Improving satellite ranging equipment engineering algorithm by utilizing an expert system

Andrey N. Zotov
HSE Tikhonov Moscow Institute of Electronics and Mathematics
ul. Tallinskaya, d.34
Moscow, Russia
azotov@hse.ru

***Abstract*—This paper discusses shortcomings of the modern equipment design algorithm and proposes usage of an expert system as one of the tools for improving the algorithm. Problems of creating such a system are discussed. An expert system for satellite ranging equipment engineering process is developed.**

***Keywords*—CAD, expert system, reliability**

I. Introduction

Constant growth in the level of technology leads to an increase in the functionality of radio engineering devices and, accordingly, of the complexity of their structure. For each new generation of equipment, more and more requirements are put forward for their characteristics and parameters, including reliability. Technologies are permeating an increasing number of fields of human activity, making it possible to automate or perform some activities at all. The field of satellite laser ranging (SLR) is not an exception, the equipment of which makes it possible to improve the quality of the use of satellite navigation systems.

Global satellite navigation systems have shown their suitability for performing a variety of tasks: geodesy, navigation, satellite monitoring of transport, cellular communications, and their use in the military filed is difficult to underestimate. One of the main characteristics of any satellite navigation system is its accuracy. To achieve high positioning accuracy, precise geodetic, ephemerides and time-frequency support of the satellite navigation system is required, and there is no better system than a laser rangefinder to ensure these parameters. The laser rangefinder allows both measuring the distance to the satellite and synchronizing or transmitting the exact time to the satellite. To ensure high accuracy of geolocation, more and more stringent requirements for the accuracy of range measurements and time registration are put forward to modern laser ranging systems. In addition, frequent unfavorable weather conditions and a rigid schedule for working with satellites make each range measurement session a responsible task, and equipment failure before or during a session is unacceptable. A quick repair or replacement of a faulty component also does not guarantee the measurement, because the duration of a measurement session is often limited to minutes. Accordingly, to work in such conditions, complex, high-precision, reliable and fault-tolerant equipment is required.

Advances in technology have transformed the design process in factories. The advent of computer-aided design systems (CAD), product lifecycle management (PLM) systems, as well as other automated tools, made it possible to simplify and accelerate the design of electronic equipment and other products. The use of automated tools and automation in general is the standard of the modern manufacturing industry and beyond.

A modern design engineer must have a deep knowledge of many science fields related to the design process, as well as knowledge specific to the subject area of the enterprise. The abundance of various modern software tools made it possible to simplify and automate the development process, but also led to the problem of a narrow specialization of engineers (the so-called "one-button engineer"). An engineer, especially a beginner, has enough knowledge in his field to perform his direct duties, but often it turns out to be a simple skill of working with some CAD program. Only a lot of experience will allow the engineer to design considering the influence of, for example, heat, vibration, radiation, electrical interference, and reliability characteristics. Although these parameters are nonetheless verified and monitored by other people in other departments at later stages of the design, ensuring the reliability characteristics in the early stages will allow more time to fine-tune the product, which will lead to more reliable products.

The developer's lack of the necessary knowledge in the field of reliability leads to a slowdown in the design process, since The calculation of reliability parameters is usually performed by reliability specialists located in another department, and in order to perform reliability modeling, the developer needs to transfer a large amount of information about the product being developed to the reliability department [1].

This disunity, as well as the underestimation of the required level of quality and the amount of initial data for calculating the reliability leads to an increase in the cost, development time and negatively affects the reliability of the final device. Developers do not aim to create a reliable device, they simply strive to create a device that works here and now.

Analysis of a SLR station's operation log showed that about a third of total electrical equipment's faults were due to design failures (see Fig. 1).

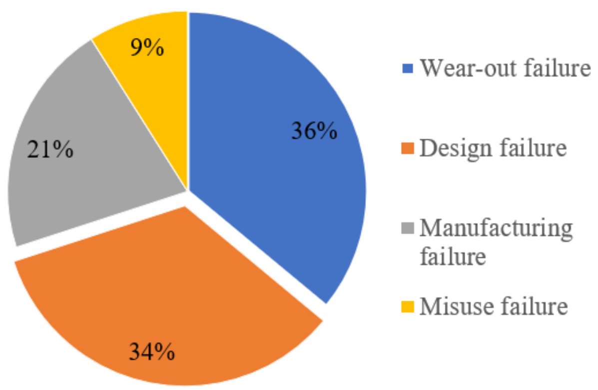

Fig. 1. Faults distribution of an SLR station's electrical equipment

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To solve this problem, an improvement of engineering process is suggested in [2]. In short, this improvement aims to help engineers design reliable equipment/hardware by introducing some level of automation into the process of controlling reliability characteristics while in the design stage. Since an engineer knows neither the process of setting up reliability calculation, nor how to interpret its results into actual improvements of reliability, a set of tools is required to help with these processes. This paper discusses the tool which interprets reliability calculation results to actual improvements of reliability and thus, automates decision taking — an expert system (ES).

II. Usage of expert systems in the engineering process

Expert systems proved to be useful in many fields [3]. Usually, an ES is dedicated to finding best solution of a problem in some subject area. Expert systems must be constrained by a certain filed of knowledge, a narrow field of expertise is where they work best [4].

A. *Expert system sctructure*

Base structure of an expert system is show on Fig. 2. The structural elements that make up the expert system perform the following functions.

- The knowledge base contains facts and rules according to which, depending on the input information, a particular decision is made. Knowledge in the knowledge base is presented in a specific form, and the organization of the knowledge base makes it easy to define, modify and replenish. The knowledge base implements functions of knowledge representation in a specific subject area and their management.
- The working memory is intended for storing the initial data and the intermediate facts of the problem being solved at the current moment. As a rule, it is located in the computer's RAM and reflects the current state of the subject area in the form facts with confidence coefficients of the truthfulness of these facts.
- The explanatory module forms the conclusion of the expert system and presents various comments attached to the conclusion and explains the reasons for the conclusion.
- The inference engine performs inferences based on the knowledge available in the knowledge base. General knowledge about the process of finding a solution is called a mechanism of inference. It performs two main functions: addition, changing the knowledge base based on the analysis of the knowledge base and initial information, and managing the order of processing rules in the knowledge base.
- The knowledge acquisition module is necessary for obtaining knowledge from an expert, supporting the knowledge base, and supplementing it if necessary.
- The graphical user interface (GUI) is necessary for the correct transmission of answers to the user, otherwise using the system is extremely inconvenient. End user or a knowledge engineer along with an expert interact with the ES by the means of the GUI.

The listed structural elements are the most typical, although in real expert systems their functions can be appropriately strengthened or expanded.

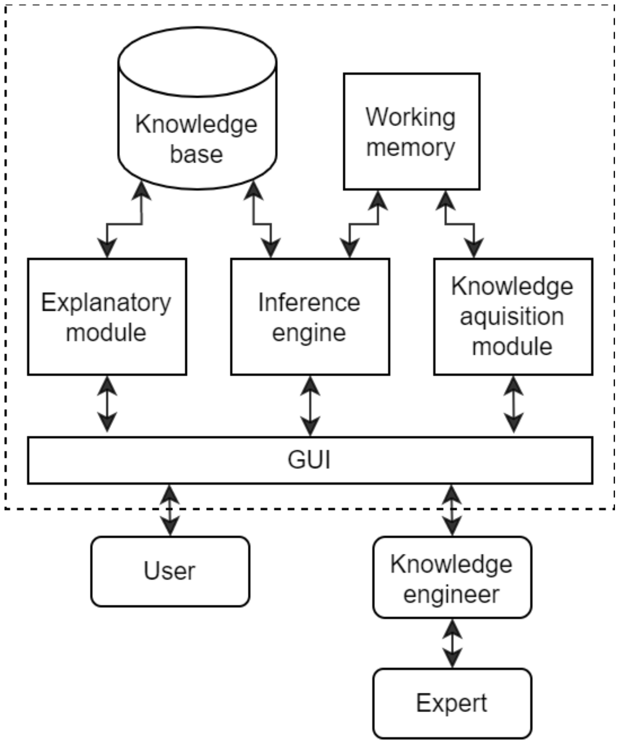

Fig. 2. Conventional expert system structure

B. *Expert system in an SLR equipment problem domain*

So, for an ES to be applicable in the process of equipment design, and to give recommendations which would improve the design in terms of reliability, knowledge base of an ES has to consist of data relevant to the system for which the equipment is being designed for. For example, technical conditions for some satellite are going to be different from technical conditions of an MRI scanner. There are similarities for sure, these machines both use electrical components, they may even share some, and the processes in and between these components are well known, but the structure, environment of operation and a lot of other things are different. And these differences render usage of one expert system for all intents and purposes impossible. The more nuances an ES knows the closer it will be to giving a meaningful and relevant solution. So, for demonstration purposes, the process of creating the expert system will be shown on a satellite ranging equipment field. Creating such system aims to show advantages of its usage and its positive impact on the reliability of equipment.

One of the processes in creating radio devices of a SLR station is designing electrical circuits, and for that, an electronic design automation software package is used. The task of automating the calculation of reliability parameters was taken over by various software systems, such as Windchill Risk and Reliability, Lambda Predict, iQT or ASONIKA. These complexes allow not only to automatically make calculations, but also to do it for users without experience in the field of reliability. A major downside of these systems is the need for a lot of initial calculation data, which somewhat complicates otherwise automated process of reliability prediction [1,5].

After the engineer has finished the design, it is evaluated by the reliability department, and in the case of inadequate results, the design is sent back to the engineer (see Fig. 3).

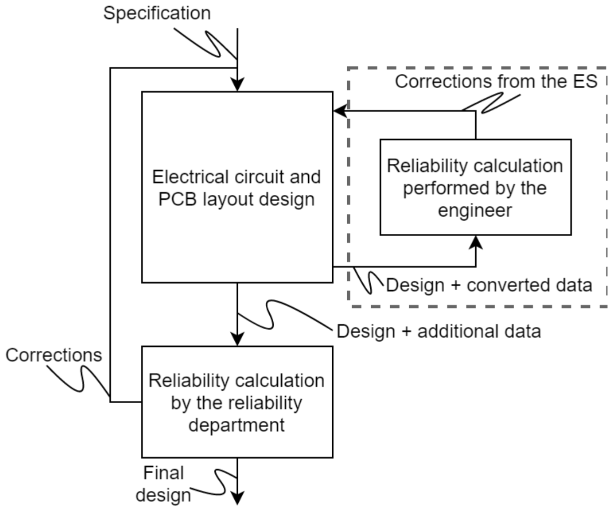

Fig. 3. Modern engineering algorithm and the proposed change

The proposed improvement of the engineering process changes the algorithm to the one shown on Fig. 3 (dotted line area). To make that work, aside from the process of automatic data conversion into reliability software which is discussed in [5], an expert system must be able to solve a number of problems.

Since the expert system must give recommendations on improving reliability of electrical circuits, it must have some way of calculating it and choosing the most adequate solution. There are several ways to improve reliability on this development stage.

- Alleviating modes of operation of overperforming components.
- Replacing electrical component with a more reliable one.
- Reserving elements.

And for an expert system to perform most of calculations necessary for choosing the most appropriate reliability improvement method, the most reasonable course of action is to attach the expert system to a reliability prediction software package. This way, the ES will gain access to all the mathematical models, databases of electrical components of the software, thus extending the number of tools and information available for usage in the process of synthesizing a recommendation (see Fig. 4). Although some mathematical models do have to be included into the ES, for example, models for calculating thermal radiation and heat transfer.

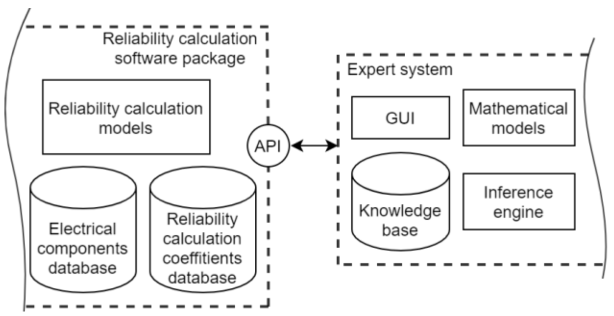

Fig. 4. ES and reliability calculation software relation

The expert system also must have a graphical user interface for the purpose of interacting with it. The ES must contain a representation of the SLR's equipment in some shape or form. And the more details the ES contains in its knowledge base, the better it's predictions will be.

So, for a quality representation of real-world equipment the GUI has to offer user-friendly controls for inputting the information. Knowledge acquisition must also include past equipment failures. Taking this into account, a good tool for building the expert system would be CLIPS. To create expert systems CLIPS uses two main constructions: rules and facts. Facts can be both ordered and unordered, they are called templates, or frames. A powerful rule creation tool includes the ability to prioritize rules. CLIPS supports seven different strategies conflict resolution: depth strategy, breadth strategy, simplicity strategy, complexity strategy, LEX strategy, MEA strategy and random strategy. CLIPS allows to interface with multiple traditional programming languages such as C++, C#, Java, etc. [6]. Although its inference engine uses forward chaining, it is possible to implement a backward chaining algorithm. CLIPS in conjunction with a GUI will and a reliability prediction software package meets all the requirements of a tool which helps engineers design reliable equipment.

III. DELEVOPING THE EXPERT SYSTEM

The currently revamped ASONIKA-K-SCH was chosen as the reliability prediction software package as it allows to use its reliability calculation engine and electrical component databases through an application programming interface (API). The expert system is integrated into the package to support the process of reliability calculation. The GUI is built using Windows Presentation Foundation (WPF) graphical subsystem.

All the data from the experts was formalized and inputted in the knowledge base. The complete structure of the SLR system, the subsystems, the submodules, the signals which are sent and received, the reliability calculation projects, past faults and the causes of these faults were inputted to the expert system to fill its knowledge base. Data were gathered from multiple human experts who worked in this field for a considerable amount of time. Due to a lack of human resources an unstructured interview was used as the method of knowledge acquisition from the experts. The acquired data were then categorized, formalized, and inputted into the knowledge base by the knowledge engineer. Since CLIPS uses production model for storing rules, all the data had to be converted to “IF=>THEN” structure.

The GUI of the expert system uses "blocks" to represent an element of the system. Blocks are laid out in a tree-like form, from top to bottom abstraction levels (from SLR system as a whole to each submodule and its electrical components), so each element has a parent and children blocks. Blocks have a set of properties, which contain the information about the signals it uses, the faults it had in the past, and other relevant data. This structure is converted into CLIPS code, an example of which is shown on Fig. 5. Since by default CLIPS uses forward chaining reasoning algorithm it is only possible to predict faults based on the submodule's reliability calculation and previous faults, but incorporating backward chaining algorithm allows the ES to perform the reverse operation and find the reason of a fault that already happened.

```
(deftemplate module
   (slot id)
   (slot type)
   (slot parent (default none))
   (slot response (default none))
   (multislot children (default none)))
   (multislot prev-failures)
   (multislot signals))
```

Fig. 5. Example of a module template in CLIPS

One of the expert system's GUI windows is shown on Fig.6. This window is used for editing module's submodules and the utilized electrical signals. Rounded squares represent the submodules, green circles – outcoming signals, purple circles – incoming signals. Knowledge engineer builds a representation of equipment using these tools.

After the reliability calculation user can request an analysis of the results. The expert system then begins to evaluate the possible changes of the design. It recalculates the reliability values using all of the values of ranged coefficients and finds what change is easiest to implement but has the most impact. For example, if a calculation has shown that voltage regulator D1 has a high value of failure rate, then the expert system may suggest lowering the temperature of D1 by a certain amount of degrees. But if the estimated cost of lowering the temperature is too high, e.g. temperature of the component is 32°C and the ambient temperature is 30°C, the ES will rate this solution lower in the ranged solution list. In the end, this list is presented to the user and they can choose a suitable solution from it.

The ES also allows to traceback failures of subsystems or modules to the components which may have failed and halted the operation of the system. This is done by combining data from previous faults, information about the relations of the submodules, and reliability prediction data (e.g. electrical components with highest fault rate may have caused the failure). During this process user chooses the faulty unit in the modules tree structure and answers the expert system's questions with "Yes" or "No" answers. The ES will ask the user to perform some real-world checks (e.g. checking a voltage level of an electrical signal). State of operation and current session can be saved and loaded and continued later.

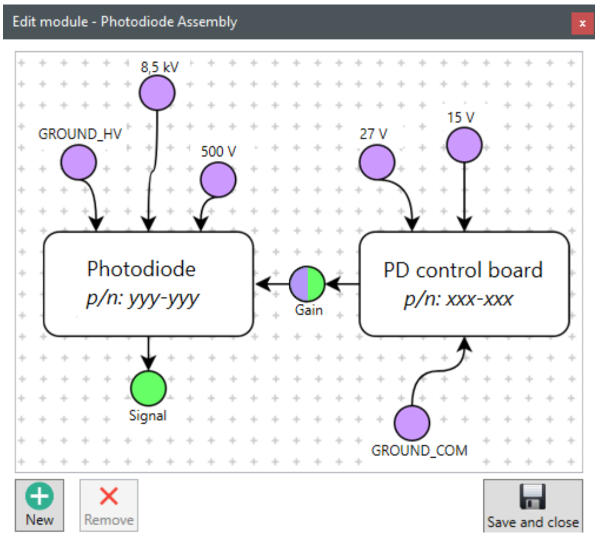

Fig. 6. Module editing window

The backward chaining algorithm is implemented by defining a consequent and antecedent of a rule as fact, making the consequents of these rules goals to be resolved. If this rule has an antecedent then the antecedent becomes a goal, if it has no antecedent, then a "conclusion" fact is created. Facts called "answers" are used to confirm or negate a goal. See [7] for detailed information.

One of the more important aspects of using an expert system is that it can display its way of reasoning, e.g. which and in what order rules were triggered and which facts were synthesized in the process. This heightens the level of trust to the expert system. The reasoning process, and the conclusions of the ES to a greater extent, were compared with the ones inferred by the human expert when presented with the same problem to verify the accuracy of the expert system.

IV. Conclusions

- Using an expert system by an engineer as tool for controlling equipment's reliability on the design stage will improve final reliability characteristics as it minimizes the amount of design failures of the system. For current generation of SLR stations it will lessen the amount of failures by a third.
- An expert system must utilize a set of external tools to give accurate predictions in the field of reliability calculation. Pairing an ES with a reliability prediction software package benefits the both, expert system gets access to electrical components database and reliability calculation mathematical models, while reliability prediction software can now present a clear and concise recommendation of improving reliability characteristics.
- The developed expert system along with the data converting tools [2] seamlessly integrate into modern design process and allow to achieve better quality of equipment by moderately altering the engineering algorithm.

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