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A Control Algorithm Based on Modular Design Approach to Complex Product Engineering

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Abstract: Compared with the traditional design, modular design has the prominent agility feature in dynamic integration, integrated system control of product modular design Meta-data was analyzed in this research, and then Meta modeling process throughout product modular design Meta-data was also proposed. Based on modular design Meta-model, under the same conditions, the same instance of a modular product sequence optimization was applied with IPSO control algorithm, from several test experiments result show, IPSO control algorithm global search ability and convergence rate has been the improvement, which is a practical and effective optimization algorithm model. Particle population is smaller by using IPSO algorithm, which convergence rate has a more distinct advantage. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Modular design, IPSO, Meta-model, Integrated control.

1. Introduction

Modular design is widely applied to different engineering domains. Flexible manufacturing systems with reduced time and cost for tool design can fabricate many types of products that are made by the different modular fixture system or tooling. As the result of increasing market competition and popularization of information technologies, network technologies enables customers to quickly obtain information from the global market, customers now demand the product not only with high quality, and also hope that price remain virtually steady, and product delivery cycle can be as short as possible [1].

In addition, in modular design system, modules are considered as the semi-autonomy subsystem which has a separable definite function. Modules can be connected each other, according to standardized interfaces and communication rules, to form more complex system. Modular design approach is through the agile combination of different standard modules, to design different combinative varieties as much as possible with limited modules, and to realize the object on saving energy and material.

2. Oriented Integration Meta-modelling of Modular Design

Complex product modular design process, the various disciplines of design activities is the link information integration, information integration management objective is to integrate all aspects of information involved can meet the design goals of its own, if the model describes the inconsistency will lead to difficulties in collaboration, to the product of product modular design process adversely affect the integrated control [2, 3]. Oriented Integration of product modular design Meta-model is a meta-model integration of product modular design for integrated product meta-model, process meta-model, knowledge meta-model, resource meta-model composed of four parts together, is a kind of abstract-level meta-model of integrated management model.

Basic Summary of Meta-model.

Meta-model is the description model, which is also about the basic concepts of the model, the basic relationship between the semantics of the basic constraints, the model can be described as specific models or specific objects. In layman's terms, meta-model is the model standards. Between the meta-model and model of the relationship with the instance of a class: each model is an instance of meta-model.

Compared with meta-model and model, meta-model has its own characteristics, as follows Table 1.

Table 1. Major characteristic of Meta-model.

Major Characteristic	Meta-Model	Model
Description	Description of model	Description of Specific object
Dependence	Independence of model	Dependence of meta-model
Reusability	Larger range	Smaller range
Stability	Stable	Changeable
Sharing ability	Strong	Poor

Meta modeling techniques used to establish the meta-model of integrated products, integrated process meta-model, product meta-model, knowledge meta-model and resource meta-model composed of product modular design Meta-data, must go through the following four phases: analysis phase of Meta-model, attributes creation phase of Meta-model, rules creation phase of Meta-model and checking phase of Meta-model.

1) Analysis phase of Meta-model.

Meta modeling techniques combined with the characteristics of the extraction of the implementation of the abstract model of integrated design, complete meta-model analysis. Analysis should include: product demand information of multidisciplinary collaborative design analysis, structural analysis of product components, collaborative design process and characteristics of the task analysis, multi-disciplinary analysis of knowledge acquisition, design objects and associated object analysis, object analysis, the scope and design rules .

2) Attributes creation phase of Meta-model.

Meta modeling techniques used to extract meta-attributes, which included the state for analysis. Subject knowledge for analysis, design objects and associated object analysis, object analysis, the scope and design rules.

3) Rules creation phase of Meta-model.

Meta-model through the establishment of effective rules of restraint, to reduce the redundancy models, element models to ensure the accuracy and effectiveness. Meta modeling following technical rules: the attribute definition rules of meta-model, generality rules, the execution rules, integration rules, modular rules and extensibility rules.

4) Checking phase of Meta-model.

Meta modeling is completed by the check of certain testing standards or specifications, its tests and analysis, to improve the model. Meta-model of the check process including content check, property evaluation, calibration and interface to the effectiveness of the implementation of rules of the inspection and so on, through constant iteration, repeatedly revised, and ultimately improve the meta-model. Module division level of modular design Meta-model, shown in Fig. 1.

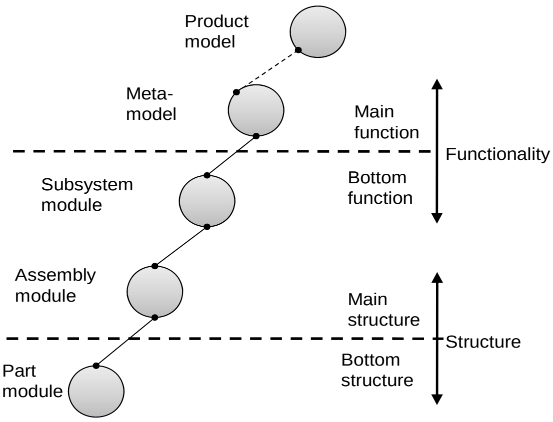

Fig. 1. Module division level of product modular design Meta-model.

Meta modeling techniques used to establish the meta-model of integrated products, integrated process meta-model, product meta-model, knowledge meta-model and resource meta-model composed of product modular design Meta-data, must go through the following four phases: analysis phase of Meta-model, attributes creation phase of Meta-model, rules creation phase of Meta-model and checking phase of Meta-model. The Meta modeling process throughout product modular design Meta-data is shown in Fig. 2.

The purpose of design and construction modular design Meta-model is to determine from requirements to conceptual product design, overall design data in all stages of the process, knowledge acquisition, design and analysis tools and other information as well as the organic association between this information, the definition of an interdisciplinary, cross-phase global model.

3. IPSO Optimized Model

Particle Swarm Optimization (PSO) is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. PSO optimizes a problem by having a population of candidate solutions, here dubbed particles, and moving these particles around in the search-space according to simple mathematical formula over the particle's position and velocity [4, 5]. Each particle's movement is influenced by its local best known position but, is also guided toward the best known positions in the search-space, which are updated as better positions are found by other particles.

In order to overcome the disadvantage of PSO is easy to fall into local optimal solution. Based on modular design Meta-model, the integrated collaborative globe meta-data for improving the basic PSO algorithm was introduces by the integrated Particle Swarm Optimization (IPSO), which key advantage of the algorithm is its ability to find a more sustainable solution for the optimization.

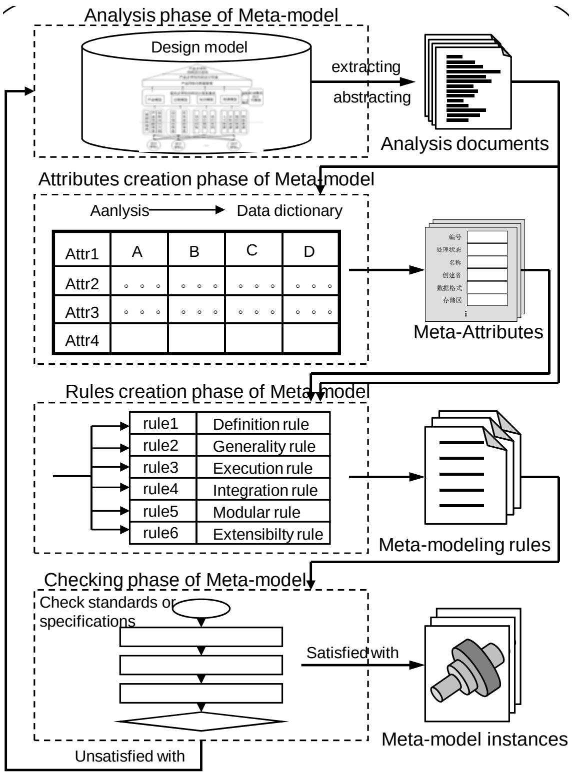

Fig. 2. The Meta modeling process throughout product modular design Meta-data.

3.1. IPSO Control Algorithm to Modular Product Sequence

Particle swarm of the population is determined by the number of parts to design and construction of the object. For a product object of contains *n* parts which each particle is initialized to a n dimensional vector $s_i = (p_{i1}, p_{i2}, ...p_{in})$, give a corresponding sequence of product and an representation for assembly product process is carried out sequentially by $p_{i1}, p_{i2}, ...p_{in}$ components. To compare the optimization product process of the cost of the amount of sequence, but also set the geometric constraints n_g and the process constraints:

$$n_p, n_s, n_t, n_d, n_c,\ c_p, c_s, c_t, c_d, c_c\,.$$

Definition and generation switching sequence velocity.

In the product sequence optimization problem, velocity operator function is to adjust parts of the product sequence, the initial design and construction of iterative sequence evolution to a more optimal direction, its definition is as follow [6]:

Velocity operator: $vo\ (u,\ w)$ is to change the product sequence of the first *n* part and the first *w* part swap positions, to result the new sequence s\`.

Velocity operator sequence: *vos* (velocity operator sequence) indicates the group of velocity operator subsequence, denoted as $vos = (vo_1, vo_2, ...vo_n)$, where $vo_1, vo_2, ...vo_n$ is the velocity operator of product sequence, the order between them is not commutative [7].

Merge subsequence: In addition there is an assumption that the velocity operator sequence *vos*\` can get the same $s'$ in the same process sequence *s*, then, the new velocity operator subsequence *vos*\` called merged subsequence of vos_1, vos_2, respectively, respectively, vos_1, vos_2, can be merged into the new velocity operator sequence *vos*\` based on probability $q_1,\ q_2\ (0 \le q_1,\ q_2 \le 1)$, that is:

$$vos' = q_1 vos_1 * q_2 vos_2\,,$$

where "*" is the merged operator of the velocity operator subsequence, $q_1 vos_1$, means the retention of vos_1 operator subsequence by the probability, q_1, $q_2 vos_2$, it is also the same token [8, 9].

For IPSO control algorithm in optimization model, the cost of product sequence can be defined as the line expression:

$$f(s) = c_p n_p(s_i) + c_s n_s(s_i) + c_t n_t(s_i) + c_d n_d(s_i) + c_c n_c(s), \quad (1)$$

where n_p, n_s, n_t, n_d, n_c are the geometric constraints, c_p, c_s, c_t, c_d, c_c are the process constraints of sequence.

The update expression of velocity operator subsequence:

$$\begin{gathered} vos_{i,k+1} = c_0 vos_{i,k} * c_1(p_{best_{i,k}} - s_{i,k}) * c_2(g_{best_k} - s_{i,k}) \\ s_{i,k+1} = s_{i,k} + vos_{i,k+1}\,, \end{gathered} \quad (2)$$

where c_1, c_2, c_3 are the random probability between 0-1, $vos_{i,k}$, represents the Step *k* of velocity operator sequence belong to the i particle, $vos_{i,k+1}$, represents the Step *k*+1 of velocity operator sequence belong to the *i* particle, $s_{i,k}$ represents the Step *k* of product sequence belong to the i particle, $p_{best_{i,k}}, g_{best_k}$ denote the first particle, respectively, to the local search optimization product sequence so far and the swarm search to global optimum product sequence.

Thus, it can use IPSO control algorithm to generate optimum product sequence. Detailed optimization steps as following:

Step 1. Using logistic mapping as a collaborative cross-issued mechanism, which μ is the control parameter. As $\mu = 4$ and $x_k \notin \{0, 0.25, 0.5, 0.75, 1\}$, Variable trajectory x_k optimization problems can traverse the entire search space.

$$x_{k+1} = \mu x_k (1 - x_k),\ x_k \in (0,1)$$

Step 2. To calculate the next position in the sequence of parts exchange $u_{i,k+1}$, $w_{i,k+1}$. Choose two different initial value $t_{i,k}^1, t_{i,k}^2$ ($t_{i,k}^1 \neq t_{i,k}^2$), according to the formula to get the value of $t_{i,k+1}^1, t_{i,k+1}^2$, then calculate value of $u_{i,k+1}, w_{i,k+1}$,

$$u_{i,k+1} = [t_{i,k+1}^1 * PartNum], w_{i,k+1} = [t_{i,k+1}^2 * PartNum].$$

Step 3. According to switching probability q to set the switching position $u_{i,k+1}, w_{i,k+1}$ in the product sequence $s_{i,k}$, a new sequence $s_{i,k+1}$ can be obtained.

Step 4. Calculate the cost adapt function $f(s_{i,k+1})$ for sequence $s_{i,k+1}$, if $f(s_{i,k+1}) = f(s_{i,k})$, jump step 5, otherwise jump step 6.

Step 5. As all of the individual particles to find the optimum product sequence, that is to say, $s_i^* = s_{i,k+1}, t_{i,k}^1 = t_{i,k+1}^1, t_{i,k}^2 = t_{i,k+1}^2$, jump step 7.

Step 6. If $s^* = s_k, t_{i,k}^1 = t_{i,k+1}^1, t_{i,k}^2 = t_{i,k+1}^2$, Jump step 2.

Step 7. Output optimum product sequence of each particle by $p_{best_{i,k}}$.

4. Case Study

Large ship is part of manufacture in accordance with orders production of complex customized product engineering, which has complex structure, involved in its design and manufacturing process should concern more multi-disciplinary, multi-data, multi-departments.

Integrated data structure of large ship product process can be shown in Fig. 3.

In order to demonstrate the feasibility of this article's proposal, product process of a certain type large bulk ship was studied as an example.

After simplification, the product of ship's structure consists of 10 large modular units, the initial product design module 5 was designated as product basic unit, which task resource set and constraint type was also appointed as T_1 and C_1. In this case the task resource set and constraint type of each module are given in Table 2. The parameters of cost function in product sequence:

$c_g = 50$, $c_p = 0.15$, $c_t = 0.15$, $c_d = 0.4$, $c_c = 0.15$.

The retention probability of velocity operator in the IPSO algorithm: $c_0 = 0.75$, $c_1 = 0.8$, $c_2 = 0.6$

The initial product sequence and switching positions generated using random function.

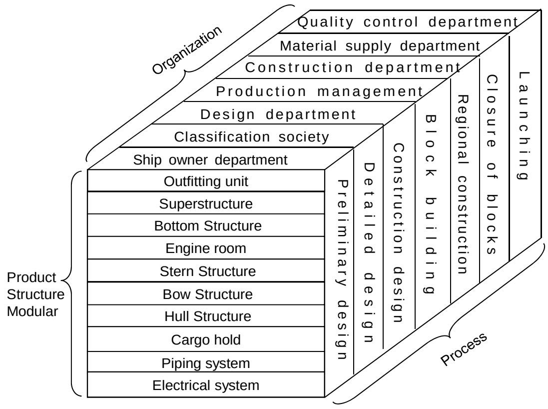

Fig. 3. Integrated data structure of large ship product process.

Table 2. Task resource set and constraint type of sequence.

No.	Modular Unit	Task resource set	Constraint Type
1	Engine room	T_1 T_2 T_3	C_5
2	Stern structure	T_1 T_2 T_4	C_1
3	Bottom structure	T_1 T_2 T_5	C_3
4	Hull structure	T_2 T_3 T_4	C_1
5	Bow structure	T_1	C_4
6	Super structure	T_3 T_4 T_5	C_3
7	Outfitting unit	T_1 T_2 T_4	C_1
8	Cargo hold	T_1 T_2 T_5	C_2
9	Piping system	T_2 T_3 T_4	C_2
10	Electrical system	T_1 T_4 T_5	C_1

IPSO control algorithm need use C language programming, in order to verify the convergence rate and global optimization ability by several test experiments. In this IPSO algorithm, the initial of iterations is set for 200, the population of particles is from 20 to 50. In the results of test experiments are shown in Table 3, by using ipso control algorithm can reduce the complexity of the algorithm is initialized at the same time, and convergence rate has also improved remarkably.

Through this several test experiments, data are summarized in Fig. 4, before the iterative search of 80 to satisfy the constraint product sequence, particle population is smaller by using IPSO algorithm, which convergence rate has a more distinct advantage.

5. Conclusions

Through deeply analyzing process integrated control of modular product meta-data, process data, information resources, systems integration design point of view in product modular design, the process integrated control modular implementation methods was proposed based on modular design theory.

Since IPSO algorithm is an intelligent optimization algorithm, the control algorithm optimization process, application of the heuristic search of information, we can make the computational complexity of the assembly sequence generation is not proportional to the search of the solution space. To verify the IPSO control algorithm to optimize performance problems modular product sequence, under the same conditions, the same instance of a modular product sequence optimization, from several test experiments result show, IPSO control algorithm global search ability and convergence speed has been the improvement, which is a practical and effective optimization algorithm model.

Table 3. IPSO control algorithm optimization results.

Test	Optimized Sequence										n_p,	n_s	n_t	n_c	n_d	f(s)	Iteration number	Particle number
Product sequence	5	3	7	1	2	6	4	10	8	9	0	0				4.10	181	20
Task set	T_2	T_1	T_1	T_2	T_2	T_1	T_2	T_5	T_2	T_4			1					
Constraints type	C_2	C_1	C_1	C_2	C_2	C_1	C_2	C_3	C_2	C_4				6				
Direction	+X	+X	+X	+X	-X	-X	+X	+X	-X	+Y					7			
Product sequence	5	7	6	2	1	4	4	10	9	8	0	0				3.75	126	30
Task set	T_2	T_5	T_1	T_2	T_2	T_4	T_2	T_5	T_4	T_4			3					
Constraints Type	C_2	C_1	C_1	C_2	C_3	C_2	C_1	C_2	C_2	C_4				7				
Direction	-X	-X	-X	+X	+X	-X	+X	+X	-X	+Y					5			
Product sequence	5	3	4	2	1	6	7	10	8	9	0	0				3.02	146	40
Task set	T_2	T_1	T_1	T_2	T_5	T_2	T_2	T_4	T_4	T_4			3					
Constraints Type	C_2	C_4	C_1	C_3	C_2	C_2	C_3	C_2	C_2	C_4				6				
Direction	-X	-X	-X	+X	+X	+X	-X	-X	-X	+Y					5			
Product sequence	5	7	10	1	2	3	4	6	8	9	0	0				2.98	78	50
Task set	T_2	T_1	T_1	T_2	T_2	T_2	T_2	T_4	T_4	T_4			1					
Constraints Type	C_2	C_1	C_1	C_3	C_2	C_1	C_2	C_2	C_2	C_4				7				
Direction	-X	-X	-X	+X	+X	+X	+X	-X	-X	+Y					5			

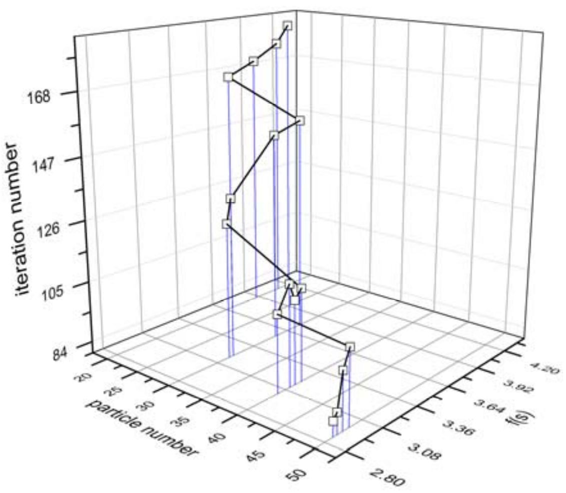

Fig. 4. Changes in the cost of iterative test experiments.

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