3차원배치설계에 대한 어닐링법의 적용

Application of the Annealing Method to the Three Dimensional Layout Design

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Abstract

The layout design of component plays an important role in the design and usability of many engineering products. The Engineering artifacts of today are becoming increasingly complicated. The simulated annealing method has been applied effectively to the layout and packing problems of wafer. The main characteristics of simulated annealing method is that an optimum can be obtained from the many local optimums by controlling the temperature and introducing the statistic flickering. The objective of this study is to suggest a method to apply the simulated annealing method to the three dimensional layout design of submergible boat which has multiple constraint conditions and evaluation criteria. We describe an approach to define cost function, constraints and generate layouts using a computer. In this research three dimensional LAYout Design Optimization Program(LAYDOP ver.2) has been developed. The layout result(the total value of evaluation criteria) designed by a human layout expert has been improved by 31.0% using this program.

Key Words: Simulated Annealing Method, Quenching Method, Submergible Boat, Layout Design, Global Optimum

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1. Introduction

The layout design of component plays an important role in the design and usability of many engineering products. The Engineering artifacts of today are becoming increasingly complicated. The simulated annealing method have been applied effectively to the layout and packing problems of wafer[1]. In the electrical engineering field, there exist a lot of commercial tools and papers that place hundreds to millions of components in a small domain. Here, components are limited to two dimensional shapes[2-4].

For the three dimensional component layout problem, a variety of non-linear programming techniques have been applied. Three dimensional component layout and packing problems have also been studied by using the genetic algorithms[5]. However, most of these approaches place restrictions on problem complexity and component orientations.

The simulated annealing method does not share these weak points in the restrictions. J. Cagan developed a method to extend the simulated annealing method from the two dimension to the three dimension[6]. T. Kämpke reports a solution to a bin packing test problem using this technology with results superior to previous researches[7]. The simulated annealing method has also been used on the other types of three dimensional layout design problems, such as facilities layout[8].

W. Hills and N. Smith presented work in spatial engineering for made-to-order products such as offshore oil rigs[9]. Their efforts also used the simulated annealing method to produce initial layout configurations for later manipulation by intervention of layout expert to get the final layout result. J. Cagan, D. Degentesh and S. Yin reported a simulated annealing-based algorithm using hierarchical models[10]. However, this study does not provide any definite evaluation criteria and any guide line to categorize the various constraint conditions in three dimensional layout problem[11-14].

The objective of this study is to suggest a method to apply the simulated annealing method to the three dimensional layout design of submergible boat which has multiple constraint conditions and evaluation criteria. In this paper we describe an approach to defining cost function, constraint condition and generating layout state in computer. Also our work introduces the result of computer simulation by the suggested method.

2. Requirement of three dimensional layout design of submergible boat

We selected the submergible boat as an example of the three dimensional layout design. The submergible boat is for searching the suboceanic resources and for making undersea map. Table 1 is the list and shape of components of submergible boat. In this paper shape of layout components are modified as cylindrical and hexahedral shape as shown in Fig. 1. The functions of main components are summarized in Table 2.

The requirements of layout design of submergible boat are as follows:

a) Wiring: The length of wiring(for signal and power line) between components should be short if possible. Figure 2 is the wiring diagram of components of submergible boat.

Table 1. List of components for submergible boat

Name	Dimension(mm)			Weight (Kg)	Buoyant Force (Kg)	Shape
	a	b	c			
E1: ballast(right)	65	65	130	6.50	-1.70	hexahedron
E2: ballast(left)	65	65	130	6.50	-1.70	hexahedron
E3: deballaster(right)	50	50	120	3.00	-0.84	hexahedron
E4: deballaster(left)	50	50	120	3.00	-0.84	hexahedron
E5: central processing unit	130	130	360	20.86	-23.85	hexahedron
E6: inverter(right)	150	408	-	8.21	-7.46	cylinder
E7: inverter(left)	150	408	-	8.21	-7.46	cylinder
E8: power source ⓐ	70	90	500	24.99	-12.31	hexahedron
E9: power source ⓑ	70	40	220	6.62	-3.40	hexahedron
E10: AMP of distance measuring sensor	60	60	60	0.50	-0.17	hexahedron
E11: receiver of distance measuring sensor	60	60	60	0.50	-0.17	hexahedron
E12: camera	77	196	-	1.05	-0.94	cylinder
E13: Strobo	92	116	-	0.05	-0.79	cylinder
E14: beacon	45	460	-	1.60	-0.65	cylinder
E15: transporter	35	35	250	1.40	-0.38	hexahedron
E16: pinger	68	260	-	1.50	-1.00	cylinder
E17: emergency air bombe(right)	105	340	-	2.80	-0.87	cylinder
E18: emergency air bombe(left)	105	340	-	2.80	-0.87	cylinder
E19: telecommunication apparatus	65	94	-	0.88	-0.30	cylinder
E20: thruster(right)	145	396	-	9.80	-3.00	cylinder
E21: thruster(left)	145	369	-	9.80	-3.00	cylinder
E22: compensator	40	40	350	3.00	-1.44	hexahedron
E23: horizontal rudder actuator(right)	105	340	-	2.80	-0.87	cylinder
E24: horizontal rudder actuator(left)	105	340	-	2.80	-0.87	cylinder
E25: vertical rudder actuator	105	340	-	3.00	-0.87	cylinder
E26: rear tank	105	340	-	2.80	-0.87	cylinder
E27: PH meter	30	30	70	0.88	-0.30	hexahedron
E28: water temperature sensor	30	30	65	0.88	-0.30	hexahedron
E29: water current meter	45	50	65	3.00	-1.44	hexahedron
E30: antenna ascent and descent equipment	60	60	-	0.50	-0.17	cylinder
E31: supersonic sensor(front)	20	10	50	0.50	-0.17	hexahedron
E32: supersonic sensor(rear)	20	10	50	0.88	-0.88	hexahedron
E33: paint emitter(for emergency)	77	196	-	1.05	-0.94	cylinder
E34: inertial navigator(sensor)	80	70	250	7.65	-8.54	hexahedron
E35: inertial navigator(power source)	90	30	160	2.75	-2.08	hexahedron
E36: azimuth sensor	65	94	-	0.88	-0.30	cylinder
E37: distance measuring sensor	135	180	180	3.23	-2.73	hexahedron

Table 2. Function of component of submergible boat

Component	Function
a) Central processing unit	Unit for computing the posture, stability, position, etc.
b) Inverter	Frequency transformer for AC motor
c) Driver	Control system of actuators
d) Communication apparatus	Ocean retrieval beacon and supersonic emergency communication apparatus
e) Power source	Power of CPU, sensors, drivers, inverters, controllers, etc.
f) Controller	Control system of thrusters, rudder actuators, etc.
g) Sensors	Sensors for water temperature, distance, azimuth, water current, etc.

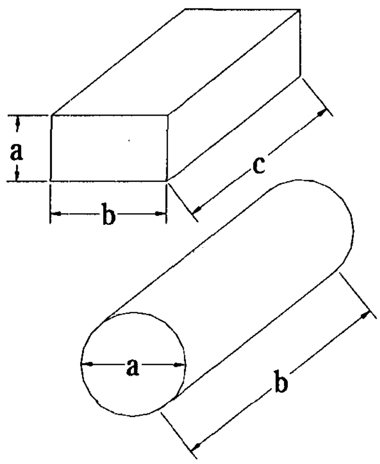


Fig. 1 Shape and dimension of component of submergible boat

b) Gravitational center: The position of gravitational center of submergible boat should be located at $0.4\times l$ point(l is the length of submergible boat) from the front part of submergible boat. If the position of gravitational center is located at the rear part of submergible boat, the controllability of submergible boat becomes worse.

c) Metacenter: The position of metacenter of submergible boat should be located at $0.406\times l$ point from the front part of submergible boat.

d) Layout space of components: All internal space of body of submergible boat is the layout space of components. All the

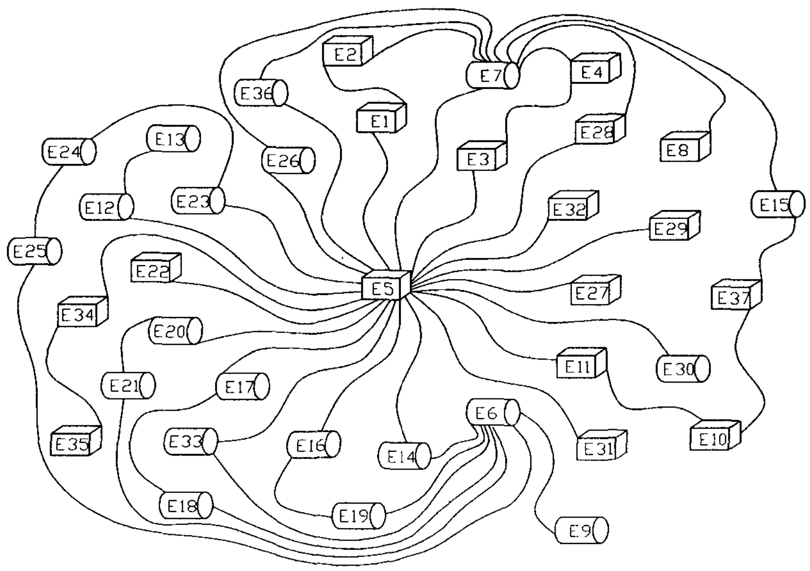


Fig. 2 Wiring diagram of components of submergible boat
Numbers represent each component.

components should be arranged in this space. However, each components should not be overlapped.

e) **Noise countermeasure**: The noise from the inverters, actuators, thrusters, power sources etc., should not effect on the sensors and CPU if possible.

In addition the components should not be jammed up locally for repairing the submergible boat. The Strobo should be located near the camera.

3. Algorithm and method of evaluation

3.1 Algorithm of simulated annealing method and quenching method

The algorithm of simulated annealing method is shown in Fig. 3. The main characteristic of this method is the acceptance of deterioration of value of cost function with some restraints as well as the acceptance of improvement of it.

At the high temperature state, large deterioration of value of cost function can be accepted, however, as the temperature becomes lower, only small deterioration is accepted. At last temperature becomes zero and deterioration is not accepted at all. By this characteristic the global optimum can be obtained from the many local minimums. The quenching method is a kind of local searching method and the temperature is fixed at zero.

3.2 Evaluation criteria and cost function

Nine kinds of evaluation criteria are defined to evaluate the layout design result of submergible boat as follows:

```
M = Number of Moves to Attempt;
T = Current temperature;
for ( m = 1 ; m<=M ; m++)
{
        Generate a Random Move,
        e.g. move a component;
        Evaluate the Change in Energy, △E;
        If (△E<0)
        { //Downhill move; accept it
        accept this move and update configuration;
        }
        else{ //Uphill move; accept maybe
        accept with probability P = e^(-△E/T)
        update configuration if accepted;
        }
}
```

Fig. 3 Search procedure of simulated annealing method

a) Interference between noise sources: Length between noise sources(for example inverters and thrusters, etc., $L_I = L_1 + L_2 + L_3 \ldots + L_n$).

b) Superimposition of components: Overlapped volume between components ($V_S = V_1 + V_2 + V_3 \ldots + V_n$).

c) Protrusion from special domain: Protrude volume of components from the layout space($V_P = V_1 + V_2 + V_3 \ldots + V_n$).

d) Functional relation between components: Length between components which have functional relation(for example camera and Strobo, etc., $L_F = L_1 + L_2 + L_3 \ldots + L_n$).

e) Effect of noise to sensors: Length from noise sources to sensors ($L_E = L_1 + L_2 + L_3 \ldots + L_n$).

f) Total packaging rate: Total empty space after layout design divided by total layout space($V_T = V_{tes} / V_{tls}$, where, V_{tes} is total empty space, V_{tls} is total layout space).

g) Change of position of gravitational center after deballasting: Length from the position of gravitational center before dropping the ballast to the position of it after dropping the ballast ($L_C = L_1 + L_2 + L_3 \ldots + L_n$).

h) Deviation of gravitational center from ideal position: Length from the ideal position of gravitational center to the designed position of gravitational center of submergible boat ($L_D = L_1 + L_2 + L_3 \ldots + L_n$).

i) Total wiring length between components: Total length of power lines and signal lines ($L_T = L_1 + L_2 + L_3 \ldots + L_n$).

The following dimensionless cost function is suggested to estimate the three dimensional layout design result.

$$CF(\text{Cost function}) = \sum_{i=0}^{m} \frac{E_i}{E'_i} \times 100 \text{ ------(1)}$$

Where, E_i is the value of evaluation criteria for current layout solution, E'_i is the value of evaluation criteria for randomly selected initial layout(or layout design result by layout expert), m is the number of evaluation criteria.

4. Constraint conditions and method of layout state generation and transformation

The conditions of relational constraint and layout constraint are suggested for the three dimensional layout design as follows:

4.1 Conditions of relational constraint

The conditions of relational constraint between components consist of the constraint of symmetrical layout and the constraint of layout dependency as follows:

a) Constraint of symmetrical layout: Components which must be arranged symmetrically in right and left, front and rear of submergible boat, like horizontal and vertical rudder actuators, inverters, thrusters, etc.

b) Constraint of layout dependency: Components which have dependency with other components in arrangement, like ballast and deballaster(the position of ballast is depend on that of deballaster), right thruster and left thruster, etc.

4.2 Conditions of layout constraint

The conditions of layout constraint consist of the constraint of layout domain, the constraint of layout direction, the constraint of layout position and layout direction as follows:

a) Constraint of layout domain: Components which must be arranged in some specified domains, that is, the components which have limitations of layout space, like distance measuring sensors(this sensor must be placed at the front part of submergible boat), CPU, power source, etc.

b) Constraint of layout direction: Components which have limitations of layout direction, like thruster(constraint of x direction), compensator(constraint of z direction), distance measuring sensor (constraint of x direction), etc.

c) Constraint of layout position and layout direction: Components which have limitations of layout position and layout direction, like ballast and deballaster(these components must be paced under part of submergible boat and have constraint of x direction), camera and Strobo, etc.

4.3 Method of layout state generation and transformation

The layout state of each component is represented as position coordinates and axis directions of components in three dimensional space. The layout state is generated under the constraint conditions mentioned in 5.1 and 5.2. A new subsequent layout solution is generated by the layout state generation process in Fig. 4.

Layout state transformation is to select one of the new subsequent layout solution randomly from the surroundings of the .

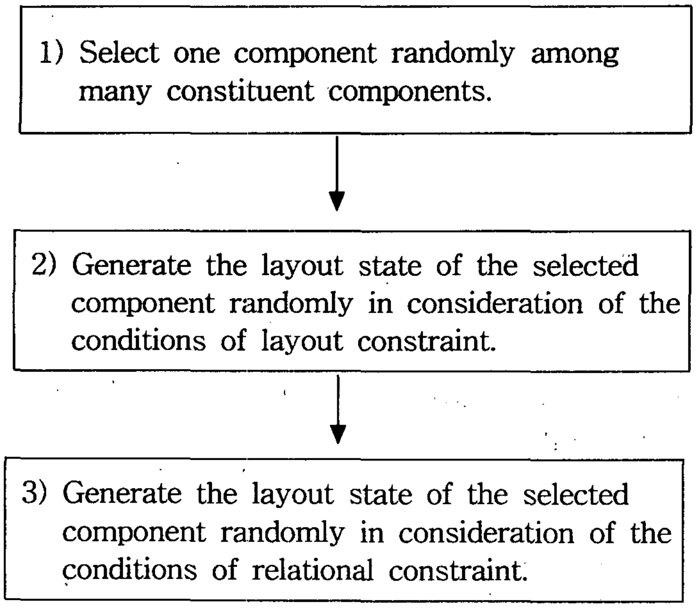


Fig. 4 Layout state generation process

current layout solution. That is, the layout state is transformed by interchanging the current layout solution with the new subsequent layout solution with probability by the Metropolis criterion

$$P(\text{Probability of state transformation}) = \min[1, \exp(-\triangle E/T)] \quad \text{------}(2)$$

$$\triangle E = r_1 - r_2 \quad \text{------}(3)$$

Where, r_1 is the value of cost function of current layout solution, r_2 is the value of cost function of subsequent layout solution, $\triangle E$ is energy, and T is temperature.

5. Experiments

LAYout Design Optimization Program (LAYDOP ver.2) has been developed by the suggested method. In LAYDOP ver.2 there are two functions, i.e., annealing method and quenching method. Pentium III, 550MHz PC and C^{++} were used as hardware and software. By using this LAYDOP ver.2 a) layout design result by layout expert, and b) randomly selected initial layout were optimized. As layout specifications for submergible boat, the numbers of components, layout constraint conditions, relational constraint conditions, and evaluation criteria were 37, 3, 2, and 9, respectively.

Table 3 is the schedule parameter and the improvement rate for annealing and quenching method. In this table annealing schedule A1, A2 and quenching schedule Q1 are the optimization of the layout design result by layout expert (in this case the initial cost value was 900.0). Annealing schedule A3, A4 and quenching schedule Q2 are the optimization of the randomly selected initial layout(in this case the initial cost values were 1532.3, 1450.7, and 1584.6, respectively).

Table 3. Schedule and improvement rate by LAYDOP ver.2

Name of schedule		Parameter		Initial cost value	Final cost value	Improvement rate(for layout design expert)
		Initial temp.	Temp. renewal coef.			
Annealing	A1	40.0	0.98	900.0	682.4	+24.2%
	A2	300.0	0.95	900.0	697.2	+22.5%
	A3	300.0	0.98	1532.3	932.5	-3.5%
	A4	40.0	0.95	1450.7	621.7	+31.0%
Quenching	Q1	0.0	0	900.0	748.6	+16.8%
	Q2	0.0	0	1584.6	699.3	+22.3%

Where, A1, A2 and Q1 are the improvement for layout design result by layout expert. A3, A4 and Q2 are the improvement for randomly selected initial layout.

Table 4. Result of layout design optimization by annealing schedule A4 and quenching schedule Q2

Schedule / Evaluation criteria	Annealing schedule A4 (%)	Quenching schedule Q2 (%)
1) Change of position of gravitational center after deballasting	+4.2	+3.1
2) Deviation of gravitational center from ideal position	+5.5	+5.7
3) Interference between noise sources	+2.2	+2.1
4) Superimposition of components	+7.3	+3.8
5) Protrusion from special domain	+6.2	-5.2
6) Functional relation between components	-3.0	+7.5
7) Effect of noise to sensors	-3.9	-3.6
8) Total packaging rate	+5.8	+3.4
9) Total wiring length between components	+6.7	+5.5
Total improvement rate	+31.0	+22.3

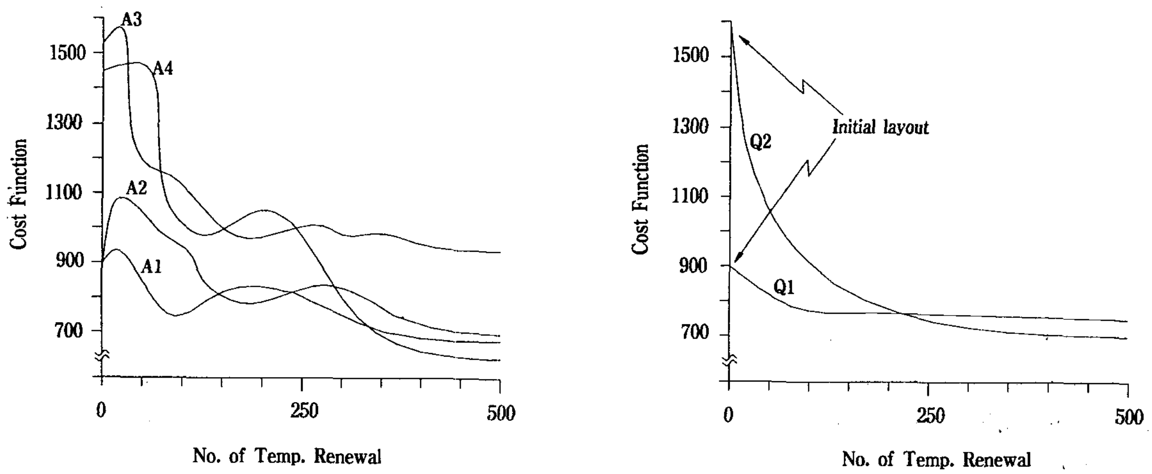
By the schedule A4, the value of cost function was improved 31.0% with 500 times temperature renewal. And by the schedule Q2 it was improved 22.3%. Average cpu-time was 6.5 hours to get the 500 times temperature renewal. The temperature renewal was done by multiplying initial temperature value by 0.95 or 0.98 at each point. The changed values for each evaluation criterion of cost function by schedule A4 and Q2 were summarized in Table 4.

Figure 5 is the transition of cost function by temperature renewal when executed the LAYDOP ver.2 under the schedule of Table 3. As shown in Fig. 5.a annealing method, at the high temperature state(in the beginning of program execution) the values of cost function were increased. This means that the deterioration of value of cost function was accepted at the high temperature state by the statistic flickering of temperature. As shown in Fig. 5.b, however, the value of cost function was decreased only, this means that no deterioration of value of cost function was accepted in quenching method.

Comparing the annealing schedules A1, A2, A3, and A4 in Fig. 5.a, it was found that the solution of layout design could be converged into the local minimum if the annealing schedule was not appropriate, since schedules A1, A2 and A3 were converged into the local minimum.

Comparing the annealing schedule A1, A2, A3, and A4, it was found that there was no need to input the layout design result by the layout design expert to LAYDOP program to get the optimal layout solution, since better solution was obtained by schedule A4 than schedule A1 or A2.

From the result of quenching schedule Q1 and Q2 in Fig. 5.b, it was found that when using the quenching method, the layout solution could be converged fast (within about 250 times temperature renewal in this case), however, the global optimal solution could not be obtained always.



a) Annealing method b) Quenching method

Fig. 5 transition of cost function by temperature renewal

6. Concluding remarks

The following results were obtained from the optimization of three dimensional layout design of submergible boat by annealing method and quenching method.

1) A method to apply the annealing method and the quenching method to the layout design of submergible boat was suggested.
2) By the suggested method three dimensional LAYout Design Optimization Program (LAYDOP ver.2) was developed.
3) By executing the LAYDOP ver.2 for the submergible boat, the following results were obtained
   a) The solution of layout design can be converged into the local minimum if the annealing schedule is not appropriate.
   b) There is no need to input the layout design result by the layout design expert to LAYDOP program to get the optimal layout solution.
   c) When using the quenching method, the layout solution can be converged fast, however, the global optimal solution can not be obtained always.

4) The layout result designed by layout expert has been improved 31.0% using LAYDOP ver.2. By this it has been verified that the suggested method has validity.

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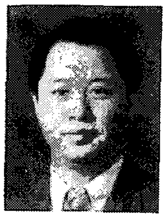

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