A Combination of DNA Coding Method with Pseudo-Bacterial GA for Acquisition of Fuzzy Control Rules

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Abstract
The authors have proposed a new coding method based on biological DNA and a mechanism of development from the artificial DNA\cite{1}\cite{2}. We call this coding method "DNA coding method". This method has redundancy and overlapping of genes. This paper combines this method with the Pseudo-Bacterial Genetic Algorithm (PBGA)\cite{3}\cite{4}. The PBGA utilizes mechanisms of genetic recombination in bacterial genetics. This algorithm is efficient in improving local portions of chromosomes. This paper applies this combined method to the acquisition of fuzzy rules. Selection of input variables and tuning of membership functions are done. Effective fuzzy rules for mobile robots are acquired through chasing and avoiding operations.

I. INTRODUCTION

Genetic Algorithm (GA)\cite{5}\cite{6} have been widely studied and applied to many problems. The authors have proposed a new coding method based on biological DNA and a mechanism of development from the artificial DNA\cite{1}\cite{2}. We call this coding method "DNA coding method". The DNA coding method and a mechanism of development from the artificial DNA are suitable for knowledge representation. This method has redundancy of the chromosomes and overlapping of genes. The effectiveness of redundancy and overlapping are shown in \cite{2}. The length of the proposed DNA chromosome is variable and it is easy to insert and delete parts of the chromosome.

The authors have also proposed the Pseudo-Bacterial GA (PBGA) which is very efficient in improving local portions of chromosomes\cite{3}\cite{4}. This paper combines the DNA coding method with the PBGA, and studies acquisition of effective fuzzy rules using this combined method. These fuzzy rules are used to control mobile robots which play chasing and avoiding. Selection of input variables and tuning of membership functions are done. Effective fuzzy rules of a robot are found through interactions with the other robots. This paper shows the effectiveness of the improvement of local portions of chromosomes by the new combined method.

II. DNA CODING METHOD

Fig.1(a) shows a flow from biological DNA to cells. The biological DNA consists of nucleotides which have four bases, Adenine(A), Guanine(G), Cytosine(C), Thymine(T)\cite{7}\cite{8}. Most of these bases in the top figure in Fig.1(a) are not used for the synthesis of proteins. A messenger RNA (mRNA), which has many unused parts, is first synthesized from the DNA. In the synthesis of RNA, each base is translated into the complementary base i.e. T into A, G into C and so on. Moreover in the RNA the base U is used instead of T. Then the unused parts are cut out. This operation is a splicing. After this splicing has occurred, the mRNA is completed. Three successive bases called codons are allocated sequentially in the mRNA. These codons are the codes for amino acids. 64 kinds of codons correspond to 20 kinds of amino acids. The details of translation into amino acid from codons are omitted here. This allocation of amino acid makes proteins, and proteins make up cells.

Fig.1(b) shows the proposed DNA coding method and the flow of development to sets of fuzzy rules. This figure shows a correspondence of the proposed method to the biological development. The GA usually used a coding method specifically devised for each problem and it had no redundant parts. This conventional coding method could be regarded as a coding into complete mRNA. The authors have presented a new coding method using the DNA itself and a way of development from the DNA to sets of fuzzy rules. A chromosome consists of combinations of four bases, A, G, C, T. The chromosome has many redundant parts, and after a splicing, the mRNA is completed. In this artificial RNA synthesis, each base is translated into the same base. The codons in
Fig. 1(b) also correspond to amino acids. Unlike the biological amino acid, each artificial amino acid has several meanings, and the meanings of a gene is determined by the combination of the amino acids. An amino acid can be translated as an input variable or a form of membership function, and so on. A sequence of amino acids makes a fuzzy rule. The DNA chromosome makes up sets of fuzzy rules for controlling a mobile robot.

Fig. 2 shows an example of the DNA chromosome and its translation mechanism. In this figure a gene starts from the start codon ATG, and ends at the end codon TAG, and codons in the gene are translated into amino acids: Tyr, Thr, ... Each amino acid has its own role for the problem.

By the proposed mechanism of development from the DNA, the starting point can be shifted from a base to another and some genes overlapping on other genes can be translated. Each overlapping gene plays an important role. Fig. 3 shows this overlapped representation. In this figure, GENE5 in addition to GENE3 and GENE4 can be read from the DNA chromosome. This chromosome has redundancy and also compresses information by overlaps of genes.

Fig. 4 shows examples of crossover and mutation. Fig. 4(a) is an example of one point crossover. Right hand sides from the crossover points are exchanged and newly generated and new GENE7 is generated. The DNA coding method has the following features:

(a) Flexible representation of knowledge.

(b) This Method

Fig. 1 Flows of Development from DNA Chromosome

Fig. 2 Example of a Chromosome and Translation Mechanism

Fig. 3 Overlapping of Genes

Fig. 4 Crossover and Mutation
(b) The coding is redundant and overlapped.
(c) The length of the chromosome is variable.
(d) No constraint on crossover points.

III. PSEUDO-BACTERIAL GA

Bacterial genetics provides interesting mechanisms for genetic recombination[7]. Bacteria can transfer DNA to recipient cells through mating. Male cells transfer strands of genes into female cells. Then the female cells acquire characteristics of the male cells, and finally change into male cells. By these means, the characteristics of one bacterium can be spread among the entire bacteria population.

Bacteriophages carry a copy of the host gene across and incorporate it into the chromosome of the infected cell. This process is called transduction. By the transduction, it is also possible to spread the characteristics of a single bacterium among other bacteria.

These genetic recombinations have led to a mechanism of microbial evolution[9]. Mutated genes can be transferred from a single bacterium to others and effect rapid evolution.

The authors introduce the mechanisms of the above bacterial genetics into the DNA coding method. From one chromosome, multiple bacteria are reproduced, and the same gene in each new born bacterium is mutated. The best gene among the bacteria is chosen and transferred to other bacteria. The PBGA streamlines this mechanism in the extreme. Fig.5 shows the example of the bacterial operation. In this figure, the GENE1 is reproduced to 4 clones. The clones except one are mutated. The elite among them is selected and the rest are deleted. This operation is applied to the whole population one by one. After this operation, the conventional selection, reproduction, crossover, and mutation operations are applied.

IV. PROBLEM FORMULATION FOR KNOWLEDGE ACQUISITION

Fig.6 shows the simulation conditions of the problem and the construction of two robots. Two different types of mobile robots play chasing and avoiding in the area of 2.33m wide and 3m long surrounded by walls. There are several foods in the area for the avoiding robot. The radius of the chasing robot is 150mm, and that of the avoiding robot is 100mm. The chasing robot has eight ultra-sonic sensors (seven in the front, and one in the rear). These sensors can measure the distances between obstacles and themselves in the range of 200mm to 1700mm. The chasing robot must acquire rules to catch the other robot. The avoiding robot has twelve infrared sensors to see around. These sensors can measure limited distance less than 350mm. Therefore the avoiding robot cannot recognize the approaching robot until the enemy comes near to it. The avoiding robot must find fuzzy rules not to be caught by the other robot. The serial number of the front sensor of each robot is No.0. That of the next sensor in the counterclockwise side is No.1. Each robot has a chromosome containing a set of fuzzy rules. The fuzzy rules steer and accelerate/decelerate the robot to chase/avoid the other robot and stay away from the walls.

The robot which reaches or avoids the other robot receives more payoffs from the environment. Considering these payoffs as fitness values, the genetic operations are applied to the chromosomes and the fuzzy rules are evolved.

V. APPLICATION OF THE COMBINED METHOD

The way of development from DNA chromosome to the fuzzy rules and the way of genetic operations are described in this section.

4.1 Representation of rules

The candidates for the input variables of each robot are the detected values of sensors $D$ and the robot's velocity $V$, and those for the output variables are the steering angle $\alpha$, and its velocity $V$. The chromosome has sets of fuzzy rules which are represented by IF-THEN- rules. The chromosome determines
combinations of input/output variables and membership functions of each fuzzy rules. The central position \( x_c \) and the width \( \sigma \) of the membership functions are also encoded into the chromosome.

In the biological DNA, a gene starts from the start codon ATG, and ends at the end codon TAA, TAG or TGA. In this paper, a gene also starts from the start codon ATG which corresponds to IF. The end codon is not definitely determined. A gene consists of the codons between IF codon and some related codons succeeding to THEN codon. Reading from the top of the DNA chromosome, translation to a fuzzy rule starts upon finding the start codon ATG. As described in Section II, overlaps of genes is allowed in the DNA chromosome. After reading a fuzzy rule, re-reading is restarted from the second base of the IF-codon and a new IF codon is sought. Fig.7 shows the flow of translation from the DNA chromosome into a fuzzy rule, and Table 1 shows the correspondence between the amino acids and the parameters defined in this paper. Like the biological process, the 64 kinds of codons correspond to 20 kinds of amino acids. The meanings of each amino acid is determined by its position in the sequence of amino acids. For example, (1) When Phe is in the next position of the start codon ATG, its meanings is that the input variable is the sensor. (2) When Tyr follows Phe, the meanings of Tyr becomes that the number of sensors is 2. (3) In this case succeeding two amino acids determine the sensors to be used. In the same way, the meanings of amino acids in the sequence are determined by the translation rules in Table 1. Fig.8 shows an example of the DNA chromosome and genes (fuzzy rules). In this figure, bases are read from the head of the DNA chromosome, and if the start codon ATG is found, a fuzzy rule starts from this part. In this example, the next codon GCT is Alanine, and Alanine here means that the input variable is sensor. The sequence of Alanine, Serine, Leucine means that this sensor is SENSOR0. (4) (5) AND or THEN

4.2 Genetic operations

The bacterial operation is applied to each chromosome one after another. From a chromosome, one gene is randomly chosen and reproduced to \( m - 1 \) clones. To the \( m - 1 \) clones, the mutation is applied at the rate of \( P_m \) per a base. Each clone is recombined with the rest of the chromosome and evaluated. The evaluation is done in the following way:

Each chromosome having one clone, either chasing or avoiding, is tested twice by randomly choosing its opponents from the seven counterparts. Each robot has initial payoffs \( E_i \). Each test ends when either of the two confronting robots crashes into the wall, or the chasing robot catches the other, or a certain amount of time has passed. The payoffs for fitness values of the chromosomes are given as follows:

If the robot crashes into the wall, the robot loses

![Fig.7 The Flow of Translation from the DNA Chromosome into a Fuzzy Rule](image)

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<th>Serial Number of Sensor</th>
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*1: Velocity

![Fig.8 Example of Chromosome and Genes](image)
payoffs $E_a$; If the chasing robot can reach the avoiding robot within a fixed time, the chasing robot receives payoffs $E_c$, conversely the avoiding robot loses payoffs $E_m$; If the chasing robot cannot reach the avoiding robot in a fixed time, the chasing robot loses payoffs $E_{m}$; If the avoiding robot can reach the foods, the avoiding robot gains payoffs $E_f$ per a food.

Each of $m$ clones is tested one by one. The elite among $m$ clones is selected and the rest are deleted. The above process—reproduction, mutation, evaluation and selection is repeated to randomly selected $n$ genes of a chromosome. After this bacterial operation is done to all of the chromosomes, the following conventional genetic operations are applied to the population of chromosomes by regarding the payoffs of the robots as their fitness values:

One chromosome of chasing robot which has the smallest payoffs is deleted. Two chromosomes which are selected from the remaining six robots are reproduced, and one-point crossover is applied to them. One of the two new chromosomes is selected randomly for a chasing robot. The chromosome of avoiding robot is newly generated in the same way. There is no constraint on the crossover points as described in section II. The mutation operation is also applied to the newly generated chromosomes. The mutation operation can be done simply by changing the bases. This mutation is done to each base at a rate of $P_m$. The payoffs of all robots are reset at $E_1$ again.

After another simulation for the new generation is done, the genetic operations are applied again. These steps are repeated, and fuzzy rules which control the robots to chase or avoid the other robot and to avoid the wall are expected to be evolved.

V. SIMULATION

Simulations were done. The length of each initial DNA chromosome was 500. The payoffs $E_1, E_5, E_c, E_m, E_m, E_f$ were 0, 20, 50, 20, 20, 5, respectively. The probability of the mutation $P_m$ was 0.05. The numbers of genes and clones $n$, $m$ for the bacterial operation were 1, 6, respectively, in this paper. The chasing robot which could not reach the avoiding robot within 30 seconds lost payoffs $E_m$. The genetic operations were applied to the chromosomes of chasing and avoiding robots for 100 generations alternately.

The effectiveness of the combined method was examined. First, the effectiveness of the DNA coding method was examined. Fig.9 shows the average of all payoffs of 7 chasing robots during the 3000-5000th generation. The solid line is the case (i) where the chasing robots used the DNA coding method and the avoiding robots used the conventional method in [10]. The dotted line is the case (ii) where the chasing robots used the conventional method and the avoiding robots used the DNA coding method. In both the cases, no bacterial operation was used. Each is the average of 10 trials. In a trial, the simulation from the initial generation to the 5000th generation was done. Since the genetic operations were applied to the chromosomes of chasing and avoiding robots for 100 generations alternately, the payoffs fluctuated periodically. The parameters of the genetic operations of the conventional method were tuned and the result in Fig.9 was the best among we obtained. This figure shows the advantage of the proposed DNA coding method having the redundancy and overlapping of genes.

Next, this paper examined the effectiveness of the bacterial operation. Fig.10 shows the average of the payoffs of 7 chasing robots during the 3000-6000th generation. The solid line was the case (iii) where the chasing robots used the DNA coding method and the bacterial operation and avoiding robots used only the
DNA coding method. The dotted line was the case (iv) under the condition vice versa. The alternating period of the application of the genetic operations to the chromosomes of chasing and avoiding robots was 120. To make the evol utional oppor tunity equal, one generation of the bacterial operation was converted to \( n * m = 6 \) generations in Fig.10. The bacterial operation worked well. The parameters \((n, m)\) were changed from \((1, 6)\) to \((2, 3)\), \((1, 4)\), \((2, 2)\), \((1, 8)\) and \((2, 4)\). The results showed the same effectiveness of the bacterial operation.

**VI. CONCLUSIONS**

The authors combined the DNA coding method with the PBGA. The DNA coding method is suitable for knowledge representation. The DNA chromosome has a redundancy, and allows overlaps of genes. The PBGA is efficient in improving local portions of chromosomes. This paper applied the combined method to acquisition of fuzzy rules based on chasing and avoiding actions of mobile robots. The DNA coding method and the PBGA worked well for the acquisition of control rules.

**REFERENCES**


