A Simulated Annealing Algorithm based on Parallel Cluster for Engineering Layout Design

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Abstract. The layout design problem is a kind of nesting problems that is naturally NP-hard and very difficult to solve. Layout designing of machine is even more difficult because of its nesting items are actually machine parts that have both irregular shapes and complex constraints. A feasible way to solve machine layout problem is to employ ameliorative algorithms, such as simulated annealing algorithm. But these kinds of algorithms are usually CPU-time thirsty, sometime the computing time is unbearable. In this paper, the authors advocate to parallel the simulated annealing algorithm on a multi-computer network (a parallel cluster). We have combined Message Passing Interface (MPI) with Visual C++ to integrate Simulated Annealing Algorithm based on Parallel Cluster and Engineering Layout Design Support System. An engineering example about vehicle dynamical cabin layout design is presented to test validity of the Algorithm. If appropriate temperature piece is chosen and seemly a number of nodes are used, the integration of Simulated Annealing Algorithm based on Parallel Cluster and Engineering Layout Design Support System definitely will improve the efficiency for engineer.

Keywords. Collaboration engineering, Simulated annealing algorithm, Layout, Parallel computing.

1 Instructions

It is difficult to solve the problems of Complex product layout. In order to solve them, there are many conventional algorithms, such as accurate algorithm[1], simulated annealing[2], genetic algorithm[3, 4] and extended pattern search algorithm [5], hybrid algorithm, expert system[6], virtual reality[7] etc. are used for solving this kind of problems. As a kind of heuristic algorithm, simulated annealing algorithm is usually used in engineering layout design. However, because of dozens of existing shortcomings, such as inefficiency, simulated annealing algorithm will spend too much time in solving a layout design question to complex mechanical products. Moreover, a lot of professional knowledge and

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expertise are required in practical layout design. So the availability of simulated annealing algorithm is limited in the field of practical engineering.

A Simulated Annealing Algorithm based on parallel cluster is presented to solve the problem of inefficiency, and combines Message Passing Interface (MPI) with Visual C++ to integrate Simulated Annealing Algorithm based on Parallel Cluster and Engineering Intelligent Layout Design Support System to solve the problem of high requirement of professional knowledge and expertise.

2 Simulated Annealing Algorithm based on Parallel Cluster

Because of randomicity of simulated annealing algorithm, the temperature of simulated annealing algorithm can be divided into small pieces, and each piece can be computed on different node. We will collect results on current stage from every computer, so that we can get the best conclusion after comparing them. Then, the condition of nodes will be adjusted in order to continue with a better point.

The number of nodes is p, the number of temperature pieces is q, the goal function is $f(X)$, the design variables is $X=(x_1,x_2,\cdots,x_n)$, the simulated annealing function is $S(T_b,T_e,X_b)=X_e$, T_b is initial temperature, T_e is final temperature, X_b is initial value of design variables.

The generic steps of Simulated Annealing Algorithm based on Parallel Cluster are like this:

(1) Divide the temperature into small pieces, and get the initial temperature (equation 1) and final temperature (equation 2) of each computing step.

$$T_{bh}(h)=T_0-\left(\frac{T_0-T_1}{q}\right)(h-1) \qquad (1)$$

$$T_{eh}(h)=T_b(h)-\left(\frac{T_0-T_1}{q}\right) \qquad (2)$$

In this equation, h is the index of current temperature piece ($h=1,2,\cdots,q$). T_{bh} is initial temperature of stage h, T_{eh} is final temperature of stage h, T_0 is initial temperature of all computing process, T_1 is final temperature of all computing process

(2) Do Simulated Annealing Algorithm with the current temperature and value of design variables on every node.

For example, on node m (m is the index of nodes, $m=1,2,\cdots,p$), the process of Simulated Annealing Algorithm computing is $S(T_{bh},T_{eh},X_{bh})=X_{ehm}$, T_{bh} is current initial temperature, T_{eh} is current final temperature, X_{bh} is the current initial value of design variables , X_{ehm} is the current final value of design variables, after Simulated Annealing computing on stage h, and on node m.

(3) Collect results from every node on current stage after Simulated Annealing computing so that we can find the optimum point with comparing the results. The rule of compare is $\min(f(X_{eh1}),f(X_{eh2}),\cdots,f(X_{ehp}))$. The optimum node is k ($k=1,2,\cdots,p$). After that, the best values of design variables are sent to all of

nodes, so that we can keep the situation synchronal on different node. The equation $X_{b(h+1)} = X_{ehk}$ will be set to prepare for next computing.

3 Integration of Simulated Annealing Algorithm based on Parallel Cluster and Engineering Intelligent Layout Design Support System

The modeling and computing complexity of complex product packing is obvious. Its layout solution made by an algorithm is usually not better than the one made by people with rich professional experience. The reason is that the diversity of professional experience and expertise make it more complicated to solve by a single optimal algorithm. So it is important to integrate Simulated Annealing Algorithm based on Parallel Cluster and Engineering Intelligent Layout Design Support System.

3.1 Framework of integrative system

Figure 1 shows the framework of Engineering Intelligent Layout Design Support System.

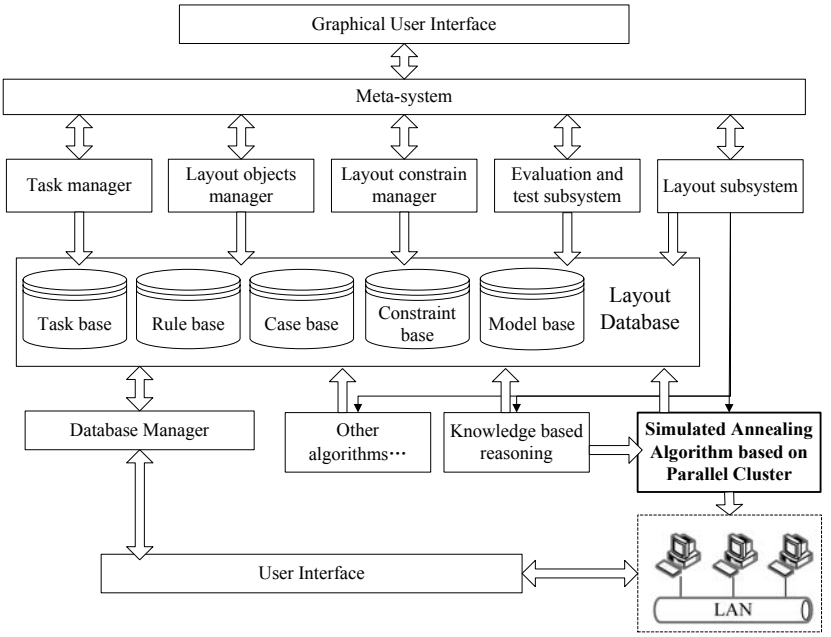

Figure 1. Framework for Engineering Intelligent Layout Design Support System

A whole process of engineering layout design follows this step:

(1) Define a layout task.
(2) Choose layout objects.
(3) Define layout constrains.
(4) Give the primary layout result.
(5) Optimize the layout result.
(6) Evaluate the layout result.

Each step has a subsystem to support, and all of the design resources are kept in the database. Meta-system manages other subsystems, database, knowledge base and graphics base. The Simulated Annealing Algorithm based on Parallel Cluster is a part of the layout algorithm subsystem. It will work with other modules.

3.2 Simulated Annealing Algorithm Subsystem

Figure 2 shows the detail flow chart of Simulated Annealing Algorithm based on Parallel Cluster, and the algorithm works with other modules.

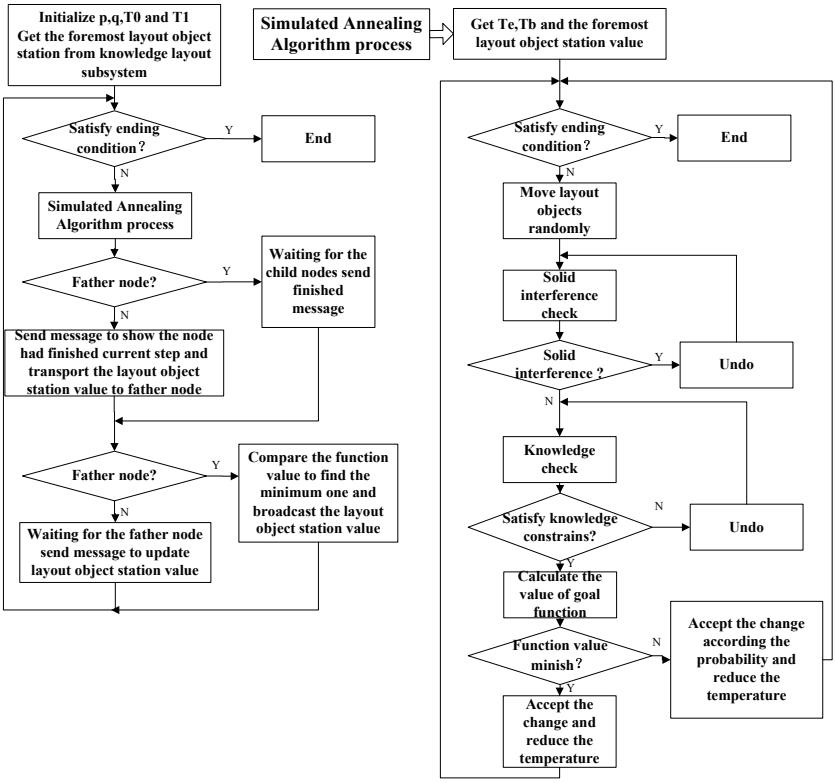

Figure 2. Flow chart of Simulated Annealing Algorithm based on Parallel Cluster

In the process of this solution, the Simulated Annealing Algorithm module cooperates with solid interference check module and layout knowledge check module. The efficiency of parallel computing almost depends on other subsystems.

In the process of computing, the transmission of messages during nodes depends on MPI (Message Passing Interface). MPI library support many methods to translate and broadcast messages. MPI is a kind of message transmission model, which is widely used in the field of parallel computing. MPI is so efficient and easy to be mastered that we use MPI and C++ to integrate the system and the parallel algorithm.

The messages which need to be translated contain design variables information and layout object model information. For high efficiency, simplified objects model is designed to replace the complicated one. Complicated objects are simplified as the combination of cuboids and cylinders, as shown in figure 3. Because of expansibility, XML format is used to express simplified objects model.

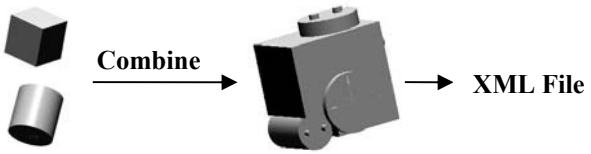

Figure 3. Simplified shape

4 Example

An engineering example about vehicle power cabin layout design is presented to test validity of Simulated Annealing Algorithm based on Parallel Cluster. The knowledge constrains have been defined. The number of layout objects is 15, the number of nodes is 4 ($p = 4$). Table 1 shows the result.

The goal function is minimum volume (m^3).

Hardware: CPU 2.5GHz, RAM 768MB, 100M Ethernet.

Software: OS Windows XP SP2, MPICH-2 1.0.3.

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Table 1. Result of the test

Initial Temperature (T0)	Final Temperature (T1)	Time (q=1)	Time (q=4)	Volume (q=1)	Volume (q=4)
10	0.01	7’15"	7’21"	4.467346	4.056414
50	0.01	10’45"	11'01"	3.845643	3.164648
128	0.01	12’30"	13'25"	3.513285	2.856683
320	0.01	13’57"	15'15"	3.348564	1.054785
800	0.01	15’20"	17'08"	1.845643	0.697365

The results from table 1 show that because of the message translation time, Simulated Annealing Algorithm based on Parallel Cluster spends more time than single Simulated Annealing Algorithm does. But it can achieve much better target function value. The higher Initial Temperature can get much better result. Figure 4 shows the layout result ($T_0 = 800$, $q = 4$).

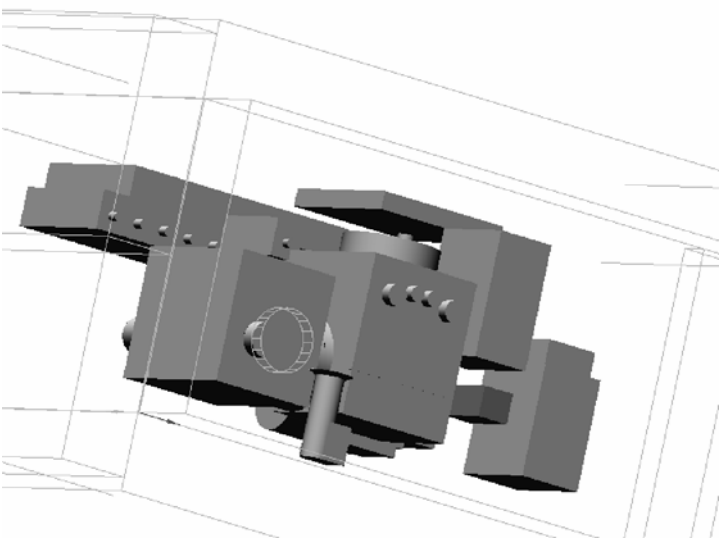

Figure 4. Layout result of the vehicle power cabin

5 Conclusions

The test shows that the Simulated Annealing Algorithm based on Parallel Cluster is useful and efficient. The result and the computing time not only depend on algorithm efficiency, but also relate to the style of layout object model, the condition of network and so on. For complex mechatronic products, it is hard to solve layout problems with a single conventional algorithm. There are a lot of layout knowledge and constrains to influence the process and result of a layout problem. So the algorithms have to cooperate with other intelligent systems and human-computer interactive systems sometimes. The integration of Simulated Annealing Algorithm based on Parallel Cluster and Engineering Intelligent Layout Design Support System is superior to others in this field.

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