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# AGENT BASED ENGINEERING DESIGN SIMULATION AND OPTIMIZATION UNDER UNCERTAINTY

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**ABSTRACT**

In this paper a multi-agent based simulation and optimization framework was put forward to solve the aleatory and epistemic uncertainty in engineering design. Agent structures were designed to extract engineering knowledge from experiments and simulation and to communicate an internal message and domain engineering knowledge base. The framework can deal with complicated time-varying structure analysis. A prototype simulation for working equipments of an excavator was developed. The research results provide a feasible methodology to fuse multidisciplinary uncertainty information in agent environment.

**Keywords:** *Multidisciplinary Optimization, Multi-Agent System, Uncertainty Reduction Theory, Time-Varying Structure*

## 1. INTRODUCTION

Uncertainty influences the engineering process and its final products. Today's enterprises must be responsible and able to tackle uncertainty due to competitiveness [1]. The conventional simulation and optimization framework for engineering design thus has been extended from deterministic to uncertainty, thus the designer not only consider the deterministic problems, but also solve uncertainty problems. It lead to a long and hard coordination for engineering design process. A unified framework to solve the aleatory and epistemic uncertainty engineering together is in need.

In engineering community, uncertainty can be divided into aleatory and epistemic uncertainty according to its origin [2]. Aleatory uncertainty results from variations associated with the inherent system or environment; while epistemic uncertainty results from lack of cognition on the system or environment. The methodologies for dealing with these two uncertainties are also quietly different. The former one is usually modeled with the theory of probability, and the latter one is usually modeled with Dempser-Shafer theory of evidence, possibility theory, rough set and interval analysis [3]. It is still a hard work to model the two uncertainty issues unified in engineering simulation and optimization. Du [4] uses evidence theory to quantify the effect of aleatory and epistemic uncertainties. In Ref. [5] an approach combined random variables with fuzzy variables is proposed to account for aleatory and epistemic uncertainties. However, the barrier between a unified theory supporting aleatory and epistemic uncertainty and a developed tool to simulate and optimize the performances of products still exists.

In an attempt to solve the aleatory and epistemic uncertainty engineering problems mentioned above in a unified environment. In this paper a multi-agent based simulation and optimization framework was put forward. This framework is designed on the basis of agent technologies. Agent structures were designed to extract engineering knowledge from experiments and simulation and to communicate an internal message and domain engineering knowledge base. The information on aleatory and epistemic uncertainty was fused to a unified express with the help of uncertainty description agent and uncertainty simulation and optimization knowledge library. The framework can deal with complicated time-varying structure optimization and simulation, for example, an working equipment of the excavator was used to verify the effectiveness of this framework.

The paper is organized as follows. Section 2 describes the methodology of unified uncertainty

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description with the support of uncertainty reduction theory and agent modeling technology. Section 3 presents the agent based simulation and optimization framework for engineering design under certainty. Section 4 discusses simulation and optimization of the working equipments of the excavator to verify. Section 5 presents the conclusions and suggests topics for further research.

## 2. METHODOLOGY

### 2.1. Design Optimization under Uncertainty

Engineering design optimization under uncertainty can be stated by the following mathematical problem [6]-[7]:

$$\text{Max/Min} \quad f(x) \qquad (1)$$

Subject to the constraints

$$g_i(x,\theta) \le 0, \quad i = 1,\dots,I$$
$$s_j(x,\theta) = 0, \quad j = 1,\dots,J$$
$$h_k(x) \le 0, \quad k = 1,\dots,K \qquad (2)$$

Where $x$ is the vector of design variables, $\theta$ is the vector of uncertainty parameters, $f(x)$ is the objective function, $g_i,\ i = 1,\dots,I$ and $s_j,\ j = 1,\dots,J$ are functions that define the set of inequality constraints, and $h_k,\ k = 1,\dots,K$ are the functions that define the set of deterministic constraints. The Eq. (1) can be sensitive to changes that are likely to occur from different sources. When dealing with uncertainty constraints such as inequality constraints,another way to handle these conditions is to guarantee the probability. That is

$$P_r(g_i(x,\theta)) \le 0 = \int_{g_i(x,\theta)} f(\theta)d\theta \ge P_i^* \qquad (3)$$

Where $P_r(g_i(x,\theta))$ is the probability that the expression in parenthesis is true, $f(\theta)$ is the joint probability density function of uncertainty parameters, and $P_i^*$ is the confidence probability.

The probability method can be treated easily with the above model. As an epistemic uncertainty domain, we introduce an agent based modeling to deal with. In the end, the aleatory uncertainty can also be included in this framework.

### 2.2. Agent based Simulation and Optimization

Engineering design is essentially a collaborative process that requires various selection, comparison and evaluation of design variables to acquire an optimal result form global design space. With the help of agent technology, existing engineering tools, like CAD/CAE tools, expert system, or domain knowledge based system can be integrated into an easily accessible portal and system.

In this study simulation and optimization model's run flow is driven by the agents [8]-[12]. After reading some parameter values of demands and the required time windows of the data structure of an order, the model will get outputs, according to which the sequential scheduling of subsystems is carried on. When trying to collect the uncertainty information, it turned out to be very difficult to get useful information directly from expert engineers.

In engineering design simulation and optimization, agents are natural for describing the whole system composed of behavior entities. The relationships of agents here like that of the human communication process described in [13]-[14]. The interaction of agents can reduce design uncertainty gradually under the framework in Section 3. The technology of agents [15, 16] helps us to build a model in computer simulating interaction like experts. It deals with the situation in which the agents would like to find the possibilities of which many sets of input parameters lead to optimal performance of the design tasks.

## 3. AGENT BASED SIMULATION AND OPTIMIZATION FRAMEWORK UNDER UNCERTAINTY

### 3.1. Internal Structure of Agents

Agents are autonomous cognitive entities, with deductive, storage, and communication characteristics. Autonomous here means that an agent can function independently of any other agent.

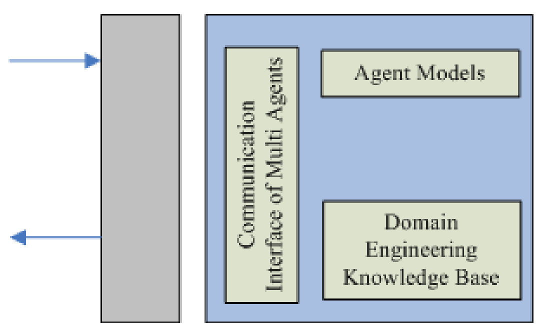


*Fig. 1. Structure Of An Agent*

As shown in Fig. 1, an agent is composed of the following parts: (1) a communication interface; (2)

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a domain engineering knowledge base; (3) agent models with associated methods to use. The agent functions were modeled behind the interface. Domain engineering knowledge base was built according to the technology of ontology. The behaviors of agents could be inferred according to the task input variables.

### 3.2. Agent based Simulation and Optimization Framework

In this study an agent based simulation and optimization under uncertainty framework was put forward. Fig. 2 showed the multi-agent based engineering design simulation and optimization under uncertainty.

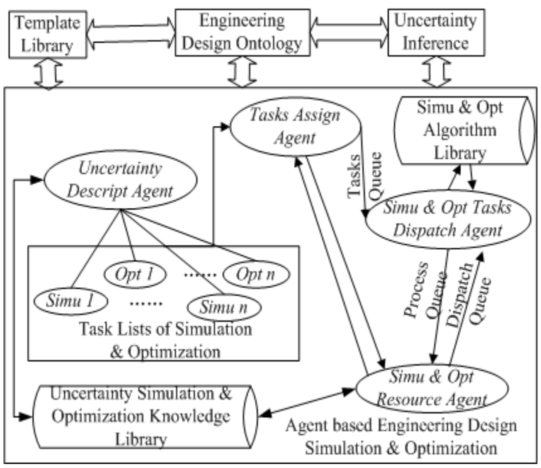


*Fig.2. Agent Based Engineering Design Simulation And Optimization Framework Under Certainty*

The main components were as follows:

(1) Engineering Design Ontology. Ontology in the specific engineering domain was constructed with standard agent modeling methods [11], it included the definitions and sets about various types of simulation and optimization.

(2) Simulation and Optimization Template Library. The templates of simulation and optimization should be adjusted flexibly. And these templates should be written with the web service description language (SWDL) to accordance with the web service framework (WSRF).

(3) Uncertainty Inference. With the help of uncertainty description agent and uncertainty simulation and optimization knowledge library, the specific tasks matched the template in Simulation and optimization template library. The tasks assign and dispatch agents executing at appropriate resource.

## 4. APPLICATION

In order to very the effect of the proposed framework, we designed a prototype simulation for working equipment of an excavator which is a kind of complicated time-varying structure. The prototype of simulation and optimization service for the working equipments of the excavator was implemented in a developed distributed concurrent design simulation and optimization platform. As shown in figure 3, the designer only communicated with multidisciplinary optimization portal, the simulation and optimization process run behind the portal. The portal controlled uncertainty reduction theory (URT) based knowledge library, finite element analysis agents, optimization agents and parallel computing resources.

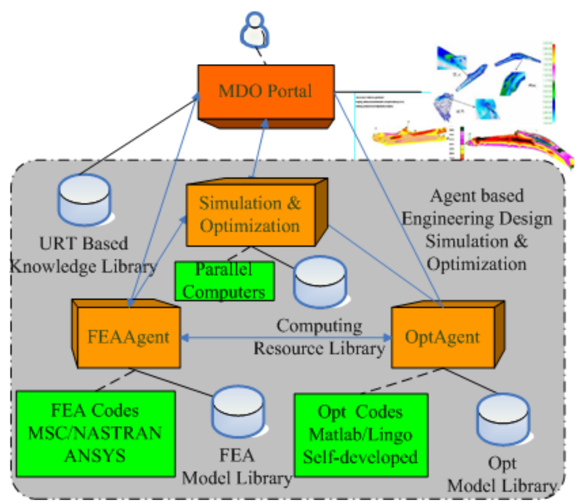


*Fig.3. Agent Based Engineering Design Simulation And Optimization Under Certainty For The Working Equipments Of The Excavator*

In multidisciplinary optimization (MDO) portal there were three kinds of agents: simulation and optimization control agents, finite element analysis (FEA) agents and optimization (Opt) agents. The simulation and optimization control agents operated parallel computers resources. The FEA agents compute the analysis tasks with some commercial and self developed analysis codes. The Opt agents treat variables got from the portal with optimization algorithms. The URT based knowledge library was used to inferred variables and output performances. The whole model of the working equipment of the excavator was built with parametric technology. Fig. 4 showed an optimization scheme of the working equipments of the excavator.

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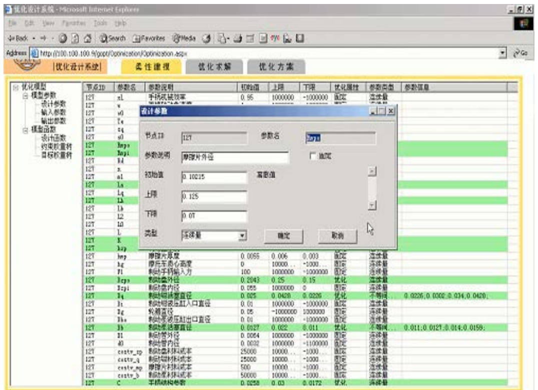

*Fig.4. Simulation Scheme Of The Working Equipments Of The Excavator*

The information of boundary condition during computation where extracted by agents behind the platform. Then optimization models and simulations tasks were constructed with the help of tasks assigned agents. The engineering design simulation and optimization platform managed the design and analysis resources distributed in intranet or internet environment. FEA and Opt agents were loaded to compute the stress, displacement and frequency et al of the working equipments. Finally the results were provided to the designers via the MDO portal. It showed that the time of working equipment design decreased greatly from 3 days to 6 hours with this prototype.

## 5. CONCLUSIONS

A framework of agent based engineering design simulation and optimization under certainty was put forward in this study. The engineering knowledge extraction from these experiments and simulation was used. Agent based URT was developed to provide simulation and optimization service. A prototype simulation for working equipments of an excavator was developed. The research results provide a feasible methodology to fuse multidisciplinary uncertainty information in agent environment.

The work will still be improved to support the whole design process. The platform will be carried out to refine friendly graphic user interface, security, and convenient automatic process integration.

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