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(54) Method for controlling machine with control module optimized by evolutionary computing

Verfahren zur Steuerung von Maschinen mit einem mittels genetischer Algorithmen optimierten Steuerungsmodul

Méthode de commande d’une machine avec un module de commande optimisé par un calcul évolutif

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(73) Proprietor: YAMAHA HATSUDOKI KABUSHIKI KAISHA
Iwata-shi Shizuoka-ken (JP)

(74) Representative: Grünecker, Kinkeldey, Stockmair & Schwanhäusser Anwaltsozietät
Maximilianstrasse 58
80538 München (DE)

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This invention relates to a method for controlling performance of a machine, especially to a method and apparatus for optimizing performance of a machine such as a motor, and particularly to an improved method and apparatus for optimizing a control module that controls performance of the machine.

In the past, optimal values of a characteristic of a control module (namely, parameter values for deciding input-output relationship of the control module) to control a controlled system were determined by experiment at the stages of design or setting before shipment, so that users of a product comprising a controlled system were assumed and the users’ characteristics (preference, technique, personality, and use) could be met.

However, with the diversity and advancement of recent technology, the conventional method of deciding optimal values of a characteristic of the control module by experiment brings about difficulty for optimizing the control module, and requires a lot of time.

Since personal characteristics or preferences vary from one person to another, the conventional control method cannot provide a characteristic of products which satisfy all users.

In view of the problems described above, there is proposed a para-evolutionary method. In this method, a control apparatus produces a plurality of chromosomes (individuals) by using control parameters of the control apparatus that exert influence on characteristics of a controlled subject or machine and then have some of the chromosomes evolve by a genetic algorithm by selecting excellent chromosomes based upon intention of the user.

In the method that has been proposed formerly, the machine is actually operated with the respective chromosomes that are produced initially and the user evaluates the respective operations to select out undesirable chromosomes (individuals). Characteristics that fit to the user can be obtained in this method. In the above evolutionary computing, individuals of one generation are created, the individuals of the generation are screened to select and leave parent individuals, a group of individuals of the next generation are created by performing calculation of crossing or mutation using the parent individuals, and individuals of higher suitability are obtained by repeating the above operation.

In evolutionary computing, chromosomes are defined by genes which are derived from the genes of parent chromosomes under predetermined rules. Genes can be represented by numerical values which can be defined using coordinates in a selection space ("gene pool") having a predetermined size. In this way, only genes included in the selection space can be selected, and the diversity of genes can be restricted so as to maintain their species such as engine control parameters. In other words, the selection space is defined by the species.

However, in evolutionary computing, individuals are created using genes of their parents, and adapted (fitted) individuals of offspring are selected to obtain relatively better individuals among the offspring at each generation. This relative evaluation leads to a problem in that although relatively better genes are passed onto subsequent generations, finally selected relatively better individuals may not provide an optimum solution in view of absolute standards. That is, although genes of offspring are selected randomly in the selection space, the selection points or positions are concentrated in a small region of the selection space. That the individuals are created densely in a small region means that many of the individuals are similar to each other. This is a significant problem in evolutionary computing because the individuals lack versatility and evolution does not make progress. This problem may be alleviated to a certain degree by creating mutants. However, mutants are created in random positions in the selection space, and in some cases, individuals are created more different from each other than necessary in the selection space. If the differences among the individuals (distances in the coordinates in the selection space) tend to be greater than necessary as described above, a problem arises that individuals in the vicinity of optimum solution cannot be obtained and the evolution does not converge. The above problems arise due to the relative evaluation of offspring, the limited diversity of genes carried over from parents, or the randomness of genes of mutants.

It is an objective of the present invention to provide a method for controlling performance of a machine having a high efficiency.

According to the present invention, said objective is solved by a method for controlling performance of a machine according to claim 1.

Accordingly, an evolution efficiency improving method is provided for use in evolutionary computing for creating the subsequent generation of individuals by making it possible to restrict the positions of individuals in the selection space to some extent for efficient proceeding of evolution.

Preferred embodiments are laid down in the dependent claims.

 Said method controls performance of a machine controlled by at least one control module having an input-output relationship regulated by control parameters. In an embodiment, the method comprises the steps of: (a) configuring a first generation of chromosomes coding for the control parameters by preselecting genes constituting the first generation of chromosomes from a selection space used as a gene pool, and activating the machine using the first generation of chromosomes, said genes being defined by coordinates in the selection space; (b) selecting and scoring adapted chromosome(s) by evaluating each chromosome based on signals indicative of performance of the
According to the above, the search area is set and changed depending on the score(s) of the adapted chromosome(s). Thus, in an embodiment, when relatively better chromosomes are selected among chromosomes of one generation, not only the chromosomes are selected based on relative evaluation, but also the search area (i.e., available gene pool) changes in accordance with the scores (i.e., absolute evaluation). Accordingly, by a combination of relative evaluation and absolute evaluation, the search area can be configured appropriately. For example, if selected chromosomes are well adapted among others but are not good in view of absolute standards, the search area is expanded in a certain direction. This approach is very different from simply creating mutants, because mutants are created in entirely random coordinates and thus a chance to obtain good chromosomes is low, and if mutants are created frequently, evolution may not converge. The search area approach lowers the randomness but maintains the diversity of chromosomes. Hereinafter, the term “individuals” may be used as a synonym for “chromosomes”. Also, the term “positions” may be used as a synonym for “coordinates”.

There are several ways to determine the position and the size of a search area, which will be explained later. In an embodiment, the aforesaid indicative signals are sensory signals, and a user who operates the machine scores the chromosomes based on the sensory signals. By doing this, the selection mechanism can technologically be simplified, and the performance of the machine can be changed adaptive to the user. In another embodiment, the indicative signals are electronic signals, and a device which receives the signals scores the chromosomes by comparing values of the signals with preselected target values. This autonomous approach reduces a users task and eases the user’s operation.

In the present invention, a machine to be controlled includes any machine which can be controlled electronically using a control module. The input-output relationship of the control module is regulated by control parameters. Conventionally used control parameters can be used. The number of control parameters is not limited. Preferably, at least two parameters are used for sophisticated control. The control module can be provided with the machine or separately from the machine. The control module and the machine can be linked via the Internet. The machine includes an engine or a motor for a vehicle or a robot, an actuator for valves, and the like. The machine further includes a control module or unit for controlling another control module or unit, and a simulation machine for simulating another machine. When using a simulation machine, a control unit can be configured to be adaptive to a user on a real-time basis by applying the present invention. The characteristics of the control unit can then be adapted to a machine.

For purposes of summarizing the invention and the advantages achieved over the prior art, certain objects and advantages of the invention have been described above. Of course, it is to be understood that not necessarily all such objects or advantages may be achieved in accordance with any particular embodiment of the invention. Thus, for example, those skilled in the art will recognize that the invention may be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other objects or advantages as may be taught or suggested herein.

Further aspects, features and advantages of this invention will become apparent from the detailed description of the preferred embodiments which follow.

These and other features of this invention will now be described with reference to the drawings of preferred embodiments which are intended to illustrate and not to limit the invention.

Figure 1 is a schematic diagram showing an embodiment of the present invention;

Figure 2 is a general block diagram of an optimization device employing the method of an embodiment of this invention for improving the evolution efficiency;

Figure 3 is a flowchart of the process in the search area changing section 33;

Figures 4A(a), 4A(b), 4B(a), and 4B(b) show a specific example method of changing the search area; with A(a) and (b) showing an example of determining the next generation search area on the basis of the size of the current generation search area, and B(a) and (b) showing an example of determining it irrespective of the size of the current generation search area;
Figures 5A(a), 5A(b), 5B(a), and 5B(b) show other example methods of changing the search area; with A(a) and (b) showing an example of determining the next generation search area on the basis of the size of the current generation search area, and B(a) and (b) showing an example of determining it irrespective of the size of the current generation search area;

Figures 6A(a), 6A(b), 6B(a), and 6B(b) show still another example method of changing the search area; with A(a) and (b) showing an example of determining the next generation search area on the basis of the size of the current generation search area, and B(a) and (b) showing an example of determining it irrespective of the size of the current generation search area;

Figure 7 is a flowchart of an evolutionary computing process in the evolutionary computing section 20 and in the evolution efficiency improving section 30;

Figure 8 is a general block diagram explaining an inter-individual distance calculating section usable in the method of an embodiment of this invention;

Figure 9 is a flowchart of the process of the next generation individual choosing method on the basis of inter-individual distances;

Figures 10(a) and 10(b) both show the relation between the individuals stored in the data storage section 11 and the next generation candidate individuals created in the next generation individuals creating section 4;

Figure 11 is a flowchart of an evolutionary computing process in the evolutionary computing section 1 and in the evolution efficiency improving section 10;

Figure 12 generally shows the relation between an engine 40 and a control device 41 employing the evolution efficiency improving method of an embodiment of this invention;

Figure 13 is a general block diagram of the control device 41;

Figure 14 is a general block diagram of an electronic throttle control module;

Figures 15(a), 15(b), and 15(c) show examples of static characteristics of several throttle devices;

Figure 16 shows examples of dynamic characteristics of several throttle devices;

Figure 17 shows an example of coding control parameters as gene type individuals;

Figure 18 is a general block diagram of the optimizing device 43;

Figure 19 is a flowchart of the process in the optimizing device 43;

Figure 20 shows an example flow of evaluation value acquiring method in the evaluation value acquiring section 47;

Figures 21(a) and 21(b) show examples of data used for changing the search area size; (a) shows the data used for changing the search area size of the next generation irrespective of the current search area size, and (b) shows the data used for changing the search area size of the next generation on the basis of the current search area size;

Figure 22 shows an example of creating the next generation candidate individuals in all-inclusive manner within the search area;
Figure 23 is a flowchart of the next generation individual choosing process with the individuals operating section using the inter-individual distances and estimated evaluation values; and

Figures 24(a), 24(b), and 24(c) show the concept of flow of the next generation individual choosing process with the individuals operating section using the inter-individual distances and estimated evaluation values.

[0022] The present invention can be applied to various types of machine controlled using at least one control module, the input-output relationship of which is regulated by control parameters. According to the present invention, the control module is optimized in real time, i.e., while operating the machine.

[0023] Figure 1 is a schematic diagram showing an embodiment of the present invention. In this figure, performance of a machine 102 is controlled by at least one control module 101 having an input-output relationship regulated by control parameters. The machine 102 is operated by a user 100. However, the machine 102 can be controlled automatically, and optimization of the control module can be performed autonomously. In this figure, the first step is (a) configuring a first generation 105 of chromosomes 104 coding for the control parameters by preselecting genes X(1)ij constituting the first generation of chromosomes from a selection space 103 (or Xij region) used as a gene pool, and activating the machine 100 using the first generation 105 of chromosomes (one chromosome at a time). The genes are defined by coordinates in the selection space 103. The next step is (b) selecting and scoring adapted chromosome(s) by evaluating each chromosome based on signals indicative of performance of the machine 102. Scores, Y(1)i; may be values of absolute evaluation and can be given to each chromosome. Alternatively, scores can be assigned only to adapted chromosome(s) after selecting the adapted chromosome(s) based on relative evaluation without using scores. One chromosome or multiple chromosomes can be selected as adapted chromosome(s) which will be used as parents for a subsequent generation. In one generation, any number of chromosomes can be created. For example, 3-30 chromosomes, preferably 5-20 chromosomes, can be used depending on the type of machine and the type of control module. The number of chromosomes may be determined depending on a user's capability of recognizing changes resulting from different chromosomes.

[0024] The next steps are: (c) setting a search area 107 in the selection space 103 in accordance with the score(s) under predetermined rules (which will be explained later); (d) selecting genes X(2)ijj for a second generation 106 of chromosomes within the search area 107, and operating the machine 102 using the second generation 106 of chromosomes; and (e) repeating steps (b) through (d) while operating the machine 102 until desired performance of the machine 102 is demonstrated. The search area changes in accordance with the score(s) when moving to a subsequent generation. For example, a third generation 110 are created from a search area 108 which has a broader region than the search area 107 in a direction and has a narrower region than the search area 107 in another direction, depending on the predetermined rules. This is the same in a fourth generation 111 which is created from a search area 109. In some cases, a subsequent search area may be broader or narrower than the previous area in all directions.

[0025] The present invention employs a method of improving evolution efficiency in optimization method using evolutionary computing to obtain individuals of higher suitability. The method comprises the steps of: forming one generation with a group of individuals, and performing calculation using individuals of at least said generation to create a group of individuals of the next generation, characterized in that a search area is provided for the individuals of the next generation in a selection space and that the individuals of the next generation are created within the search area. In the above, the following methods can be used for configuring the search area:

1) The position and the size of the search area are changed according to the situation of evolution.

2) In 1), the position, in the selection space, of the individual that has obtained the highest evaluation value among the group of individuals of the current generation, is made the central position of the search area of the next generation.

3) In 1), a weighted average position, determined from evaluation values as weights given to respective positions of individuals in the selection space of the current generation, is made the central position of the search area of the next generation.

4) In any one of 1)-3), the size of the search area of the next generation is changed according to the evaluation values given to respective individuals of the current generation.

5) In 4), the size of the search area of the next generation is changed according to the highest of the evaluation values given to the group of individuals.
6) In 4), the size of the search area of the next generation is changed according to the average value of evaluation values given to respective individuals of the current generation.

7) In any one of 1)-3), the size of the search area of the next generation is changed according to the positions of individuals in the selection space created in the evolution process.

8) In 7), a distance between the central position of the current generation search area and the central position of the search area of the newly determined next generation is calculated, and the size of the search area of the next generation is changed according to the distance.

9) In 7), the size of the next generation search area is changed according to the central position of a newly obtained next generation search area in the current search area.

10) In any one of 1)-9), a group of candidate individuals of the next generation are created in the next generation search area, inter-individual distances between any candidate individuals of the next generation in the selection space are calculated, and individuals to be the group of the next generation are chosen from among the candidate individuals so as to restrict the position of the group of individuals of the next generation in the selection space on the basis of information on the inter-individual distances.

11) In any one of 1)-9), a group of candidate individuals of the next generation are created in the search area of the next generation, inter-individual distances between the candidate individuals and individuals up to the current generation in the selection space are calculated, and individuals to be the group of the next generation are chosen from among the candidate individuals so as to restrict the position of the group of individuals of the next generation in the selection space on the basis of information on the inter-individual distances.

12) In any one of 1)-9), a group of candidate individuals of the next generation are created in the search area of the next generation, inter-individual distances between any candidate individuals of the next generation in the selection space are calculated, also inter-individual distances between the candidate individuals and individuals of the previous generation in the selection space are calculated, and individuals to be the group of the next generation are chosen from among the candidate individuals so as to restrict the position of the group of individuals of the next generation in the selection space on the basis of information on the inter-individual distances.

13) In any one of 10)-12), individuals for which the calculated inter-individual distances are within a predetermined range are chosen to be the group of the next generation.

14) In any one of 10)-13), parameters the individuals have are represented with vectors, the differences between the same components of the vectors are determined in absolute values, and the sum of them is used as the inter-individual distance.

15) In any one of 10)-13), parameters the individuals have are represented with vectors, and the square of the norm determined for the difference of those vectors is used as the inter-individual distance.

[0026] A method for improving evolution efficiency in optimization method using evolutionary computing (hereinafter simply called the "evolution efficiency improving method") will be hereinafter described by way of several embodiments.

[0027] FIG. 2 is a general block diagram of an optimization device employing the method of an embodiment of this invention for improving the evolution efficiency.

[0028] As shown in the figure, the optimization device comprises an evolutionary computing section (or "unit") 20 and an evolution efficiency improving section 30.

[0029] The evolutionary computing section 20 has an initial individual creating section 21, an evaluation value acquiring section 22, and a next generation individual creating section 23, to actually perform evolutionary computing such as hereditary algorithm. The initial individual creating section 21 creates a set of initial individuals on the basis of a search area defined with the search area initial value setting section 31 of the evolution efficiency improving section 30.

[0030] The evaluation value acquiring section 22 acquires all the evaluation values of the individuals created with the initial individual creating section 21 or the next generation individual creating section 23. Concretely, evaluation values for all the individuals are acquired by repeating the operation of converting a gene type individual in the individuals set to an expression type individual and acquiring the evaluation value for the expression type individual.

[0031] The next generation individual creating section 23 creates an individuals set of the next generation within the
search area defined with the search area changing section 33 of the evolution efficiency improving section 30. Incidentally, the next generation individual creating section 23 usually uses hereditary calculation such as crossing or mutation to create next generation individuals. However, the next generation individuals can be created with the following methods by narrowing the creating range of individuals by providing a search area.

[0032] To create once all the individuals that can be created within a search area, and choose individuals for the next generation out of the individuals created. To create individuals randomly within a search area.

[0033] To create individuals by the use of the design of experiments.

[0034] The evolution efficiency improving section 30 has the search area initial value setting section 31, a data storage section 32, and the search area changing section 33. The search area initial value setting section 31 sets the initial values of position and size of the individuals search area. The initial individual creating section 21 creates initial individuals within the search area of the initial values.

[0035] The data storage section 32 stores pieces of information on; the individuals created in the evolutionary computing section 20, the evaluation values given to the individuals, the time of creation of the individuals, etc.

[0036] The search area changing section 33 determines how to change the position and size of the search area for the individuals depending on the state of evolution so that the individuals of the next generation are created in positions nearer to optimum solutions in the next generation individual creating section 23, and changes the position and size of the search area. Specifically, as shown in the flowchart of FIG. 3, before the individuals of the next generation are created with the next generation individual creating section 23 in the evolutionary computing section 20, whether the position and size of the search area are to be changed is determined (step 3-1). If determined to be changed, the central position of the search area is determined on the basis of the data stored in the data storage section 32 and is changed (step 3-2). Then the size of the search area is determined and changed (step 3-3).

[0037] The time point of changing the position and size may be arbitrary; may be every time of generation alternation. The next generation individual creating section 23 creates the individuals of the next generation within the search area determined with the search area changing section 33.

[0038] A method of changing the position and size in the search area changing section 33 is described below.

[0039] Changing the position of the search area.

[0040] The search area changing section 33 changes the position of the search area to an area where higher evaluation values are expected to be obtained. Specifically, there are the following two methods:

(a) The central position of the search area is assumed to be the position of the best individual of the current generation.

(b) The central position of the search area is assumed to be the weighted average position determined by weighting with evaluation values for the positions of individuals of the current generation.

[0041] Specifically for example, it is assumed that the individuals of the current generation set are Xi = (Xi1, Xi2, ..., Xin) and the evaluation values given to the individuals Xi are Yi (i = 1 to N, where N is the number of individuals in the set). When the above method (a) is used, the individual Xi having the greatest value of Yi is set as the central position Xc = (Xc1, Xc2, ..., Xcn) of the search area of the next generation. When the above method (b) is used, the central position Xc of the search area of the next generation is determined with the following equation.

\[ X_{cj} = \frac{\sum_{i=1}^{N} x_{ij} y_i}{\sum_{i=1}^{N} y_i} \quad (j = 1 \text{ to } n) \quad \ldots \ldots \quad (5) \]

[0042] Therefore, in case a generation is made up of three individuals; X1 = (20, 50), X2 = (40, 30), and X3 = (100, 20); and the evaluation value given to the individual X1 is Y1 = 70, the evaluation value given to the individual X2 is Y2 = 90, and the evaluation value given to the individual X3 is Y3 = 40, the central position Xc of the search area of the next generation determined using the methods (a) and (b) becomes as follows.

[0043] With the method (a), the individual X2 = (40, 30) provided with the highest evaluation value Y2 becomes the central position Xc of the search area of the next generation. With the method (b),

\[ X_{c1} = \frac{20 \times 70 + 40 \times 90 + 100 \times 40}{70 + 90 + 40} = \frac{9000}{200} = 45 \]
The central position of the search area of the next generation $X_c = (45, 35)$

The search area changing section 33 reduces the size of the search area of the individuals of the next generation when the individuals of the current generation are expected to be near the optimum solution, and increases the size when the individuals of the current generation are expected to be distant from the optimum solution. Specifically, four methods, (c) to (e) below, can be enumerated.

(c) To change according to the evaluation value of the best individual of the current generation.

(c-1) The greater is the evaluation value of the best individual of the current generation, the smaller is made the search area.

(c-2) The greater is the value calculated by subtracting the average value of the evaluation values given to all the individuals created up to the current generation from the evaluation value of the best individual of the current generation, the smaller is made the search area.

(c-3) The greater is the value calculated by subtracting the average value of the evaluation values given to the individuals of the current generation from the evaluation value of the best individual of the current generation, the smaller is made the search area.

The size of the search area may be changed either on the basis of, or irrespective of the size of the current generation search area.

(d) To change according to the average of evaluation values given to the current generation individuals.

(d-1) The greater is the average of evaluation values given to the current generation individuals, the smaller is made the search area.

(d-2) The greater is the value calculated by subtracting the average value of the evaluation values given to all the individuals created up to the current generation from the average value of the evaluation values given to the individuals of the current generation, the smaller is made the search area.

(e) To change according to the shift distance of the central position of the search area.

The longer is the distance between the centers of current and next generation search areas, the greater is made the search area.

A more specific example of the above method (e) is described below in reference to FIG. 5.
FIG. 5A shows an example of determining the size of the next generation search area using the above method (e), on the basis of size of the current generation search area. As shown in the table of FIG. 5A(a), the search area changing section 33 has pre-stored data of the amount of change in the search area size (center-to-edge distance) corresponding to the search area center position shift distance (d), namely the distance (d) between the i-th generation search area center position and the (i+1)th generation search area center position, and changes the size of the search area on the basis of the table. Therefore, for example, if the search area center position shift distance (d) is 5, according to the table of FIG. 5A(a), the amounts of changes in the search area size in X1 and X2 directions are -10 and -5, as shown in FIG. 5A(b), the size of the search area of the next generation becomes (10, 15) on the basis of the search area size (20, 20) of the i-th generation.

In the FIG. 5A(b), the white circle indicates the search area center position of the i-th generation, the white square indicates the search area of the i-th generation, the black circle indicates the search area center position of the (i+1)-th generation, and the hatched square indicates the search area of the (i+1)-th generation.

FIG. 5B shows an example of determining the size of the next generation search area irrespective of the size of the current generation search area using the above method (e). As shown in the table of FIG. 5B(a), the search area changing section 33 has previously stored data of the search area size (center-to-edge distance) corresponding to the search area center position shift distance (d), and changes the size of the search area on the basis of the table. Therefore, for example, if the center position shift distance (d) is 5, according to the table of FIG. 5B(b), since the search area size is (10, 15), the size of the search area of the (i+1)th generation is made (10, 15) irrespective of the search area size of the i-th generation.

(f) To change according to the next generation search area center position in the current search area.

The flow of the evolutionary computing process in the evolutionary computing section 20 and the evolution efficiency improving section 30 constituted as described above will be described below in reference to a flowchart shown in FIG. 7.

First, the initial values of the position and size of the search area (initial search area) are determined with the search area initial value setting section 31 (step 7-1). Next, a set of gene type of individuals within the initial search area are created with the initial individual creating section 21 (step 7-2).

Then, one of the gene type individuals in the set is converted to an expression type individual, and the evaluation for the individual is acquired with the evaluation value acquiring section 22 (step 7-3).

And, data of the individual and the evaluation value given to the individual are stored in the data storage section 32 (step 7-4).

A judgment is made whether evaluation values for all the individuals in the set are obtained (step 7-5). If the
evaluation values are not obtained for all the individuals, the steps 7-3 and 7-4 are repeated. After the evaluation values are obtained for all the individuals, the position and size of the next generation search area are determined with the search area changing section 33 on the basis of the data stored in the data storage section 32 (step 7-6).

[0065] Then, with the next generation individual creating section 23, a set of gene type individuals are created within the new search area created with the search area changing section 33 by hereditary calculation or the like (step 7-7).

[0066] Here, another example method of improving the efficiency of evolution, that can be combined with the above-described evolution efficiency improving method of the invention, will be described.

[0067] FIG. 8 is a general block diagram explaining an inter-individual distance calculation section which is useable in the present invention. In this figure, the search area changing section is not indicated for convenience.

[0068] As shown in the figure, the optimizing device comprises an evolutionary computing section 1 and an evolution efficiency improving section 10.

[0069] The evolutionary computing section 1 has an initial individual creating section 2, an evaluation value acquiring section 3, and a next generation individual creating section 4, to actually perform evolutionary computing such as hereditary algorithm.

[0070] The initial individual creating section 2 creates a set of individuals corresponding to the first generation of gene type individuals for evolutionary computing, and starts evolution based on the individuals set.

[0071] The evaluation value acquiring section 3 acquires evaluation values for all the individuals created with the initial individual creating section 2 or the next generation individual creating section 4. Specifically, the section 3 repeats the steps of converting a gene type individual in the individuals set to expression type individual and of acquiring the evaluation value for the expression type individual, to acquire evaluation values for all the individuals.

[0072] The next generation individual creating section 4 converts each evaluation value acquired with the evaluation value acquiring section 3 to a suitability degree, performs calculation to acquire a higher evaluation value, and creates gene type individuals set of the next generation.

[0073] The evolution efficiency improving section 10 comprises a data storage section 11, an inter-individual distance calculating section 12, and an individuals set operating section 13.

[0074] The data storage section 11 stores pieces of information on such items as individuals created with the evolutionary computing section 1, the evaluation values given to the individuals, and the time of creating the individuals, in succession.

[0075] The inter-individual distance calculating section 12 calculates the distance between any two individuals. The term "distance" here means a numerical expression of the extent of difference between two individuals in question. The type of the individuals as the objects of calculating the distance may be either gene type or expression type. To calculate the distance, the following two methods may be enumerated:

(g) The parameters the individuals have are represented with vectors, the differences between the same components of the vectors are determined in absolute values, and the sum of them is used as the inter-individual distance.

[0076] Specifically, in case the distance between individuals Xa and Xb is calculated, the parameters the individuals respectively have are expressed with vectors using equations (1) and (2) below. The sum of differences in absolute values between respective components is calculated with the equation (3) and is used as the inter-individual distance.

\[
\text{Individual } X_a = (X_{a1}, X_{a2}, \ldots, X_{an}) \quad (1)
\]

\[
\text{Individual } X_b = (X_{b1}, X_{b2}, \ldots, X_{bn}) \quad (2)
\]

\[
\text{Inter-individual distance} = \sum_{i=1}^{n} |X_{ai} - X_{bi}| \quad (3)
\]

Therefore, according to this method (g), the inter-individual distance between for example \( X_a = (20, 30, 15) \) and \( X_b = (25, 30, 25) \) is calculated as follows:

\[
\text{Inter-individual distance} = |20-25| + |30-30| + |15-25|
\]
(h) The parameters the individuals have are represented with vectors, and the square of the norm determined for the difference of those vectors is used as the inter-individual distance.

Specifically, to calculate the distance between individuals $X_a$ and $X_b$, the parameters the individuals respectively have are expressed with vectors using equations (1) and (2) below. The square of the norm obtained for the difference between the vectors using the equation (4) below, and the result is used as the inter-individual distance.

$$\text{Inter-individual distance} = \left| \left| X_a - X_b \right| \right|^2$$

$$= \sum_{i} \left| X_{ai} - X_{bi} \right| . . . . (4)$$

Therefore, with this method (h), the inter-individual distance between for example $X_a = (20, 30, 15)$ and $X_b = (25, 30, 25)$ is calculated as follows:

$$\text{Inter-individual distance} = (20 - 25)^2 + (30 - 30)^2 + (15 - 25)^2$$

$$= 25 + 0 + 100$$

$$= 125$$

The individuals set operating section 13 chooses individuals for use as the next generation individuals from the set of next generation candidate individuals created with the next generation individuals creating section 4 in the evolutionary computing section 1 on the basis of the inter-individual distance calculated with the inter-individual distance calculating section 12.

A method of choosing the next generation individuals on the basis of the inter-individual distance is described below in reference to a flowchart shown in FIG. 9. First, inter-individual distance is calculated between each candidate individual in the individuals set and each individual in the data storage section 11 to determine a minimum value of the inter-individual distance (step 9-1).

Next, inter-individual distances are calculated between one and the rest all of the candidate individuals in the individuals set to determine a minimum value of the inter-individual distance (step 9-2).

For each candidate individual, the minimum value is determined from the two distances obtained in the above steps 9-1 and 9-2 (step 9-3).

And, individuals, each having a minimum value determined as described above falling within a specified range, are chosen as the next generation individuals (step 9-4). Incidentally, in the above-described example, the minimum value is determined in the step 9-3 out of the two distances determined in the steps 9-1 and 9-2, and the next generation individuals are chosen in the step 9-4 on the basis of the value determined in the step 9-3. However, the method of choosing the next generation individuals is not limited to the above example but may be a method in which the next generation individuals are chosen on the basis of whether one or both of the two distances determined in the steps 9-1 and 9-2 is or are within a specified range.

Referring to FIG. 10, the above method of choosing the next generation individuals is more specifically described below.

Both of the FIGs. 10(a) and 10(b) show the relation between the individuals stored in the data storage section 11 (indicated with white circles in the figures) and the next generation candidate individuals (black circles in the figures) created with the next generation individuals creating section 4. The numerals provided along the arrows in the figures show the inter-individual distances determined in the above methods (g) and (h).
and any other candidate individual are found for all the candidate individuals, and the smallest of them is made di1. In FIG. 10(a), di1 = 15. Next, according to the process of the step 2, inter-individual distances between any candidate individual Xi and each candidate individual stored in the data storage section 11 are found for all the candidate individuals, and the smallest of them is made di2. In FIG. 10(b), di2 = 10.

Further, of the di1 and di2 found, the smaller one is found and assumed to be di. In FIG. 10, since di1 = 10 and di2 = 15, di = 10.

Whether the di found as described above meets a specified equation of condition is judged. If it meets the condition, the candidate individual Xi is left as a next generation individual, and if it does not meet condition, the candidate individual Xi is not left as a next generation individual.

Specifically for example, if the conditional equation is 5 < di < 15, the candidate individual Xi is left as a next generation individual.

The flow of the evolutionary computing process with the evolutionary computing section 1 and the evolution efficiency improving section 10 constituted as described above is described below using the flowchart of FIG. 11.

First, a set of gene type individuals are created with the initial individual creating section 1 (step 11-1).

Next, in the evaluation value acquiring section 2, one gene type individual in the set of gene type individuals is converted to expression type, and its evaluation value is acquired (step 11-2).

And, data of the individual and the evaluation value given to the individual are stored in the data storage section 11 (step 11-3).

Whether evaluation values are obtained for all the individuals in the set is judged (step 11-4). If not, the processes of the steps 2 and 3 are repeated. If evaluation values are obtained for all the individuals, candidate individuals to be the candidates for the next generation individuals are created with the next generation individuals creating section 4 by hereditary calculation or the like (step 11-5).

In the individuals set operating section 13, individuals for use as the next generation individuals are chosen from the set of next generation candidate individuals created with the next generation individuals creating section 4 on the basis of the inter-individual distance information calculated with the inter-individual distance calculating section 12 (step 11-6) to create a set of the next generation individuals (step 11-6).

Finally, an embodiment of a control device is described below in which the above-described two evolution efficiency improving methods are combined together and applied to change the throttle characteristic of a motorcycle.

FIG. 12 generally shows the relation between an engine 40 and a control device 41 to which is applied the evolution efficiency improving method of an embodiment of this invention.

The engine 40 has an electronic throttle device controlled through a control device 41 based on the amount of accelerator operation by a user. The control device 41 is constituted to provide throttle characteristic matching the preference of the user.

As shown in the figure, the control device 41 receives the information on the user's acceleration operation amount and determines the electronic throttle valve opening according to the received information.

Description of the control device 41

FIG. 13 is a general block diagram of the control device 41.

As shown in the figure, the control device 41 has an electronic throttle control module 42 for determining the electronic throttle valve opening according to the accelerator operation amount, and an optimizing device 43 for optimizing the control parameter of the electronic throttle control module according to the user's evaluation while actually using a vehicle with the engine so that the throttle characteristic matching the preference of the user is provided.

Description of the electronic throttle control module

The electronic throttle control module, as shown in FIG. 14, is constituted to determine the electronic throttle valve opening according to the amount of the accelerator operation made by the user, and generally has a static characteristic changing section and a dynamic characteristic changing section. Incidentally, the term "accelerator operation amount" as used herein refers to the information resulting from the user's actual operation of the accelerator (not shown), and includes a piece of information on the "accelerator opening" and another piece of information on the "amount of change in the accelerator."

Here, the characteristic of the electronic throttle valve is briefly described. The electronic throttle valve has two, static and dynamic, characteristics.

The former characteristic stems from the relation between the accelerator opening (operation amount) and the electronic throttle valve opening, and affects the stationary running characteristic of the vehicle. FIG. 15 shows several examples of the static throttle characteristic. Changing the static characteristic in this way makes it possible to provide different degrees of electronic throttle valve opening with the same degree of accelerator opening according to the amount of change in the accelerator.
to different types of setting such as:

[0105] A small opening-rapid acceleration type in which the electronic throttle valve opens relatively wide while the accelerator opening is small, and the electronic throttle valve gradually reaches the full opening beyond a certain degree of accelerator opening (FIG. 15(a)).

[0106] A wide opening-rapid acceleration type in which the electronic throttle valve opens gradually while the accelerator opening is small, and the electronic throttle valve rapidly reaches the full opening as the accelerator opening increases (FIG. 15(b)). A proportional type in which the electronic throttle valve opens in proportion to the accelerator opening (FIG. 15(c)).

[0107] The static characteristic has only to be that the electronic throttle valve opening increases or remains unchanged as the accelerator opening increases, and can be expressed with various functions. In this embodiment, the static characteristic is optimized for the throttle valve opening rate SP1 with the accelerator opening of 0 to 20 %, and for the throttle valve opening rate SP2 with the accelerator opening of 20 to 100 %.

[0108] The latter, the dynamic characteristic of the electronic throttle valve stems from the relation between the changing speed of the accelerator and the changing speed of the electronic throttle valve, and affects the transient characteristic of the vehicle. This characteristic may be specifically constituted by combining the first-order time lag and the incomplete differential to change the changing speed of the electronic throttle valve relative to the changing speed of the accelerator. Combining the first-order time lag and the incomplete differential in this way makes it possible to provide different types of dynamic characteristic as shown in FIG. 16:

[0109] A slow response type with which the electronic throttle valve opens relatively slowly with the accelerator operation (FIG. 16(a)).

[0110] A quick response type with which the electronic throttle valve follows the accelerator operation quickly although some spikes occur (FIG. 16(b)).

[0111] A type intermediate of the above two (FIG. 16(c)).

[0112] In this embodiment, the dynamic characteristic is optimized by optimizing the first-order time lag constant DR and the acceleration compensation factor AG.

Description of the optimizing device

[0113] The optimizing device 43 codes as shown in FIG. 17 the control parameters (throttle valve opening rates SP1 and SP2, first-order time lag constant DR, and acceleration compensation factor AG) in the electronic throttle control module 42 as gene type individuals, and optimizes these control parameters.

[0114] FIG. 18 is a general block diagram of the optimizing device 43.

[0115] As shown in FIG. 18, the optimizing device 43 is provided with an evolutionary calculating section 44 and an evolution efficiency improving section 45.

[0116] The evolutionary calculating section 44 has an initial individual creating section 46, an evaluation value acquiring section 47, and a next generation individuals creating section 48. The evolution efficiency improving section 45 has a search area initial value setting section 49, a data storage section 50, a search area changing section 51, an inter-individual distance calculating section 52, and an individuals set operating section 53.

[0117] The flow of process in the optimizing device 43 constituted as described above is described below in reference to the flowchart of FIG. 19.

[0118] First, initial values of position and size of the search area for individuals are determined with the search area initial value setting section 49 (step 19-1).

[0119] Next, a set of gene type individuals are created within the range of the initial search area with the initial individual creating section 46 (step 19-2).

[0120] After the set of gene type individuals are created, one gene type individual in the individuals set is converted to an expression type with the evaluation value acquiring section 47, and an evaluation value for the individual is acquired (step 19-3). FIG. 20 shows an example of flow of evaluation value acquiring method with the evaluation value acquiring section 47. As shown in the figure, the evaluation value acquiring section 47 converts the gene type individual to an expression type (namely to four parameter values for the throttle characteristic) with a type conversion section 54, and actually applies the expression type individual to the electronic throttle control module 42. A user rides a vehicle to which the expression type individual is applied, physically feels the ride comfort (ride feeling) of the vehicle while operating the throttle device, and evaluates the ride comfort on the basis of 100 marks. The evaluation value may be handled with an input device mounted on the vehicle.

[0121] After the evaluation value is acquired, data of the individual and its evaluation value are stored in the data storage section 50 (step 19-4).

[0122] The above steps 19-3 and 19-4 are applied to every individual of the entire set. When it is judged that the evaluation values are acquired for all the individuals (step 19-5), the position and size of the next generation search area are changed according to the data stored in the data storage section 50 with the search area changing section.
modules can be determined using existing techniques such as neural networks, fuzzy neural networks, and genetic algorithms without losing versatility while restricting the random nature of individuals.

On the basis of the calculated inter-individual distance, an effect is brought about that the evolution efficiency is improved. As the individuals group of the next generation is created as described above by changing the position and size of the search area, or by choosing the next generation individuals from the candidate individuals already created on the basis of the inter-individual distance information, it is possible to restrict random nature while retaining versatility of individuals, and an effect is provided that the evolution efficiency of individuals is improved.

The above embodiment is an example of applying the evolution efficiency improving method of this invention to the control of the vehicle throttle characteristic. However, the evolution efficiency improving method of this invention may be applied to any control object if parameters are optimized by evolutionary computing. For example, the method may be applied to a device for optimizing the assist power amount in bicycles equipped with an electric motor power assist device, or to a device for optimizing the actions of robots having control objects when the robot changes its components such as the head portion, leg portion, or arm portion.

As described above, this invention relates to a method of improving efficiency of evolution in optimization method using evolutionary computing to obtain individuals of higher suitability by repeating the steps of: forming one generation with a group of individuals, and performing calculation using individuals of at least said generation to create a group of individuals of the next generation. Since the inter-individual distance between any individuals in said selection space is calculated and the position of the next generation individuals group in the selection space is restricted on the basis of the calculated inter-individual distance, an effect is brought about that the evolution efficiency is improved without losing versatility while restricting the random nature of individuals.

Additionally, in the present invention, correlations between various inputs and various outputs of the control modules can be determined using existing techniques such as neural networks, fuzzy neural networks, and genetic algorithms.

Further, in addition to genetic algorithms (GA), genetic programming (GP) or other evolutionary computing techniques can be adapted to the present invention (Wolfgang Banzhaf, et al. (editor), "Genetic Programming, An Introduction", pp. 363-377, 1999, Morgan Kaufmann Publishers, Inc., for example). These techniques are sometimes categorized as "heuristic control" which includes evolution, simulated annealing, and reinforcement learning method (S. Suzuki, et al., "Vision-Based Learning for Real Robot: Towards RoboCup", RoboCup - 97 Workshop, 23, 24, and 29 August, 1997 Nagoya Congress Center, pp. 107-110; K. and Nurmela, et al., "Constructing Covering Designs By Simulated Annealing", pp. 4-7, Helsinki University of Technology, Digital Systems Laboratory, Technical Reports No. 10, January 1993, for example). These techniques can be adapted to the present invention without complication, based on the principle described earlier; that is, in the present invention, "evolutionary computing" includes the above various techniques.

The embodiments described above are teaching a method and an apparatus for controlling performance of a machine controlled by at least one control module having an input-output relationship regulated by control parameters, said method comprising the steps of:

(a) configuring a first generation of chromosomes coding for the control parameters by preselecting genes constituting the first generation of chromosomes from a selection space used as a gene pool, and activating the machine using the first generation of chromosomes, said genes being defined by coordinates in the selection space;

(b) selecting and scoring adapted chromosome(s) by evaluating each chromosome based on signals indicative of performance of the machine;

(c) setting a search area in the selection space in accordance with the score(s) under predetermined rules;

(d) selecting genes for a subsequent generation of chromosomes within the search area, and operating the machine using the subsequent generation of chromosomes; and

(e) repeating steps (b) through (d) while operating the machine until desired performance of the machine is demonstrated.

The coordinates and/or the size of the search area in the selection space are changed in accordance with the score(s) of the adapted chromosome(s).

The selection of genes is conducted randomly in the search area and/or the selection of genes is conducted in the search area based on the coordinates of the genes of the adapted chromosome(s).

Central coordinates of the search area of the subsequent generation is set at coordinates of the genes of the adapted chromosome(s) in the selection space and/or central coordinates of the search area of the subsequent generation is set in the selection space at coordinates calculated from weighted averages of the coordinates of the chromosomes of the current generation based on their scores.

The size of the search area for a subsequent generation is changed in accordance with the score(s) of the chromosome(s) of the current generation and/or the size of the search area for a subsequent generation is changed in accordance with the score(s) of the adapted chromosome(s) and/or the size of the search area for a subsequent generation is changed in accordance with the average score of the respective chromosomes of the current generation.

The size of the search area for a subsequent generation is changed in accordance with a distance between central coordinates of the search area for the current generation and/or central coordinates of the search area for the subsequent generation.

A group of candidate chromosomes of a subsequent generation is selected based on distances between any candidate chromosomes of the subsequent generation in the selection space and/or a group of candidate chromosomes of a subsequent generation is selected based on distances between chromosomes generated currently and in the past in the selection space. The distances are defined using vectors connecting any two coordinates of genes.

The indicative signals are sensory signals, and a user who operates the machine scores the chromosomes based on the sensory signals and/or the indicative signals are electronic signals, and a device which receives the signals scores the chromosomes by comparing values of the signals with preselected target values.

According to a preferred embodiment said machine is a motor.
Claims

1. Method for controlling performance of a machine controlled by at least one control module having an input-output relationship regulated by control parameters, said method comprising the steps of:
   (a) configuring a first generation of chromosomes coding for the control parameters by preselecting genes constituting the first generation of chromosomes from a selection space used as a gene pool, and activating the machine using the first generation of chromosomes, said genes being defined by coordinates in the selection space;
   (b) selecting and scoring adapted chromosome(s) by evaluating each chromosome based on signals indicative of performance of the machine;
   (c) setting a search area in the selection space in accordance with the score(s) under predetermined rules;
   (d) selecting genes for a subsequent generation of chromosomes within the search area, and operating the machine using the subsequent generation of chromosomes; and
   (e) repeating steps (b) through (d) while operating the machine until desired performance of the machine is demonstrated.

2. Method for controlling performance of a machine according to claim 1, wherein the coordinates and/or the size of the search area in the selection space are changed in accordance with the score(s) of the adapted chromosome(s).

3. Method for controlling performance of a machine according to claim 1 or 2, wherein the selection of genes is conducted randomly in the search area and/or the selection of genes is conducted in the search area based on the coordinates of the genes of the adapted chromosome(s).

4. Method for controlling performance of a machine according to at least one of the claims 1 to 3, wherein central coordinates of the search area of the subsequent generation is set at coordinates of the genes of the adapted chromosome(s) in the selection space and/or central coordinates of the search area of the subsequent generation is set in the selection space at coordinates calculated from weighted averages of the coordinates of the chromosomes of the current generation based on their scores.

5. Method for controlling performance of a machine according to at least one of the claims 1 to 4, wherein the size of the search area for a subsequent generation is changed in accordance with the score(s) of the chromosome(s) of the current generation and/or the size of the search area for a subsequent generation is changed in accordance with the score(s) of the adapted chromosome(s) and/or the size of the search area for a subsequent generation is changed in accordance with the average score of the respective chromosomes of the current generation.

6. Method for controlling performance of a machine according to at least one of the claims 1 to 5, wherein the size of the search area for a subsequent generation is changed in accordance with a distance between central coordinates of the search area for the current generation and/or central coordinates of the search area for the subsequent generation.

7. Method for controlling performance of a machine according to at least one of the claims 1 to 6, wherein a group of candidate chromosomes of a subsequent generation is selected based on distances between any candidate chromosomes of the subsequent generation in the selection space and/or a group of candidate chromosomes of a subsequent generation is selected based on distances between chromosomes generated currently and in the past in the selection space.

8. Method for controlling performance of a machine according to claim 7, wherein the distances are defined using vectors connecting any two coordinates of genes.

9. Method for controlling performance of a machine according to at least one of the claims 1 to 8, wherein the indicative signals are sensory signals, and a user who operates the machine scores the chromosomes based on the sensory signals and/or the indicative signals are electronic signals, and a device which receives the signals scores the chromosomes by comparing values of the signals with preselected target values.

10. Method for controlling performance of a machine according to at least one of the claims 1 to 8, wherein the machine is a motor.
Patentansprüche

1. Verfahren zur Steuerung des Verhaltens einer Maschine, die von zumindest einem Steuermodul mit einer Ein-/Ausgabeverknüpfung, die über Steuerparameter eingestellt wird, gesteuert wird, wobei das Verfahren die Schritte umfasst:


   b) Auswählen und Bewerten von (einem) geänderten Chromosom/en durch Beurteilen jedes Chromosoms basierend auf Signalen, die das Verhalten der Maschine anzeigen;

   c) Bestimmen eines Suchbereichs in dem Auswahlraum in Abhängigkeit von der/den Bewertung(en) gemäß vorbestimmten Regeln;

   d) Auswählen von Genen für eine nachfolgende Generation von Chromosomen innerhalb des Suchbereichs und Betreiben der Maschine unter Verwendung der nachfolgenden Generation von Chromosomen und

   e) Wiederholen der Schritte (b) bis (d) beim Betreiben der Maschine, bis sich das gewünschte Verhalten der Maschine gezeigt hat.


9. Verfahren zur Steuerung des Verhaltens einer Maschine nach zumindest einem der Ansprüche 1 bis 8, wobei die anzeigenden Signale sensorische Signale sind und ein Benutzer, der die Maschine betätigt, die Chromosome basierend auf den sensorischen Signalen bewertet und/oder die anzeigenden Signale elektronische Signale sind und ein Gerät, das die Signale empfängt, die Chromosome durch Vergleiche von Werten der Signale mit vorausgewählten Zielwerten bewertet.

10. Verfahren zur Steuerung des Verhaltens einer Maschine, nach zumindest einem der Ansprüche 1 bis 8, wobei die Maschine ein Motor ist.

Revendications

1. Méthode pour contrôler la performance d'une machine contrôlée par au moins un module de contrôle ayant une relation d'entrée-sortie régulée par des paramètres de contrôle, ladite méthode comprenant les étapes de :

   (a) configurer une première génération de chromosomes codant pour les paramètres de contrôle en présélectionnant des gènes constituant la première génération de chromosomes dans un espace de sélection utilisé en tant que masse de gènes et en activant la machine en utilisant la première génération de chromosomes, lesdits gènes étant définis par des coordonnées dans l'espace de sélection;
   (b) sélectionner et noter un ou des chromosomes adaptés en évaluant chaque chromosome en se basant sur des signaux indiquant la performance de la machine;
   (c) établir une zone de recherche dans l'espace de sélection selon le ou les notes sous des règles prédéterminées;
   (d) sélectionner des gènes pour une génération subséquente de chromosomes dans la zone de recherche et faire fonctionner la machine en utilisant la génération subséquente de chromosomes; et
   (e) répéter les étapes (b) à (d) tout en faisant fonctionner la machine jusqu'à ce qu'une performance souhaitée de la machine soit démontrée.

2. Méthode pour contrôler la performance d'une machine selon la revendication 1, où les coordonnées et/ou la dimension de la zone de recherche dans l'espace de sélection sont modifiées selon la ou les notes du ou des chromosomes adaptés.

3. Méthode pour contrôler la performance d'une machine selon la revendication 1 ou 2, où la sélection des gènes est entreprise statistiquement dans la zone de recherche et/ou la sélection des gènes est entreprise dans la zone de recherche en se basant sur les coordonnées des gènes du ou des chromosomes adaptés.

4. Méthode pour contrôler la performance d'une machine selon au moins l'une des revendications 1 à 3, où des coordonnées centrales de la zone de recherche de la génération subséquente est établie à des coordonnées des gènes du ou des chromosomes adaptés dans l'espace de sélection et/ou des coordonnées centrales de l'espace de recherche de la génération subséquente est établie dans l'espace de sélection à des coordonnées calculées à partir de moyennes pondérées des coordonnées des chromosomes de la génération courante en se basant sur leurs notes.

5. Méthode pour contrôler la performance d'une machine selon au moins l'une de la revendication 1 à 4, où la dimension de la zone de recherche pour une génération subséquente est modifiée selon la ou les notes du ou des chromosomes de la génération courante et/ou la dimension de la zone de recherche pour une génération subséquente est modifiée selon la ou les notes du ou des chromosomes adaptés et/ou la dimension de la zone de recherche pour une génération subséquente est modifiée selon la note moyenne des chromosomes respectifs de la génération courante.

6. Méthode pour contrôler la performance d'une machine selon au moins l'une de la revendication 1 à 5, où la dimension de la zone de recherche pour une génération subséquente est modifiée selon une distance entre des coordonnées centrales de la zone de recherche pour la génération courante et/ou des coordonnées centrales de la zone de recherche pour la génération subséquente.

7. Méthode pour contrôler la performance d'une machine selon au moins l'une des revendications 1 à 6, où un groupe de chromosomes candidats d'une génération subséquente est sélectionné en se basant sur les distances entre des chromosomes candidats de la génération subséquente dans l'espace de sélection et/ou un groupe de chro-
mosomes candidats d'une génération subséquente est sélectionné en se basant sur des distances entre chromo-
somes générés couramment et dans le passé dans l'espace de sélection.

8. Méthode pour contrôler la performance d'une machine selon la revendication 7 où les distances sont définies en utilisant des vecteurs connectant deux coordonnées de gènes.

9. Méthode pour contrôler la performance d'une machine selon au moins l'une des revendications 1 à 8, où les signaux indicateurs sont des signaux sensoriels et un utilisateur qui fait fonctionner la machine note les chromosomes en se basant sur les signaux sensoriels et/ou les signaux indicateurs sont des signaux électroniques et un dispositif qui reçoit les signaux note les chromosomes en comparant les valeurs des signaux avec des valeurs cibles présélectionnées.

10. Méthode pour contrôler la performance d'une machine selon au moins l'une des revendications 1 à 8, où la machine est un moteur.
FIG. 3

Start

Are position and size of search area to be changed?

N

Y

Determines the central position of the search area using data in data storage section and change.

S3-1

S3-2

Determines the size of the search area using data in data storage section and change.

S3-3

End
(1) Change based on current size

<table>
<thead>
<tr>
<th>Best evaluation value $Y$ of 1-th generation</th>
<th>Search area size (Amount of change in center-to-edge distance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0 \leq Y &lt; 20$</td>
<td>$+20$ $+10$</td>
</tr>
<tr>
<td>$20 \leq Y &lt; 40$</td>
<td>$+10$ $+5$</td>
</tr>
<tr>
<td>$40 \leq Y &lt; 70$</td>
<td>$0$ $0$</td>
</tr>
<tr>
<td>$70 \leq Y \leq 100$</td>
<td>$-10$ $-5$</td>
</tr>
</tbody>
</table>

FIG. 4A(a)

(2) Change irrespective of current size

<table>
<thead>
<tr>
<th>Best evaluation value $Y$ of 1-th generation</th>
<th>Search area size (Amount of change in center-to-edge distance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0 \leq Y &lt; 20$</td>
<td>$25$ $10$</td>
</tr>
<tr>
<td>$20 \leq Y &lt; 40$</td>
<td>$20$ $25$</td>
</tr>
<tr>
<td>$40 \leq Y &lt; 70$</td>
<td>$15$ $20$</td>
</tr>
<tr>
<td>$70 \leq Y \leq 100$</td>
<td>$10$ $15$</td>
</tr>
</tbody>
</table>

FIG. 4B(a)
FIG. 5A(a)

FIG. 5A(b)

FIG. 5B(a)

FIG. 5B(b)
(1) Change based on current size

<table>
<thead>
<tr>
<th>Center position of</th>
<th>Search area size</th>
</tr>
</thead>
<tbody>
<tr>
<td>next generation</td>
<td>(Amount of change in center-to-edge distance)</td>
</tr>
<tr>
<td>Current search area</td>
<td>X1 direction</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>In area from 75% to 100%</th>
<th>+20</th>
<th>+10</th>
</tr>
</thead>
<tbody>
<tr>
<td>In area from 50% to 75%</td>
<td>+10</td>
<td>+5</td>
</tr>
<tr>
<td>In area from 25% to 50%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>In area from 0% to 25%</td>
<td>-10</td>
<td>-5</td>
</tr>
</tbody>
</table>

FIG. 6A(a)

(2) Change irrespective of current size

<table>
<thead>
<tr>
<th>Center position of</th>
<th>Search area size</th>
</tr>
</thead>
<tbody>
<tr>
<td>next generation</td>
<td>(Amount of change in center-to-edge distance)</td>
</tr>
<tr>
<td>Current search area</td>
<td>X1 direction</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>In area from 75% to 100%</th>
<th>20</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>In area from 50% to 75%</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>In area from 25% to 50%</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td>In area from 0% to 25%</td>
<td>10</td>
<td>15</td>
</tr>
</tbody>
</table>

FIG. 6B(a)
FIG. 7

Start

Determine initial values of position and size of the search area with the search area initial value setting section. S7-1

Create a set of individuals of gene type within the initial search area with the initial individual creating section. S7-2

Convert one gene type individual in the set to representation type with the evaluation value acquiring section and acquire an evaluation value for the individual. S7-3

Enter the evaluation value data given to the representation type individual and to the individual into the data storage section. S7-4

\[ \begin{align*}
\text{Are evaluation values determined for all the individuals in the set?} \\
\text{Y} \\
\end{align*} \]

Change position and size of search area using data of the data storage section with the search area changing section. S7-6

Create individuals of the next generation by hereditary calculation, etc. within the search area with the next generation individual creating section. S7-7
FIG. 9

1. Obtain distances between each candidate individual in the individuals set and each individual in the data storage section, and determine the minimum value of the distance.

2. Obtain distances between one candidate individual and each of other candidate individuals in the individuals set, and determine the minimum value of the distance.

3. Take whichever smaller of the two distances determined above (1) and (2) for each candidate individual.

4. Leave as the next generation of candidate individuals only those having the value obtained above within a specified range, and choose next generation of individuals from the candidates left.

Start

S9-1

S9-2

S9-3

S9-4

End
FIG. 10(a)

○: Stored data individual
●: Next generation candidate individual
Θ: Candidate individual Xi

→: Inter-individual distance

FIG. 10(b)
FIG. 11

Start

Create gene type of individuals set with the initial individuals creating section  

Convert one gene type of individual in a set to a representation type with the evaluation value acquiring section and acquire an evaluation value for the individual.

Enter the data given to the representation type of individual and to the individual into the data storage section.

Are evaluation values obtained for all the individuals in a set?

N

Y

Create individuals to be candidates for the next generation individuals by hereditary calculation, etc. with the next generation individuals creating section.

Choose individuals from individuals based on information on the inter-individual distance with the individuals set operating section, and create next generation of individuals set.
FIG. 12
FIG. 13

User

Evaluation value

Accelerator operation amount

Ride comfort

Optimizing device 43

Control parameter

Electronic throttle control module 42

Electronic throttle valve opening

Vehicle

Electronic throttle

Control device 41
FIG. 14

\[
X \rightarrow Y_1 = f(X) \rightarrow Y_1 \rightarrow \frac{1}{1 + TX_s} \rightarrow \frac{\alpha XT dX_s}{1 + \eta XT dX_s} \rightarrow \text{Incomplete differential filter} \rightarrow \text{First-order time lag filter} \rightarrow 1
\]

Electronic throttle valve opening \( Y_2 \)

\[ X : \text{Accelerator opening} \quad T : \text{First-order time lag constant (DR)} \]
\[ Y_1 : \text{Virtual electronic throttle opening} \quad Td : \text{Differential time} \]
\[ Y_2 : \text{Electronic throttle opening} \quad \alpha : \text{Acceleration compensation factor (AG)} \]
\[ f : \text{Static characteristic function} \quad \eta : \text{Differential gain} \]
FIG. 17

SP₁ SP₂ DR AG
FIG. 19

Start

Determine initial values of position and size of the search area with the search area initial value setting section.

Create a set of individuals of gene type within the initial search area with the initial individual creating section.

Create one gene type individual in the set to representation type with the evaluation value acquiring section and acquire an evaluation value for the individual.

Enter the evaluation value data given to the representation type individual and to the individual into the data storage section.

Are evaluation values determined for all the individuals in the set?

Change position and size of search area using data of the data storage section with the search area changing section.

Create individuals to be the next generation candidates by hereditary calculation, etc. within the search area with the next generation individual creating section.

Create the next generation individuals set by choosing candidate individuals based on inter-individual distance information with the individuals set operating section.

S 19 - 1
S 19 - 2
S 19 - 3
S 19 - 4
S 19 - 5
S 19 - 6
S 19 - 7
S 19 - 8
FIG. 20
1: Change by best evaluation value

(Determine irrespective of current search area size)

**FIG. 21(a)**

<table>
<thead>
<tr>
<th>Best evaluation value $Y$</th>
<th>Size of next generation search area (Center-to-edge distance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0 \leq Y &lt; 50$</td>
<td>SP1</td>
</tr>
<tr>
<td></td>
<td>25</td>
</tr>
<tr>
<td>$50 \leq Y &lt; 70$</td>
<td>20</td>
</tr>
<tr>
<td>$70 \leq Y &lt; 90$</td>
<td>15</td>
</tr>
<tr>
<td>$90 \leq Y \leq 100$</td>
<td>10</td>
</tr>
</tbody>
</table>

2: Change by best evaluation value

(Change based on current search area size)

**FIG. 21(b)**

<table>
<thead>
<tr>
<th>Best evaluation value $Y$</th>
<th>Search area size (Amount of change in center-to-edge distance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0 \leq Y &lt; 50$</td>
<td>SP1</td>
</tr>
<tr>
<td></td>
<td>+5</td>
</tr>
<tr>
<td>$50 \leq Y &lt; 70$</td>
<td>0</td>
</tr>
<tr>
<td>$70 \leq Y &lt; 100$</td>
<td>-5</td>
</tr>
</tbody>
</table>
Create the next generation candidate individuals at constant intervals in an all-inclusive manner within the search area.
FIG. 23

Start

(1) Obtain inter-individual distances between each individual in the data storage section and each candidate individual in the individuals set, and obtain the smallest distance. S 23 - 1

(2) Determine estimated evaluation values for the candidate individuals. S 23 - 2

(3) Make the best individual of current generation the first individual of the next generation. S 23 - 3

(4) Make the individual of the highest evaluation value among the candidate individuals the second individual of the next generation. S 23 - 4

i = 3

(5) Calculate the distances between each candidate individual and (i - 1) pieces of individuals already determined as the next generation of individuals, and obtain the smallest distance. S 23 - 5

(6) Calculate the product of "the distance determined in the step 1 or 2, whichever smaller" and "the estimated evaluation value determined in step 2." S 23 - 6

(7) Make the individual of the greatest value determined in the step 6 the i-th individual of the next generation. S 23 - 7

Y \( i < \text{number of individuals in one generation} \)

N \( i = i + 1 \)

End
(60): Estimated evaluation value

○: Individuals created so far.
(Individuals in the data storage section)
●: Next generation candidate individuals

●: Individuals chosen for the next generation

→: Inter-individual distance