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◉ 論 文

An Optimum Design of a Ship based on Numeric and Knowledge Processing

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지식처리기법에 의한 선박의 주요 치수 최적화

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Key Words : multiobjective optimization, knowledge based system, ship design

초 록

다목적함수 최적화를 효과적으로 수행하기 위하여 유전자 알고리즘과 직접탐색법을 결합하여 혼성형 최적화기법을 구현하였다. 이 방법은 유전자 알고리즘을 사용하여 최적점이 존재할 가능성이 높은 영역을 탐색한 후, 이 영역에서 직접탐색법을 사용하여 최종해를 찾는다. 따라서 탐색의 효율을 향상시키고 계산시간을 절약할 수 있는 장점이 있다. 그러나 최적화기법이 효율적이지만, 최적화기법을 사용하기 위해서는 전문가의 전문지식이 필요하다. 따라서 실제 최적화를 수행하기 위해서는 관련 분야의 전문지식과 최적화기법이 효율적으로 결합되는 것이 필요하다.

1. INTRODUCTION

Traditionally an optimum design is obtained through an iterative process or by solving an optimization problem. The drawbacks of the iterative process are that the designer's experience, intuition and ingenuity are required. On the other hand the advantage of the iterative design process is that the designer's experience and intuition can go into making changes in the design concepts or support decisions. Optimization forces the designer to identify explicitly a set of design variables, an objective function and all constraints for the system. Traditional optimization systems have been concentrated on numerical aspects of a design process and have not been successful in integrating the numerical parts with human expertise. Although the

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optimization algorithm provides cost-effectiveness, the design optimization process involves a number of tasks which require human expertise and experience. Therefore methods of optimization and associated programs have been used mostly by the experts in the real design world. Furthermore, the use of optimization method by general designers results in failure more than in success especially in the multiobjective optimization problems. The major reason is that there is no one algorithm which can efficiently solve all classes of design problems. However an expert can choose a suitable method to attack the problem as they understand it. Even if an algorithm is theoretically guaranteed to solve a class of problems, its numerical implementation of the design model needs related knowledge.

A multiobjective approach to the combined structure and control optimization problem for flexible space structures based on the genetic algorithm and gradient search technique is presented[1]. This method is effective. The gradient of objective function is required. An approach for optimal nesting by combining a genetic algorithm and a local minimization algorithm is presented[2]. In this approach, the genetic algorithm is used for handling the combinations which are represented in the string, and the local minimization algorithm is used for determining the embodiment layout under the fixed combinations so as to minimize the scrap volume which is corresponding to the fitness value in the genetic algorithm. The system that contains knowledge needed to select appropriate optimization algorithms to control the solution process is presented[3]. They demonstrated the technical feasibility of developing an optimization system by integrating a knowledge based system with procedural programs. In particular, the application of knowledge engineering to noninferior optimization methodology was illustrated. An expert system was developed to aid a user of the Automated Design Synthesis general purpose optimization program[4]. A systematic methodology for the implementation of engineering design optimization by using an expert system approach is developed[5]. Two cooperating knowledge based systems is also developed[6]. One is in the domain of electronics and electrical fields, which are mainly used for electronic circuits and for analyzing the optimal results from a professional point of view. The other is used in the mathematical domain to determine the optimal points of the optimization model.

Unlike the mass production auto-industry, in the shipbuilding industry ships are built in small quantity with many different designs depending on the customer's needs. To secure orders designers have to design efficient, high performance ships within a fixed time period. In time of recession more inquiries have to be processed to secure more orders. This can be a very difficult task for an inexperienced designer, but with the expert system that can support designers in the preliminary design process the efficiency can be increased.

In this paper, a hybrid optimizer with aid of heuristic and analytic knowledge is developed by coupling the genetic algorithm, the direct search method and a knowledge based system. The system, therefore, has the capability of knowledge processing and numerical computation. The system is applied to the multiobjective optimum design of a ship.

2. MULTIOBJECTIVE OPTIMIZATION

The design of systems can be formulated as a problem of optimization where a measure of merit is to be optimized while satisfying all the constraints. To solve design problems using optimization, their formulation is needed. The importance of a proper formulation of a design optimization problem must be clearly understood because the optimum solution will only be as good as its formulation. The formulation process begins by identifying a set of variables to describe the problem, called design variables. The constraints are a given set of limitations which include available resource, performance of system and so on. The constraints must be represented by the design variables of the system. An objective function is needed to judge whether or not a given design is better than others. A valid objective function must be expressed by the variables of the design problem; it must be a function of the design variables.

2.1 Multiobjective Optimization Methods

Design is a multiple criteria problem in nature and most design problems are characterized by a large number of alternative solutions. Traditionally, single objective optimization has been used in numerous design problems. When using single objective approaches, one major drawback is that they lead to the unambiguous identification of a single optimum or near optimum solution. Designers will therefore be in the position of accepting or rejecting this single solution identified as the best. Since the beginning of the last decade, the multiple criteria decision making methodology has attracted increasing attention among researchers. It basically provides a means for designers to handle problems in which several conflicting criteria are to be met. Multiple criteria analysis of the problem normally leads to the generation of several alternatives and other important information such as tradeoffs among criteria, which a designer use in selecting his best alternative.

The classification of solution techniques for multiobjective optimization problem[7] follows: 1) Generating Techniques, 2) Techniques which rely on prior articulation of preferences and 3) Techniques which rely on progressive articulation of preferences. In this paper, generating techniques is adapted to solve multiobjective optimization problem.

2.1.1 Generating techniques

Some of the methods included in this class were among the first multiobjective solution procedures developed. They employed the Kuhn-Tucker conditions for noninferior solutions. The purpose of all of the generating techniques is to identify the set of noninferior solutions. Thus the generating techniques provide most of the information that one can extract from a multiobjective design model. This is accomplished without preference information from decision makers. A proper optimal point in the noninferior solutions will be selected by decision makers. The noninferior solutions are called Pareto optimal set, or nondominated solutions. Generally the problem is not the nonexistence of the noninferior optimal set but rather too many number of elements in it. This may cause difficulties both in generating the solution set and in handling the results.

2.1.2 Constraint method

To solve multiobjective optimization problem in this paper, a constraint method that is a kind of generating techniques, which do not require preference on the objectives, is adapted. This method retains one objective as primary and treat the remaining objectives as constraints. The mathematical formulation of the constraint method is as follows;

$$Min \;\; F_j(x)$$

subject to

$$x \in X$$
$$Z_i(x) \leq m_i = 1, 2, \ldots, j-1, j+1, \ldots, p$$

where the j th objective is arbitrarily chosen for minimization and m_i are the upper bounds on the remaining p-1 objectives. Therefore multiobjective optimization problem can be transformed into a single objective problem, and can be solved by conventional optimization methods. The noninferior optimal set is then generated by solving single objective problem with a parametric variation of constraints.

2.2 Hybrid Optimizer

Constraint method determines noninferior optimal set based on conventional single objective optimization methods. In conventional optimization methods, there is no general and reliable method for finding the global optimum point. To find the global optimum point, designers must solve the problem with several initial conditions such as starting points, step size and the end condition. Finally the optimum point is selected one point by designer among the multi-solutions obtained. To more efficiently find a global optimum point, a hybrid optimizer is developed by coupling the genetic algorithm and the direct search method. It finds out a candidate region around the global optimum point by using the genetic algorithm, then searches the global optimum point using by the direct search method in the finded region.

2.2.1 Genetic algorithm

The genetic algorithm is a non-derivative based optimization algorithm imitating natural selection[8]. This algorithm mimics reproduction, crossover and mutation in nature. Design variables are analogous to chromosomes in the genetic algorithm. Design variables are described using binary strings where string length is determined by the precision desired for each design variable. Design variables are linked together to form a genotype. The design variables with genotype are decoded and mapped into the range of the design variables respectively.

The genetic algorithm is more suitable for maximization problem. To apply minimization problems, therefore, the minimization objective function is achieved through a maximization of the fitness index defined as

$$F(x) = F_{\max} - f(x)$$

where F_{max} is chosen to be greater than the largest value of the fitness in the population and $f(x)$ means original fitness value.

The genetic algorithm is mostly robust in various problems. But it cannot guarantee finding global optimum point in all kind of problems. It will be dependent on characteristics of problem, number of populations, crossover and mutation rates.

2.2.2 Direct search method

This method uses a series of local pattern searches and global pattern moves which usually provides acceleration along valley in search of the object function. The method is fairly simple and effective, and can often be very competitive with other methods with respect to time. The main weakness of this method is that it can become very slow or stop completely prior to reaching the optimum if there is a sharp valley in the object function oriented nearly 45 degrees between coordinates. The local search finds no improvement in objective function since the direction of improvement lies between the directions in which the local search steps are taken.

2.2.3 Hybrid optimizer

A hybrid optimizer is developed by coupling the genetic algorithm and the direct search method. This finds out a candidate region around the global optimum point by using the genetic algorithm, then searches the global optimum point in the region by the direct search. The genetic algorithm and direct search method can be applied to unconstrained optimization problems. To incorporate the constraints, a penalty function method is used to convert the constraint optimization problem into an unconstrained problem as

$$F(x) = f(x) + r \sum_{i=1}^{m} [\, g_i(x)]^2$$

where r is penalty coefficient of the external penalty function method, m is number of constraints and $g_i(x)$ is penalty function term.

To verify the efficiency of the developed optimizer, it is applied to some mathematical functions. The mathematical functions and results show in appendix and Table 1 respectively. It was verified that the hybrid method found the more good solution in comparison with the genetic algorithm and the direct search method, and calculating time is considerably decreased. It means that stress of designers will be lightened and reduced their effort when using optimization method.

3. OPTIMIZATION AND KNOWLEDGE PROCESSOR

Tasks of the knowledge base system in this paper are to improve efficiency of optimization by generation of proper input data for the design model before performing optimum design process.

3.1 Knowledge Base as Preprocessor

The design model for optimization is generally constructed by a design expert. Selection of design variables is very important when building a design model. If the wrong design variables are selected, the design model cannot exactly reflect the real world. And input data for the optimization method such as the starting point and step size have an effect not only on the calculating time but also on finding the global optimum point. Building a design model, preparation of input data and choice of optimization method also require expert knowledge of optimization methods and characteristics of the design problems.

Table 1 Evaluation results of the hybrid optimizer, GA and direct search method

		Function-1	Function-2	Function-3
f*(x)		-10.0	3.0	-15.0
x*		-1.0	0.0, -1.0	0.0, 3.0, 0.0, 4.0
Hybrid Optimizer	f(x)	-10.0	3.0	-14.99
	x	-1.0	0.0, -1.0	0.0, 2.99, 0.0, 3.99
	time(sec)	0.76	0.32	1.23
GA	f(x)	-9.99	3.52	-13.2
	x	-0.99	-0.01, -0.97	0.1, 2.81, 0.1, 3.92
	time(sec)	1.4	3.9	3.3
Direct Search Method	f(x)	-10.0	30.0	-12.99
	x	-1.0	0.6, -3.99	2.99, 0.0, 3.99, 0.0
	time(sec)	0.04	0.03	0.04

f*(x) : global optimum value, x* : value of design variables at global optimum point

Therefore knowledge based system will contribute to the formulation of the optimization model, preparation of input data and the choice of optimization method.

The genetic algorithm has relatively superior capability of finding the global optimum point in comparison with other methods but it requires more calculation time. It must have a smaller number of generations and populations to reduce calculating time. Therefore, to improve search efficiency with a smaller number of generations and populations, the range of each of design variables must be assigned at near optimum point.

The crossover and mutation rates are also important factors in the genetic algorithm. If the crossover and mutation rates have very large values. The searching efficiency will be reduced by a loss of searching direction or consistency. If it has a smaller value, searching efficiency for optimal point will be reduced due to the loss of evolutional characteristics because searching is dominated by influence of the initial populations. Incidentally, the calculation time in the direct search method depends on starting points, step size and end conditions. In the hybrid optimizer, the point obtained from the genetic algorithm is used as a starting point for the direct search method. Therefore calculation time in the direct search method will depend only on step size and end conditions.

Knowledge related to population size, number of generations, crossover and mutation rate for the genetic algorithm is extracted from handling experience of the genetic algorithm, see reference[9),10)]. Knowledge for the direct search method such as proper step size and end conditions is also extracted from application experience of the direct search method[11)].

The difference between the ship design and the design of the similar transportation systems comes from the fact that ships are tailor-made and non-mass production mode. As a prototype is built at the end of the design stage when developing a car, ship designs cannot afford a prototype. To overcome this difficult environment, ship designers have used the data of built ships. Therefore the proper range of design variables is abstracted by analysis of database of built ships. This knowledge is implemented in the knowledge base of the system. Some expressed knowledges in the knowledge base are as follows:

If *type of ship is bulk carrier and capacity of ship is handy size*
Then *low limit of ship's length is 143.5m and step size of ship's length for direct search method is 0.2m and end condition of ship's length for direct search method is 0.01m*
If *type of ship is liquefied gas carrier*
Then *no. of population for genetic algorithm is 400*

The knowledge based system infers the knowledge base to obtain proper input data for the hybrid optimizer based on the kind of vehicle and cargo capacity. The inferred results are transferred to the hybrid optimizer.

3.2 Realization of Multiobjective Design System with Knowledge Processor

A multiobjective optimum design system with knowledge processor is developed through integration of the hybrid optimizer and the knowledge based system. The genetic algorithm and direct search method is coded by using Fortran77. The inference mechanism and knowledge base of the knowledge processor is developed by LISP. The system integration and generation procedure of the noninferior optimal set in the constraint method of multiobjective optimization are developed by using the Shell programming technique at an engineering work station. The information flow of developed system is shown in Fig. 1.

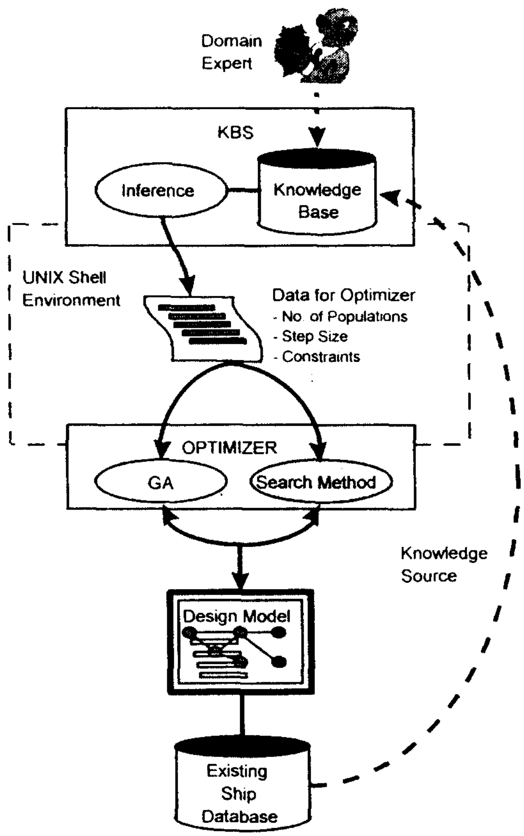

Fig. 1 Information flow of the developed system

Working procedure of the system are as follows. The knowledge processor infers knowledge base using user's input data such as kind and capacity of ship. The proper range of design variables and data obtained for hybrid optimizer by the knowledge processor are written to a file. Then noninferior optimal set is generated by the hybrid optimizer that controlled by the Shell code. In the hybrid optimizer, the genetic algorithm read necessary data from file generated by the knowledge processor and then performs optimization. The information of the candidated point obtained by the genetic algorithm are stored to the memory. Finally the direct search method finds the optimum design point based on the stored information in the memory.

4. OPTIMUM DESIGN OF A SHIP

The preliminary design of ship involves repetitive and complex analysis, trial-and-error methods, extrapolation of existing ship data, and requires a large measure of experience. An improved design procedure can be developed by formulating the process as an optimization problem. There have been a number of applications of optimization to the different aspect of the ships at preliminary design stage. There are modeled the ship design problem as a multiobjective optimization problem[12)~14)]. In this design problem, however, some highly nonlinear and extremely complex functions are used to define the performance criteria and the relationship between variables. Therefore conventional optimization method itself cannot be used to solve these design problems with efficiency. The developed hybrid optimizer can be useful design tool for these problems. The liquefied natural gas carrier with a membrane type tank that a kind of ships is selected as the design model in this paper because design variables can vary continuously in comparison to ship with other type tank.

4.1 Modeling for a ship Design

4.1.1 Design variables

The design variables chosen for the design model are the dimensioning vector X :

$$X = (x_1, x_2, x_3, x_4, x_5, x_6)$$

where x_1, x_2, x_3, and x_4 mean length, breadth, depth and design draft of ship respectively. x_5 is block coefficient and x_6 is design speed.

As length becomes longer under the same displacement or cargo hold capacity, the building cost of vehicle will be increased. But the operating cost will be decreased because it requires less propulsive power. Although wider breadth leads lower building cost and good stability performance to the same design condition, it is the cause of higher operating cost. Depth is good factor to increase the cargo hold capacity. Higher depth give a guarantee for bigger hold capacity with the inexpensive building cost. But it will be restricted by cargo terminal capacity and classification's rule because excessive sized depth produces a bad stability performance in calm water and wave. Draft is also effective factor to increase the displacement with the lower building cost and to improve the stability performance. It is restricted by maximum allowable draft of operating route and ports. Block coefficient is most effective design variable to increase the displacement and cargo hold capacity with lower building cost. But excessive valued block coefficient is the cause of higher operating cost and bad motion performance in wave. Speed of commercial ships is very important factor in the economics. Generally speaking, proper range of it rely on several factors such as kind of cargo, preference of owner and design's experience. Furthermore, ratio between these design variables are also important in the naval architectural performance. It will be expressed to the design model as technical constraints.

4.1.2 Objective functions

When designing ship, shipyards have an interest in the building cost for their income. But owners are concerned about not only the building cost but also the operating cost. These two items are contrary to each other and are function of design variables.

The first objective function to be minimize is the building cost. The building cost is divided into the material cost, the indirect material cost, the production labor cost, the direct cost and the design labor costs. The material and the production labor costs are estimated with groups such as hull, paint, cargo handling equipment, deck machinery, accommodation, propulsion machinery, insulation, navigation and electric equipments.

The second objective function to be minimize is the operating cost. The operating cost is divided into the voyage cost and the fixed cost. The voyage cost consists of fuel cost, port cost, loading and unloading cost. The fixed cost consist of crew cost, insurance fee, maintenance and repair cost. The operating cost is estimated based on the speed of the vehicle, the operating route characteristics such as round trip distance, terminal capacity, fuel oil price and so on.

4.1.3 Constraints

The constraints in ship design have been broadly categorized into three groups : the legal constraints specified by the regulation, environmental constraints by the operating route and technical constraints arising due to design process. The safety requirements such as freeboard and required minimum required GM, and the minimum length of the stem are categorized into the legal constraints. The design variables are effected by the environmental constraints such as terminal capacities and characteristics of waterway in the operating route. The buoyancy balance of the weight and the stability requirement belong to the technical constraints. Following interrelationships of the design variables are examples for constraints;

$$x_1/x_2 = 5.556 \sim 6.136$$
$$x_2/x_4 = 3.826 \sim 4.018$$
$$x_1/x_3 = 9.434 \sim 10.385$$
$$x_6/\sqrt{x_1} = 0.563 \sim 0.716$$
$$x_4 = 11.2 \sim 11.5$$
$$x_5 = 0.7 \sim 0.73$$

And depth must have a larger value than draft and all design variables must have positive sign in physical sense. In practical ship design, feasible range of these design variables can be limited based on design expertise and existing database. Therefore search space and time will be reduced and efficiency will be increased. Feasible range of the design variables inferred by knowledge in this problem are as follows:

4.1.4 Engineering modules (Design Model)

Some engineering calculation modules are required for reasonable ship design. The engineering module consists of the lightship weight estimation module, the powering performance estimation and propulsive engine selection module, the cargo hold volume estimation module, the midship section module, the longitudinal compartment division module and so on. Detail design procedure are:

1) Choose suitable mother ship to design alternative(input data) and retrieve its technical data from database.
2) Estimate required power based on empirical formula and result of statistical analysis of the tested data in the towing tank.
3) Select the main propulsive engine based on estimated power.
4) Determine midship section shape at cargo hold region based on data of the mother ship.
5) Divide the longitudinal compartment of the ship into four parts based on empirical formula, data of the mother ship and the classification rule.
6) The sectional area of the cargo hold and ballast tank at midships is calculated taking into consideration insulation thickness and midship section shape. Volume of the cargo holds and ballast tanks are estimated by using the total length of the cargo hold, the sectional area and the correction factors obtained from data of the mother ship.
7) Estimate lightship weight based on empirical formulas, correction factors and data of the ship.
8) Calculate deadweight of the vehicle based on displacement and lightship weight.
9) Calculate yearly transported cargo quantity in given operating route.
10) Calculate the building cost as objective function.
11) Calculate the operating cost as objective function.

4.2 Evaluations of Optimum Design

The complete set of the noninferior optimal set and design variables are given in Table 2. Table 2 shows that longer vehicle reduce the operating cost. The reason is that longer ships encounter

	x_1	x_2	x_3	x_4	x_5	x_6
Lower Boundary	250m	44m	26m	11.2m	0.7	18knots
Upper Boundary	270m	45m	26.5m	11.5m	0.73	22knots

less resistance in operation, which allows to install a low power engine, reducing the operating cost. The optimum breadth of the ships are given by 44.9 - 45.0 meters. Thebreadth of optimum solutions are dependent on the maximum breadth allowed due to terminal capacity, which acts as a constraint. The optimum depth of ships are 26.45 - 26.48 meters. These values are nearly same as the allowable maximum depth(26.5 meter) by terminal facility. And in case of the optimum draft, it is close to the allowable maximum draft(11.5 meter) in operating route. From the result of the optimization, it is noticed that the optimum breadth, depth and draft of the ship come close to allowable maximum values of environmental constraints in the operating route. The limitation imposed by operating route in the ship design optimization has an large effect on the principal particulars. The optimum block coefficients(Cb) are 0.713 - 0.717. The block coefficients of the ship do not have an large effect on the variation of the building and the operating costs, but are dependent on characteristics of hull form in case of medium speed vessels. The lower operating speed decreases the operating cost. On the other hand, the size of ship with low operating speed must increase to transport given cargo quantity, increasing the building cost of ship. The operating cost is very much dependent on operating speed, but the building cost is not so heavily dependent on the operating speed. These trends mean that the operating cost optimization is more important for the economical view than the building cost optimization. As the fuel cost occupies a large portion of the operating cost, it is necessary that principal particulars of a ship are selected to optimize the ship speed. In summary, as the length of the ship is lengthened, it has an advantage for the operating cost and has a disadvantage for the building cost. The breadth, depth and draft of the ship are effected by environmental constraints in operating route. The cargo hold capacity and speed of the ship are decided by the requirement to transport a given yearly cargo quantity. The block coefficient is dependent on the characteristics of a hull form suitable to the speed of the ship.

Table 2 The obtained noninferior optimal set

Object Function 1	Object Function 2	x_1 (m)	x_2 (m)	x_3 (m)	x_4 (m)	x_5	x_6 (knots)
29,384	17,098	269.08	44.91	26.44	11.31	0.7249	18.55
29,267	17,146	266.56	44.97	26.47	11.43	0.7156	18.78
29,249	17,202	265.00	44.99	26.48	11.43	0.7164	18.86
29,233	17,240	264.34	44.99	26.48	11.45	0.7148	18.94
29,234	17,240	264.34	44.99	26.47	11.45	0.7148	18.94
29,227	17,311	263.70	44.94	26.45	11.46	0.7134	19.07
29,224	17,371	262.77	44.96	26.47	11.46	0.7134	19.15
29,218	17,489	260.78	44.97	26.46	11.45	0.7136	19.31
28,995	18,055	254.80	44.94	26.44	11.38	0.7131	20.13

Unit of object functions : thousand dollars

5. CONCLUDING REMARKS

To overcome a weakness of conventional optimization methods of falling into a local minimum, and to obtain the global optimum solution efficiently by reducing search time in design space, a hybrid optimizer that does not require the gradient of objective functions was developed through combining the genetic algorithm with the direct search method. The efficiency of the developed the hybrid optimizer is confirmed by application to mathematical optimization problems. Knowledge for ship design is extracted by analyzing the database of existing ships and it can be applied to optimum design for some kind of ships. This knowledge base contains the proper input data for hybrid optimizer and the feasible range of design variables which can be used to ship design. To overcome the limitations of optimization methods and knowledge based systems when using them separately and to take the more realistic design, the knowledge based multiobjective optimum design system which has the capability of knowledge processing and numerical computation was developed by integrating the hybrid optimizer and the knowledge based system. The developed system is applied to the optimum design of a ship in the preliminary design stage. Through application to the ship design, the relative importance between the design variables in the economic analysis of the ship design was manifested.

APPENDIX

To evaluate performance of the hybrid optimizer, it is applied to three different kind of mathematical functions. These functions are minimization problem. The first function is unconstrained problem and remainder have some inequality constraints.

Mathematical function-1 : This function has one design variable without constraints as follows;

$$f = 3x^4 - 8x^3 - 6x^2 + 24x + 9$$

Mathematical function-2 : This function have two design variables with four inequality constraints as follows;

$$f = (1 + (x_1 + x_2 + 1)^2(19 - 14x_1 + 3x_1^2 + 14x_2 + 6x_1x_2 + 3x_2^2))$$
$$(30 + (2x_1 - 3x_2)^2(18 - 32x_1 + 12x_1^2 + 48x_2 - 36x_1x_2 + 27x_2^2))$$

subject to

$$-2.0 \le x_1 \le 2.0$$
$$-2.0 \le x_2 \le 2.0$$

Mathematical function-3 : This function have four design variables with ten inequality constraints as follows;

$$f = x_1 - x_2 - x_3 - x_1x_3 + x_1x_4 + x_2x_3 - x_2x_4$$

subject to

$$0 \le 8 - x_1 - 2x_2,\ 12 - 4x_1 - x_2,\ 12 - 3x_1 - 4x_2$$
$$0 \le 9 - 2x_3 - x_4,\ 8 - x_3 - 2x_4,\ 5 - x_3 - x_4$$
$$0 \le x_1,\ x_2,\ x_3,\ x_4$$

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