of which corresponds to a certain evaluation criterion. These criteria include operational requirements, EMC, production costs, technological requirements, and the effect of electromagnetic radiation on personnel/fuel/ammunition. The decomposition of analytic hierarchy process used by the authors is based on the specific technical characteristics of the equipment under test. Each axis of the three-dimensional model is limited to the values that meet the operational requirements and limitations of the system. The paper [5] considers

the main advantages and disadvantages of the three approaches that underlie most ESs in EMC simulation software. These include approaches based on analytical simulation that uses closed-form equations; numerical simulation that uses the solution of Maxwell's equations under certain boundary conditions; rule checking systems that consider the basic design rules. Taking into account the advantages and disadvantages of the approaches, the authors developed an approach based on the use of an ES that allows modeling the intellectual process of an expert in the field of EMC. The algorithm of the ES is based on the use of all available information to generate solutions to the problem. In addition to the information that can be obtained from the PCB topology, the ES is based on a DB of components, signals, circuit characteristics and EMC requirements.

Thus, the relevance of providing EMC is due to its interdisciplinary nature since REE is used in various fields of technology. In turn, using the achievements of modern technologies, including those based on the use of ESs and artificial intelligence elements, to solve problems in the field of EMC allows developers to effectively use available resources. The purpose of this work is to develop a prototype of an expert system for optimal design of radio-electronic equipment.

2. Development

The standard procedure for computer-aided design of REE includes 4 main stages: setting the input data; simulating; analyzing and processing the results; yielding the results. Further parts of the article describe the features of an ES under development in regard to quasi-static analysis of a transmission line (TL).

At the first stage, developers set the structure, i.e. the geometric dimensions of its elements, as well as the parameters of useful and interference signals. To implement the first stage procedures, the software must include: a graphical editor suitable for creating arbitrary structures of TL conductors and dielectrics, a topology design, and a signal database. At the simulation stage, procedures are performed for calculating the TL parameters, simulating the REE, and evaluating the shielding effectiveness (SE) elements of the equipment. At the same time, it is necessary for the software to contain the appropriate subsystems and modules that implement mathematical models and computational algorithms for the simulation stage procedures. At the third stage, the processes occurring in the simulated object are analyzed and evaluated, and the parameters of the simulated TL are optimized. To implement the procedures of the analysis stage, the software must include modules for single- and multi-variant analysis and optimization of the TL structure, as well as subsystems that allow developers to analyze the signal levels in the nodes. At the information output stage the simulation results are selected, as well as reference and analytical information is formed and based on the selected optimization criterion. To do this, the software must include modules and subsystems that implement mechanisms for graphical output of calculation results and generate analytical information based on these results. Also, for direct automation of the REE design process, the system must have an intelligent core that analyzes the results obtained at each stage, manages the overall process, and supports decision-making. In addition, it is important to predict the behavior of REE under the influence of various destabilizing factors such as the degradation of REE components under the climatic and electromagnetic effects. To implement this, the ES must also contain a module based on the appropriate mathematical models and algorithms.

Based on the described functional requirements, the domestic EMC simulation system TALGAT was chosen as the basis for ES development. Its capabilities were expanded by introducing new sub-systems.

2.1. Structure of the expert system

Figure 1 shows the workflow diagram of the developed prototype of the expert system. As mentioned earlier, the key role is assigned to the intelligent core, which should control the operation of each stage, and based on the results and conclusions, make the optimal route for completing the task of designing REE. If the precondition checking system detects deviations from the desired values, depending on the selected operating mode, the intelligent core either automatically returns to the

previous stages to obtain acceptable values or reports errors to the user and provides a list of possible solutions. During its solution generation, the module is guided by the knowledge base and rules database in relation to a specific task and a specific stage of REE design.

The following subsections describe modules that are part of the expert system, both already implemented and in the state of the development.
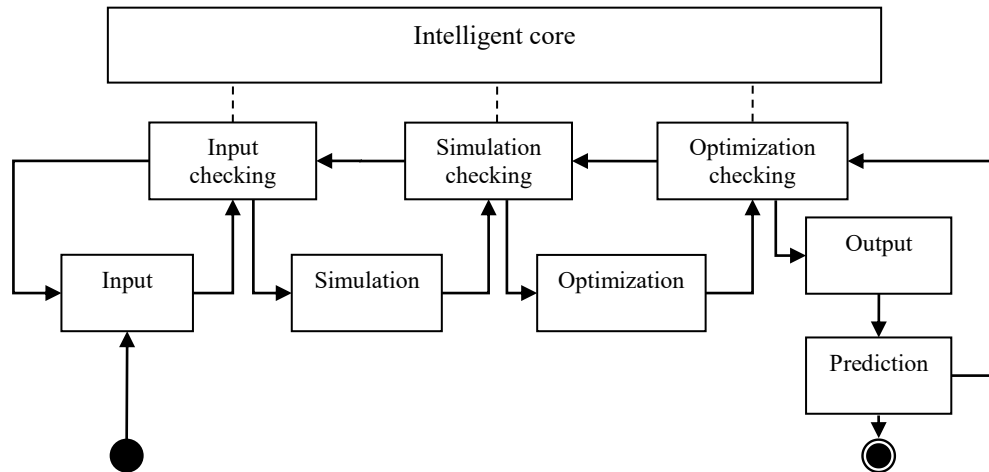

Figure 1. Workflow diagram of the EMC ES prototype.

During the development, the programming languages C++ and Python were used, as well as the Qt framework since the TALGAT system is based on the use of these tools and includes the Python interpreter. The Python language was used as an additional language to facilitate the transfer of data received from the TALGAT system to the analytical information window. Lightweight free library Three.js was used to create three-dimensional enclosure objects in the SE module. This library was employed due to its ease of use and the ability to be quickly integrated into a project created using Qt widgets technology. Also, since the main language of the ES development was C++, the OpenMP standard was used to speed up mathematical calculations by parallelizing them. Therefore, the prototype of the expert system has the following minimum system requirements: operating system – Windows 7/8/10 64-bit, memory – 1 GB RAM, processor – 1 GHz or faster, hard drive space – 600 MB.

2.2. Interference signal database

One of the important parts of the ES is the DB of interference signals, which can be directly during the simulation [6]. Using database signals, it is possible to analyze the behavior of the object under study when it is affected by interference signals. In addition, the module contains functionality for local editing of the DB elements and filling it with new elements. Access to the developed module is provided directly through the TALGAT circuit diagram editor, which is used for designing the circuit topology. Figure 2 shows the graphical user interface of the DB module (editing section).

For more efficient use of the database described in this section, as well as for analyzing the impact of signals, it is advisable to use N-norms [7]. N-norms are integral parameters that are used to determine the limits of equipment susceptibility [8]. The calculation of N-norms is based on applying mathematical operators to the entire waveform. The mechanism for calculating N-norms is implemented and integrated into the system that is used as the basis for developing the ES.

2.3. Analytical report generation module

To expand the potential of practical application of the database and N-norms, a module for generating analytical reference information has been developed. Norms and signals are used to analyze an arbitrary user topology. The graphical interface of the module window is shown in Figure 3. The

central table contains information about the number of the transmission line and the number of the segment containing the maximum value of the N-norm. Depending on the normalized maximum voltage value, the background color of the corresponding table cells changes (from green to dark red), indicating the most vulnerable parts of the topology (red color). The column on the right shows the maximum voltage of the input signal and the names of the signals from the DB. When the user clicks on the table cells in the lower part of the window, the module displays portraits of N-norms normalized relative to the N_1–N_5 values of the input interference signal. This allows the user to examine in detail the vulnerable nodes of the user-defined topology.

Moreover, an additional data export submodule has been developed to facilitate and automate the process of preparing reports based on data obtained during REE simulation. The data export submodule automatically generates a report based on the performed calculations, which includes the maximum and minimum values of the normalization parameters, portraits according to the N_1–N_5 norms, signal extremes at the nodes and time responses at these nodes, as well as at the input and the output of the circuit.
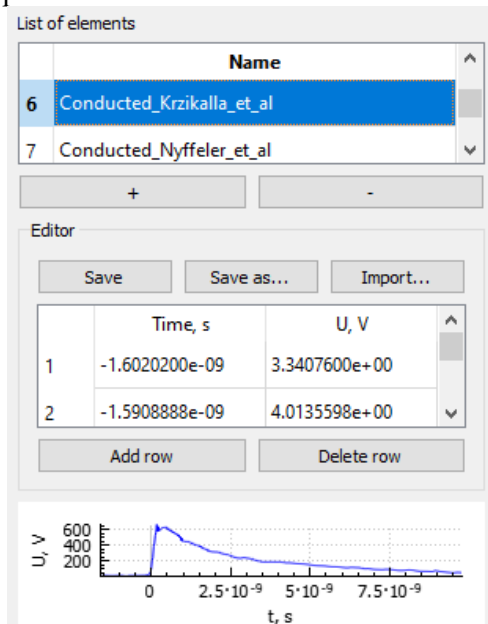

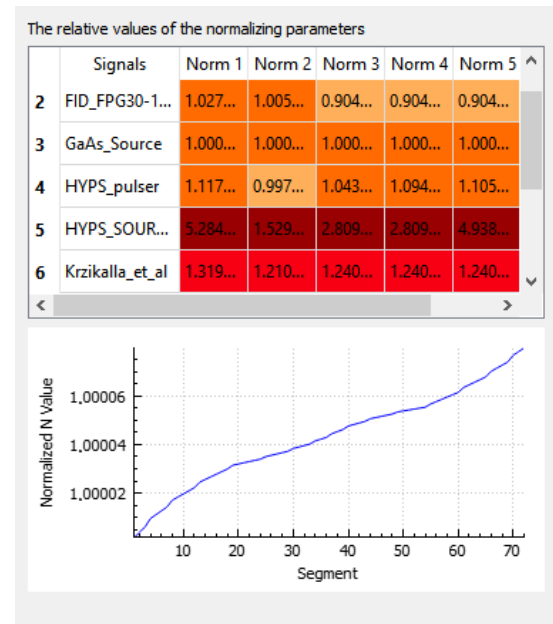**Figure 2.** Editor window of the DB module.

Figure 3. Graphical user interface of the analytical report generation module.

2.4. Ready-made solutions database

The DB of ready-made technical solutions is part of the knowledge base of the ES. It can contain ready-made scripts, circuit diagrams, and cross-sections of TLs. However, without automated control by the intelligent core, the user must decide which script to choose for a specific task. The database also contains functionality for filling in and editing it.

2.5. Shielding effectiveness module

The shielding effectiveness (SE) module is used to evaluate the SE of the designed REE parts. The module is based on the use of a number of analytical models based on the equivalent circuit method [9]. The main window of the module is shown in figure 4a. The module provides a choice of several typical shielding structures: cylindrical enclosure, rectangular enclosure with a single aperture and a perforated wall. After selecting the type of structure, the user can enter its parameters: sizes of the enclosure, the wall thickness, the size and position of the aperture. A distinctive feature of the module is the ability to display a three-dimensional SE plot depending on the frequency of exposure and the position of the observation point inside the enclosure. This functionality allows developers to

identify and localize the areas where the SE takes the worst values, as well as to evaluate the SE at various points of observation, which can be useful for choosing the optimal location of elements and components of technical equipment inside the shielding enclosure at the early design stage. An example of the three-dimensional plot display is shown in Figure 4b.
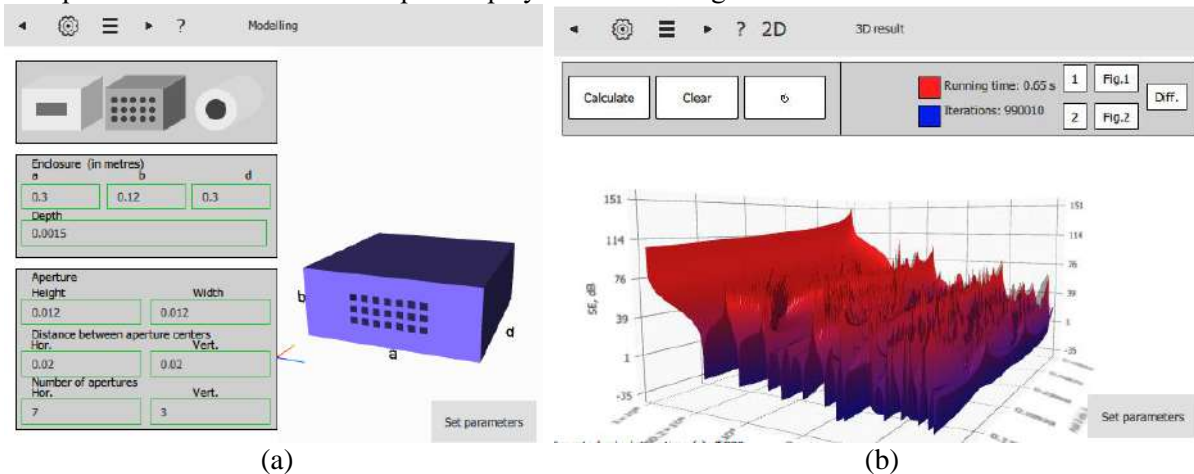

(a)   (b)

Figure 4. Main window of the shielding effectiveness module (a)
and three-dimensional shielding effectiveness dependency plot (b).

2.6. Degradation trend module

The trend module can be used to predict the degradation of materials and components of REE elements under randomized destabilizing effects. The module is based on the use of a modified least squares method, as well as specially designed statistics [10]. The module implements algorithms for identifying time series trends, estimating the correlation function and the power spectrum of a stationary random process when the measurement moments form a Poisson point process. In addition, the module makes it possible to predict the behavior of REEs when they are exposed to destabilizing factors, for example, electromagnetic and thermal influences. The graphical interface of the degradation trend module is shown in Figure 5.

2.7. Multivariate analysis module

The ES also includes a developed module for multivariate analysis of a multiconductor TL. The module allows developers to perform multiple calculations of matrices **R, L, C** and **G** of the TL when changing the parameters of the transmission line cross-section under study. It can be used to find the optimal solution in the REE design. In addition, a user interface is currently being developed for the multi-criteria optimization module, which is based on the use of a genetic algorithm and an evolutionary strategy. At the moment, to work with the current version of the module, the user has to use the built-in scripting language of the TALGAT system. Thus, the user can create multi-criteria functions for solving optimization problems of the required parameters. To design EMC-optimized REE, it is necessary to take into account the time and amplitude criteria. For instance, to protect against the signals presented in the interference signals database, it is advisable to analyze the U(t) dependence, where *N*-norms can serve as an amplitude criteria, or any other user criteria [11].

2.8. Intelligent core module

To automate the REE design process, an intelligent core module is being developed. The operation of this module is based on a system of signals (coming separately from each module) and the corresponding slots of the ES (Qt signal/slot system). The intelligent core module is an add-on to the entire ES, the so-called control link that monitors the steps of the design process, which analyzes the obtained results, and either proceeds to the next step, returns to the previous ones, or repeats the current step with changed input parameters. The module will have a graphical interface that should

inform the user about the steps of its work and the reasons for choosing a particular path, based on the expert knowledge base embedded in it.
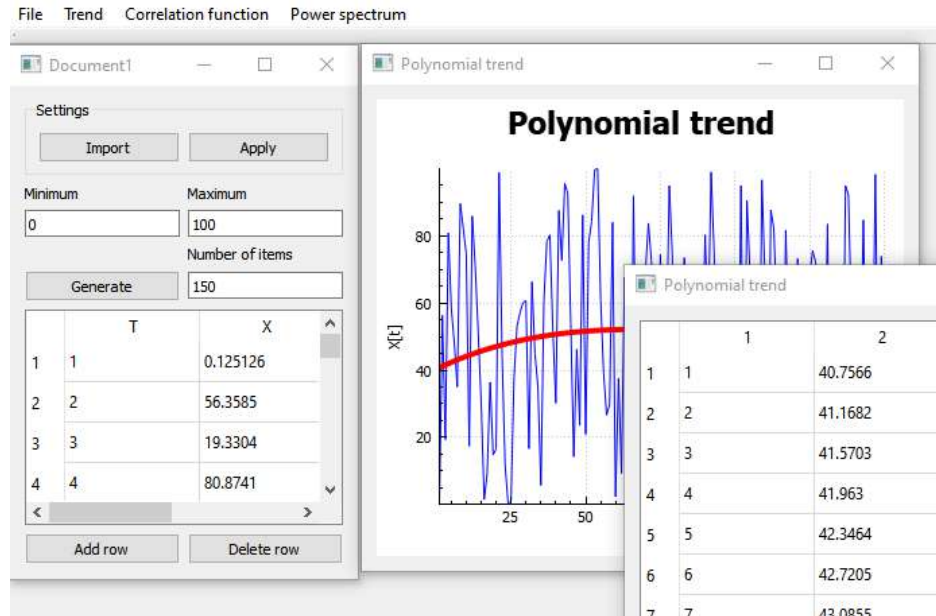

Figure 5. Main window of the degradation trend module.

3. Conclusion

Thus, this paper presents the results of developing the general structure of the ES and separate software modules that are part of the EMC ES for optimal design of radio-electronic equipment. In the future, it is planned to develop a common interface for the entire ES, as well as an intelligent core module.

Acknowledgments

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