Application of knowledge engineering in spacecraft overall design

Hanmo Zhao*, Zhaowei Sun, Hongzhu Zhang

Research Centre of Satellite Technology, Harbin Institute of Technology, Harbin, China

E-mail: 18S018065@stu.hit.edu.cn

Abstract. This paper proposes an advanced technology in spacecraft overall design based on knowledge engineering. Knowledge engineering is a branch of artificial intelligence. Applying knowledge engineering technology to improve the efficiency and quality of overall design process and enhance the automation of overall design, moreover focusing on solving overall spacecraft design knowledge representation, knowledge evaluation, knowledge acquisition, knowledge inference and related issues. Unlike the existing methods, this paper uses ontology technology to build a pint-sized spacecraft overall design knowledge base under proté gé software environment, which achieves a better performance. Finally, simulations for the designed power subsystem based on the knowledge base are performed, and the simulation results validate the effectiveness, reliability, of the power subsystem designed by the method of spacecraft overall design based on knowledge engineering.

1. Introduction
Spacecraft overall design is the supreme stratum of spacecraft system research and development. Due to spacecraft system research and development is a modern system engineering, which has great scale, complicated systems and variety of technologies, innovativeness is one of the most required character in spacecraft overall design. The increasingly stringent requirements on short research and development cycle and tight budget require that advanced methods be developed for the new generation spacecraft overall design [1,2]. Taking power subsystem for example, the main function of the electrical power subsystem is to generate and deliver electricity to all points of utilization on the spacecraft. The generated electricity must satisfy the power and energy requirements of the subsystem, be within the component ratings and voltage limits, as well as considering planned and unplanned usages of the spacecraft. J. Terrile et al. used evolutionary computation techniques for the early design search and optimization of power subsystem to demonstrate the feasibility, application and advantage [3].

In recent years, knowledge engineering as a branch of artificial intelligence and core content of future manufacturing development applied in the engineering, with the rapid development of artificial intelligence. Seshasai and Gupta presented a knowledge-based approach to facilitate the engineering design process relating to spacecraft [4]. The approach described provides a framework of knowledge acquisition, knowledge discovery, knowledge management, and knowledge dissemination. In addition, through the capture of the needs of every stakeholder in the process, as well as the details of the major decisions and rationale, one can support effective knowledge transfer between teams without requiring
intense face-to-face interaction. Such a knowledge-based framework can have a tremendous impact on the design process, by providing designers with all relevant sets of information.

In knowledge engineering domain, using ontology technology to demonstrate concepts and related relationships of knowledge has the advantage of accurate, consistent, and standardized semantic expression [5]. The ontology is very suitable for the representation of large-scale knowledge bodies that can be shared. Specifically, the knowledge of design criteria in spacecraft engineering can be stored in the knowledge model and use a source of knowledge to provide a base for the early conceptual design of spacecraft. Ontology is an effective approach of acquiring, organizing the domain expert’s knowledge allowing reusability of existing knowledge.

Motivated by the preceding discussions, this paper addresses how to model the knowledge base of spacecraft overall design based on ontology technology, which promotes the acquisition of essential knowledge in Knowledge-Based Engineering. Improving the problem of low reuse rate and serious fragmentation of knowledge of spacecraft overall design by solving the knowledge representation, knowledge evaluation, knowledge acquisition, and knowledge inference of the spacecraft overall design process. Finally, the power subsystem is chosen for an example, and simulation results demonstrate the effectiveness of the method of spacecraft overall design based on knowledge engineering.

2. Design and Construction
Project of spacecraft overall design and subsystems design should be provided and optimized in the stage of spacecraft overall design. Protociling, harmonizing, optimizing, and controlling every parameter and performance index is the key to design out spacecraft with mission requirement satisfying and technology index completing. The knowledge base of spacecraft overall design was built in four steps: knowledge representation, knowledge evaluation, knowledge acquisition, and knowledge inference.

2.1. Knowledge representation
Representing the knowledge of spacecraft overall design is important precondition of the process of spacecraft overall design. This paper uses the concept of design process ontology that basing on the ontology representation of knowledge to express the design activity as the basic element of the process of spacecraft overall design. Through describing the relationship between design activities to reflect the hierarchical and information transfer relationship of design activities.

Design $O_{PRO}$ as the process ontology. In spacecraft overall design, every $O_{PRO}$ can be considered as a system that converts externally input to the desired output by applying related technology and essential method. The form of $O_{PRO}$ is as follows:

$$O_{PRO} = \{K_I \land K_{T&M} \land K_A = K_O\}$$  \hspace{1cm} (1)

Define $\land$ is interaction between different knowledge, $K_i$ denotes input knowledge about $O_{PRO}$, $K_{T&M}$ denotes related technology knowledge and essential method knowledge about $O_{PRO}$, $K_O$ denotes input knowledge about $O_{PRO}$.

The spacecraft overall design is divided into five levels to build the knowledge ontology. The following focuses on the first-level process ontology $O_{PRO1}$ structure.

![Figure 1. First-level process ontology $O_{PRO1}$ structure.](image-url)
DAN denotes design activity serial number, KOL denotes knowledge ontology level. Under task demands as the input of the first-level ontology, spacecraft overall design scheme as the first-level ontology output is obtained through the interaction inside the first-level ontology.

2.2. Knowledge evaluation
Spacecraft overall design knowledge quality evaluation is the important part of overall design knowledge base construction technology. It is also an important guarantee to ensure that the source of design knowledge is correct and can be effectively reused. Guarantee the quality of the knowledge base by setting a confidence threshold and discarding knowledge with low confidence. Designed a knowledge quality model of spacecraft overall design, based on the CKQM proposed by Jun. Liang et al. [6]. And support designers to flexibly develop knowledge quality evaluation functions according to their business needs.

\[
\text{CKQM} = \langle C_D, C_i, C_A, C_{Os}, C_R, C_W, C_M, C_S \rangle
\]  

(2)

2.3. Knowledge acquisition
There is a large amount of explicit knowledge and tacit knowledge in the spacecraft overall design. Explicit knowledge refers to mathematical formula, rules, and definitions that can be formalized. Tacit knowledge refers to skills and empirical knowledge derived from people engaged in the activity [7]. This paper uses the concept map representation to card the spacecraft overall design process, and cooperate with OPRO structure to acquire knowledge.

![Conceptual map of spacecraft overall design](image)

**Figure 2. Conceptual map of spacecraft overall design**

2.4. Knowledge inference
In the stage of the spacecraft overall design, using the examples that have been extracted into the knowledge base for inferring. And it is possible to mine deeper tacit knowledge between design elements, thus solving the problems encountered in knowledge acquisition. This paper uses the method of inference engine to conduct rule-based reasoning (RBR). RBR abstracts the knowledge and experience of experts into production rules in several inference processes. The basic inference process is as follows.
Figure 3. Structure of RBR inference engine
①: Enter the rules that need to be executed into the working storage.
②: The working storage reads fact knowledge from the case base.
③: The rules matcher reads rules from the working storage.
④: The rules matcher reads fact knowledge from the case base.
⑤: Pass the successfully matched rules to the conflict resolver.
⑥: The conflict resolver enters the rules that need to be executed into the scheduler.
⑦: Enter the result of the rule execution into the working storage.
⑧: Update the execution results to the case base.
⑨: Output the result of the rule execution.

3. Simulation Results
Build the spacecraft overall design knowledge model in the environment of protégé software. Since the overall design of the spacecraft involves too much knowledge and the length of the article is limited, only the building of the knowledge model of the power subsystem and the simulations results are presented.

Table 1. Design results of power subsystem.

| Parameter                          | Value       |
|------------------------------------|-------------|
| Total Number of Solar Array Segments | 6           |
| Total Number of Solar Array Strings | 18          |
| Battery Technology                 | Li-Ion      |
| Battery Nameplate Capacity (amp-hrs) | 12.5        |
| Bus control method                 | Shunt limiter |
| Bus Voltage                        | 24.5-29.4   |
| Mass of Solar Array Cell           | 0.45kg      |
| Mass of Battery Cell               | 2.3kg       |
4. Conclusions

In this paper, with respect to the defects of traditional design methods, intelligent design method based on knowledge engineering for spacecraft overall design is proposed. The four key technologies of knowledge representation based on ontology, knowledge evaluation based on CKqM, knowledge acquisition based on concept map, and knowledge inference based on inference engine are studied. In the knowledge representation section, this paper introduces the description of process ontology and its method for constructing spacecraft overall design model. In the knowledge evaluation section, this paper references the concept of CKQM, and established a model for evaluating the knowledge of spacecraft overall design, to ensure the reliability and accuracy of knowledge sources. In the section of knowledge acquisition, this paper applies the acquisition method based on concept map, and draw a concept map of spacecraft overall design. More importantly, the power subsystem based on knowledge engineering is taken for an example in the design and analysis. Simulation results illustrate the advantage of knowledge-based engineering method in terms of reduction in time consuming and laborious. Credible design concepts for a spacecraft power subsystem can be generated in an hour and a space power subsystem resource and performance simulation in a parallel processing environment. The results also seem to indicate that the speed of automated design generation appears to be driven primarily by the knowledge model size of the mission to be established and speed of the processing hardware, rather than the number of design parameters to be optimized. Nevertheless, as promising as the results are there is still much work to be done before this technology can be used in the flight project design process. On the implement side, this approach also needs to be applied to other flight system subsystems. Once completed all of the subsystems need to be integrated together to provide more comprehensive design solutions. In the future, artificial intelligence techniques, such as context awareness can be utilized in the knowledge inference process to improve the automation and efficiency of building knowledge inference model.

References

[1] Liu C, Vukovich G, Shi K, et al. Robust fault tolerant nonfragile $H_{\infty}$ attitude control for spacecraft via stochastically intermediate observer, Advances in Space Research, Vol.65, No.9, 2634-2648, 2018.

[2] Shi K, Liu C, Sun Z, et al. A novel robust non-fragile control approach for a class of uncertain linear systems with input constraints, Transactions of the Institute of Measurement and Control, 2018: 0142331218799835.

[3] Richard J.Terrile, Mark Kordon, Dan Mandutianu, Jose Salcedo, Eric wood and Mona Hanshemi, ‘Automated Design of Spacecraft Power Subsystems’, 2006 IEEE Aerospace Conference.
[4] Satwiksai Seshasai, Amar Gupta, ‘Konwledge-Baed Approach to Facilitate Engineering Design’, Journal of Spacecraft and Rockets, Vol.41, No.1, January-February 2004.

[5] Hanmo Zhao, Zhaowei Sun, et al. Overall Conceptual Design for Spacecraft System Based on Knowledge Engineering. The 31st Chinese Control and Decision Conference, PID: WedAIS-26.

[6] Jun. Liang, Zuhua. Jiang, Jie. Chen, Lu. Zhen, Hai. Su, ‘The Dynamic Assessment Model and Approach of Case Knowledge’s Quality for Product Design’, Journal of Shanghai Jiaotong Universtiy, 2007, 01: 136-141.

[7] Yuli. Wei, ‘Research of knowledge acquisition’, Journal of Information, 2004, 04: 41-43.