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INTELLIGENT SYSTEM APPLIED IN ENGINEERING DESIGN EDUCATION PROCESS

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ABSTRACT
The paper presents the use of intelligent consultative computer system in engineering design education process. The system presented is able to advise the students how to perform design, especially at design verification and redesign phase. It helps and guides the students through the post-processing phase of the structural analysis and suggests them the appropriate redesign actions in case the structure is under- or over-dimensioned. Moreover, the ability of the system to explain the inference process and to present details on the proposed design actions enables the students to acquire some new knowledge. The application of the system is presented on a practical example of the student design project, dealing with design of an ice axe, which is a typical product that needs to be analysed and optimised for two obvious reasons. Fist, there is a safety aspect that have to be addressed following special standards, where some structural tests are precisely prescribed. On the other hand, the ice axe is mountaineering equipment that should be as light as possible, which requires highly optimal design solution in terms of material use.

Keywords: decision support, analysis-based design improvement, ice axe design

1 INTRODUCTION

The design education process has a very important role, as design is a highly complex activity with a significant influence to overall success of the new product on the market. Nowadays the use of Computer Aided Design (CAD) tools in design process is natural. Thus, the students in their study also acquire modern design methods and tools that increase creativity and productivity, and can lead to quality improvement for the new product. CAD tools, like geometric modellers and programs for Finite Element Analyses (FEA), are very useful and commonly used tools in education process.

Most of the students are usually very creative and innovative, but they have lack of knowledge and foremost lack of experiences. This deficiency is most obvious in the later design phases, when their proposed design needs to be examined and verified. Quite often, they do not understand basic principles of design and FEA results. Consequently, they make wrong conclusions, despite the extensive use of CAD tools. Mostly very sophisticated software is usually used as a black box, and can provide technical support, but fail to help the students with advice when needed.

In order to help the students to deal with this problem, we developed a prototype of the intelligent consultative computer system, which is able to advise the students how to perform design, especially at design verification and redesign phase. This paper presents the use of the prototype mentioned above in our design education process.

Design is an iterative process. How many iteration steps are needed directly depends on the quality of the initial design and later design changes. Basic parameters for design improvement process are often the results of some engineering analyses. In mechanical engineering practice FEA [1] is the most extensively used numerical method to simulate and verify the conditions in the structure during its exploitation.

The post-processing phase of the engineering analysis represents a synthesis of the whole analysis and is therefore of special importance. It concludes with the final report of the analysis, where the results are quantified and evaluated with respect to the next design steps that have to follow the analysis in order to find approved design solution.

Nowadays FEA software is very helpful at this point, as it offers an adequate computer graphics support in terms of reasonably clear pictures showing a distribution of unknown parameters inside the body of the structure. However, the user still has to answer many questions and solve many dilemmas in order to conclude the analysis and to choose the appropriate redesign steps. Figure 1 shows basic algorithm that the user, in our case the student, have to perform in order to conclude the analysis-based design improvement process.

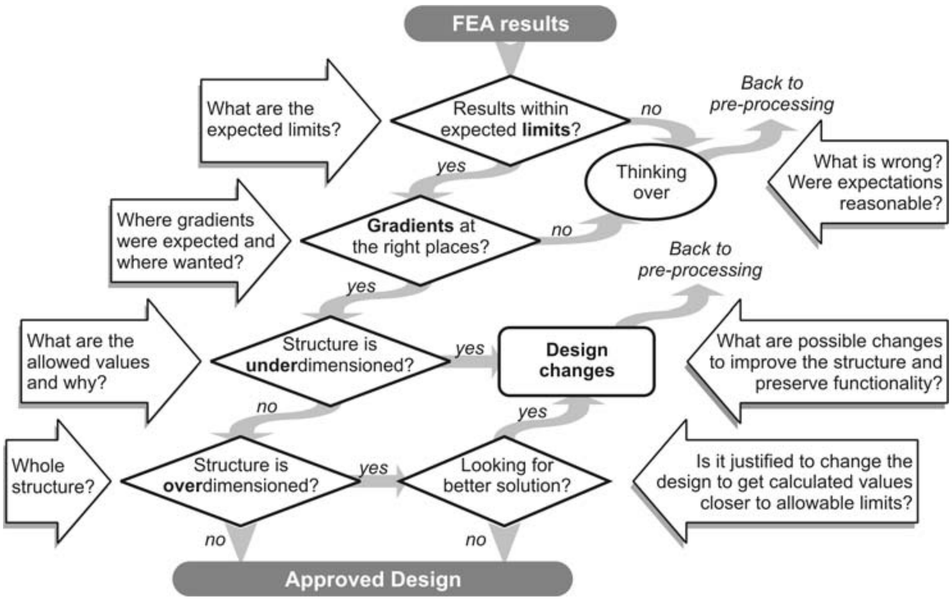

Figure 1 Some crucial decisions in FEA-based design improvement process

It is obvious the algorithm presented requires a lot of knowledge and experience, not only in the area of analysis application, but also in design, giving the word design its broadest meaning. The designer has to be able to judge, whether the results of the analysis are correct and reliable, and also to decide what kind of design changes are needed, if any. Most of the mechanical engineering design students need intelligent advice to perform the analysis' results interpretation and consequent design improvement process adequately. Unfortunately, this kind of help still cannot be expected from the present FEA software. The traditional systems are rather concentrated on numerical aspects of the analysis and are not successful in integrating the numerical parts with human expertise.

3 PROPOSE – INTELLIGENT CONSULTATIVE SYSTEM

A prototype of the intelligent system, named PROPOSE, has been developed to support engineering design education process [2]. PROPOSE provides a list of redesign recommendations that should be considered to optimise the structure considering the results of a prior analysis. As a rule, there are several redesign steps possible for design improvement. The selection of one or more redesign steps that should be performed in a certain case depends on the requirements, possibilities and on wishes.

The most important part of the system is the knowledge base. The theoretical and practical knowledge about design and redesign actions are presented within the system in form of production rules. As it can be seen in Figure 2, the knowledge base of the system is consisted of many different types of rules and facts that are necessary for the system to be functional. For example, several rules are needed just to define the status of the structure (not stiff enough, under-dimensioned, over-dimensioned or satisfactory). However, from the technical point of view, the most important rules in the knowledge base are those defining redesign recommendations.

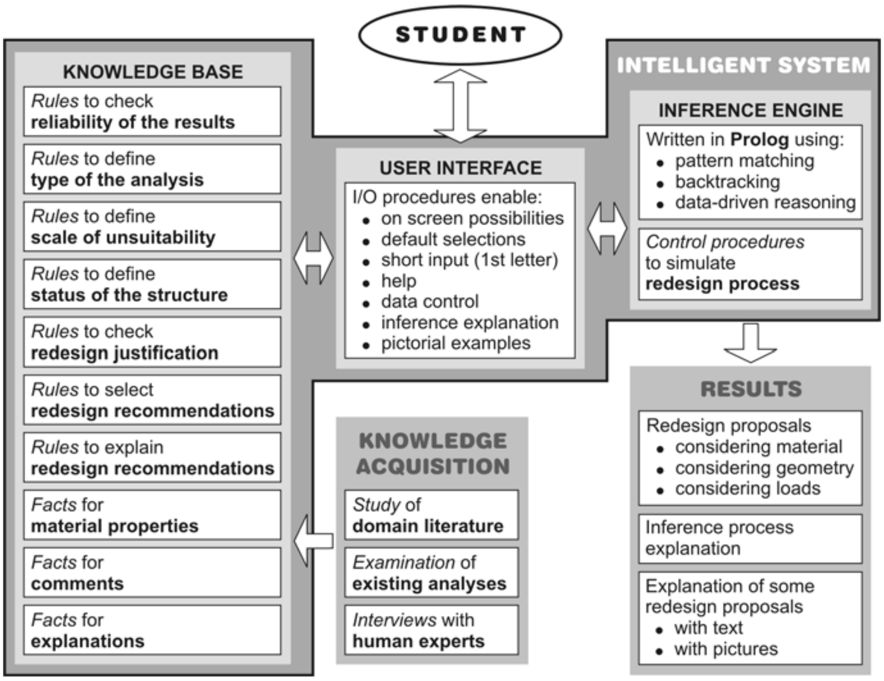

Figure 2 Basic architecture of the intelligent consultative system PROPOSE

The system is encoded in Prolog that was chosen because of its built-in features such as rule-based programming, pattern matching and backtracking [3]. Our work was concentrated on declarative presentation of the knowledge, using data–driven reasoning, which is built in Prolog. However, some control procedures were also added to the inference engine of the system to adjust the performance to the real-life design process.

For the user interface, our goal was to simulate the communication between the student and design expert. As presented in Figure 2, the user interface has many features including help, which enables the efficient and user-friendly communication. It is however evident that PROPOSE is a prototype which is still the subject of research and, as such, cannot be compared with commercial software.

4 APPLICATION OF THE PROPOSE SYSTEM IN DESIGN EDUCATION

The application of the PROPOSE system is based on interactive communication between the user and the system aiming to define the status of the structure and to generate the list of redesign proposals if applicable. The use the system is reasonable when the results of the analysis are available and also reliable. The system emphasize the importance of the results' reliability and offers some basic guidelines to help the student to clarify as to whether for example FEA results are reliable and can serve as basic parameters for verifying the design's suitability.

The current version of the system can deal with strain-stress or thermal analyses. The students need to know the allowable values for the structure being analysed. Considering the range of differences between the actual computed maximum values and allowable limits, the system defines the status of the design candidate, and the scale of design changes that need to be done to improve the structure. If design changes are advised, they should also be justified. As in most of the other cases, the students can obtain some help from the system when making this decision.

In order to generate the recommendations for design improvement, critical area where computed values exceed the allowable limits needs to be defined. For the time being, the system can deal with two types of structure: beams and general three-dimensional structures. A qualitative description of the critical area is supported by a list of predefined features, as for example: around the hole, notch area, in corner, etc. Critical area should be defined as generally as possible, to cover the majority of problems that may occur in practice. Presently, the number of predefined geometric features is relatively small. However, by answering some additional questions, a critical area can be described in a more detailed manner.

For each problem, the system searches for redesign proposals in the knowledge base and presents them on the screen listed in three groups, first referring to material changes, the second to geometry changes, and the last type of proposals referring to the loads. The students can get insight into the inference process or obtain more information about certain redesign proposals. In many cases, the pictorial explanation is also available.

5 CASE STUDY – DESIGN OF AN ICE AXE

Complex, expensive and time consuming analysis-based design improvement is justified and makes sense when the product needs to satisfy certain structural and other specific criteria. Usually, mass production where even small savings per single product can lead to significant savings for the whole production quantity is the other important criteria. Ice axe is a good example of such a product, as it needs to fulfil very strict structural criteria and at the same time it needs to be as light as possible. For this reason, it was chosen as one of the case studies to be analysed and optimised by two students, applying the PROPOSE system, as it is presented in continuation of this chapter.

5.1 Ice axe introduction

An ice axe is a piece of special mountaineering equipment. Considering the strength, two types of ice tools exist. In the project presented here, the basic type with lower strength for use in general circumstances as on glacier for snow hiking, for ski mountaineering etc., was a subject of students consideration. The material of the ice axe should be as light as possible, while at the same time it has to ensure the strength and toughness at low temperatures. There are several static, dynamic and fatigue test methods and requirements prescribed for the ice axe in special standards [4]. One of these tests is shown in Figure 3.

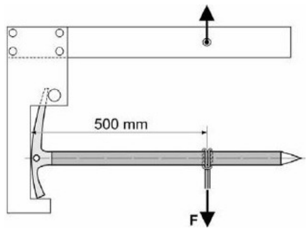

Figure 3 One of the static tests for the ice axe [4]

5.2 Intelligent analysis-based optimisation of an ice axe design

The optimisation of the ice axe design was performed in step-by-step manner [5]. First of all, a simple initial design was made in geometric modeller. This model and each consecutive design candidate was then analysed according to the tests and requirements prescribed by the standard. After every analysis, the students used PROPOSE system to get some recommendations for further design improvements. Figure 4 presents an example of the recommendations provided to the students by the PROPOSE system.

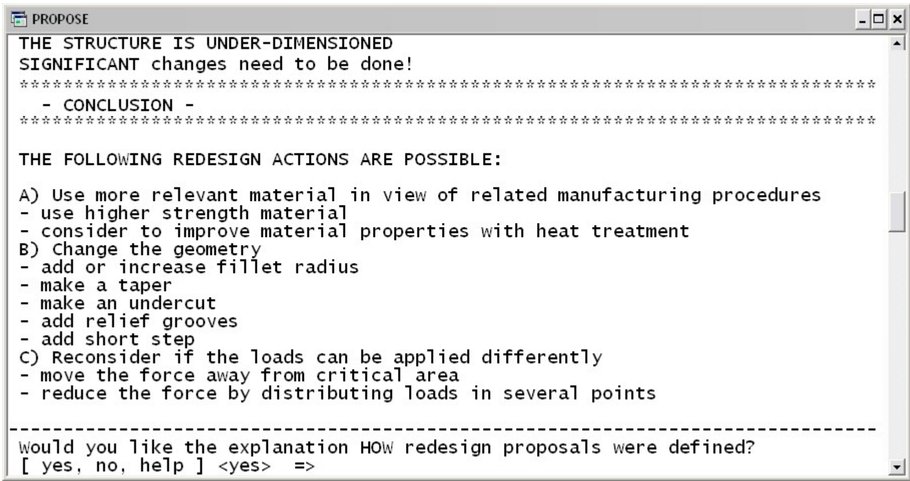

Figure 4 Screenshot of the PROPOSE application – design recommendations

In process of improving the ice axe design the students applied all three possible types of design changes. The first FEA results for the axe “made” entirely from aluminium alloy clearly shown, that the pick of the axe is not strong enough. As a consequence, it was decided to design the axe as a combination of the steel pick and aluminium shaft. The position of the juncture between both parts of the axe was chosen carefully to move the force from the critical cross-section area.

However, most of the changes addressed the geometric appearance of the axe being optimised. In earlier design optimisation phases, geometry was changed in order to improve the strength and stiffness of the structure, while later geometric changes were applied to the ice axe design to make the structure lighter and at the same time to prevent the structural properties achieved earlier. Following the optimisation procedure described above, the final design of the axe pick was reached in four consecutive analysis/design steps, as shown in Figure 5.

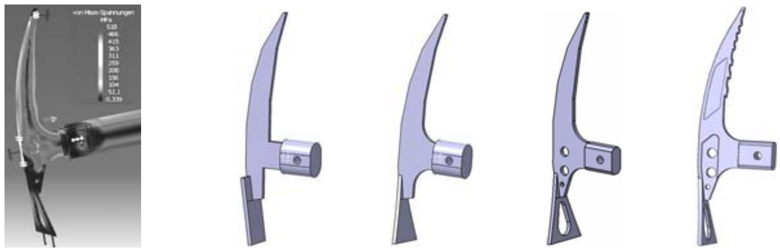

Figure 5 FEA results and design improvements for the ice axe pick (from left to right)

6 CONCLUSIONS

The paper presents an example of the intelligent computer support to design education process. The intelligent system PROPOSE is applied to provide support and advice to inexperienced mechanical engineering design students, dealing with analysis-based design improvement. The lack of experience can not be fully compensated by a rule-based system. However, the application of such intelligent tool can be very helpful and can prepare the students for their future engineering profession in which they will be confronted with various tools, including intelligent computer systems.

When using the PROPOSE system, a student has to answer some questions stated by the system to present the results of the engineering analysis qualitatively, with emphasise on the critical area that needs to be optimised. These answers are then compared with the rules in the knowledge base, and the most appropriate design changes are determined, recommended and explained to the student. The system provides constant support to the student's decisions in terms of explanations, advice and explanation of the inference process. The students that were using the system have very positive opinion on the usefulness and usability of it.

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