Pakistan Journal of Applied Sciences 1(3): 283-286, 2001
© Copyright by the Science Publications, 2001

Genetic Algorithm Synthesis of the Industrial Controllers

Rahib Abiyev
Department of Computer Engineering, Near East University, P.O. Box 670, Dikmen Yolu, Lefkosha, Turkish Republic of Northern Cyprus, Mersin-10, Turkey

Abstract: The efficiency of technological processes particularly depends on the efficiency of control system used. The construction of control system on the base of traditional technology for complicated processes characterizing with non-linearity and uncertainty is not enough satisfy such characteristics as high speed, reliability, adequacy, accuracy of the model. In this condition one of perspective way of construction of control system is the use softcomputing elements such as neural technology and genetic algorithm that satisfy above characteristics of the system.
In the paper using genetic algorithm the developments of PID- and recurrent neural controllers for technological processes control by are considered. The synthesis of the PID controller by the traditional methods requires to posses a great deal of control system knowledge, tuning experience, full information about control object. The use of genetic algorithm (GA) allows to automate the tuning process, and does not require to have much domain knowledge. Using genetic operators - selection, crossover and mutation operators the tuning of the PID controller's coefficients is carried out. The synthesis procedure and result of simulation of control system with PID controller are described.
The development of control system based on recurrent neural network is described. The learning of the recurrent neural controller is performed on the base of GA. Using this algorithm and desired time response characteristics of the system the synthesis of neural controller for technological process control is carried out. The results of simulation of the neural control system are described.

Keywords: Genetic Algorithm Synthesis

Genetic algorithm tuning of the PID controller: The synthesis of the PID controller by the traditional methods requires to posses a great deal of control system knowledge, tuning experience, full information about control object. The tuning procedure is generally done manually by trial and error, it is tedious and needs certain time for finding optimal values of the controller parameters. Therefore there is a need for some alternative approach, which would achieve a certain level of automation of the tuning process, and would not require to have much domain knowledge.
In this paper the construction of the PID controller by using genetic algorithm (GA) is considered. The output of the PID controller is determined as

$$u(t) = Kp \cdot e(t) + Kd\frac{de(t)}{dt} + Ki\int_0^\infty e(t)dt \quad (1)$$

Here e(t) is the difference between the desired response G(t) and the actual response x(t) of the control system. The problem of the PID controller design is the finding such optimal values of the controller's parameters Kp, Kd, and Ki, by using they in control system the desired response of the system would be provided.
GA determines set of solutions at each generation. They are structurally represented as chromosomes and consist of binary codes zero and one. By using evaluation function GA calculate a fitness values for each solution. The individuals of chromosomes having high fitness values are chosen as a parent to produce the next generation. In the work as a evaluation function for synthesis PID controller the inverse of the Integral of Absolute Error (IAE) is taken. The optimal parameters values correspond to the small value of the IAE. The problem is to find such optimal values of the controller's parameters Kp, Kd, and Ki, by using they in control system the value of IAE will be minimized: IAE $\to$min, or J $\to$ max.

$$J = \frac{1}{I}, \qquad \text{IAE} = \int_0^\infty |e(t)|dt \quad (2)$$

GA operation scheme: As known GA is a searching method based on the ideas of genetics and natural selection, that as members of the population mate, they produce offspring that have a significant chance of retaining the desirable characteristics of their parents by combining the best characteristics of both parents. In this manner, the overall fitness of the population can be increased from generation to generation. This procedure can be used to find the optimal solutions of the optimization, control etc. problems.
GA allows to solve local optimal problem that have traditional searching methods, and find global optimal solution. The operation principle of GA is shown in Fig. 1. At first step a set of solutions are generated randomly. By using evaluation function GA evaluates each solution, determine the value of fitness function for each solution. If among these solutions there is solution that satisfies the given criteria (2) then the optimal solution is found. Otherwise the encoding is applied to translate variable representation of the problem to a GA representation - binary strings, which resemble chromosomes in biology. After the GA operators such as selection, crossover and mutation are used to change variable values. Decoding is used to translate the GA representation of the problem to the variable representation.
The main operations in GA are selection, crossover and mutation. The aim of the selection is to give more reproductive chances to population members (or solutions) who have higher fitnesses. Parent selection, in a simple term, is to let the current population members mate to produce the next generation. There are basically four existing selection schemes - roulette, random, fit-fit, and fit-weak. More used selection technique is roulette. This technique gives more reproductive chances, on the whole, to those population members who are the most fit so that the next generation will hopefully have an overall higher quality than the current generation. It is generating n, a random number and finding the first population member whose fitness, added to the preceding population member, is greater than or equal to n, and returning it to the main program. Crossover and mutation are two main components in the reproduction process in which selected pairs mate to produce the next generation. The purpose of crossover and mutation is to give the next generation of solutions

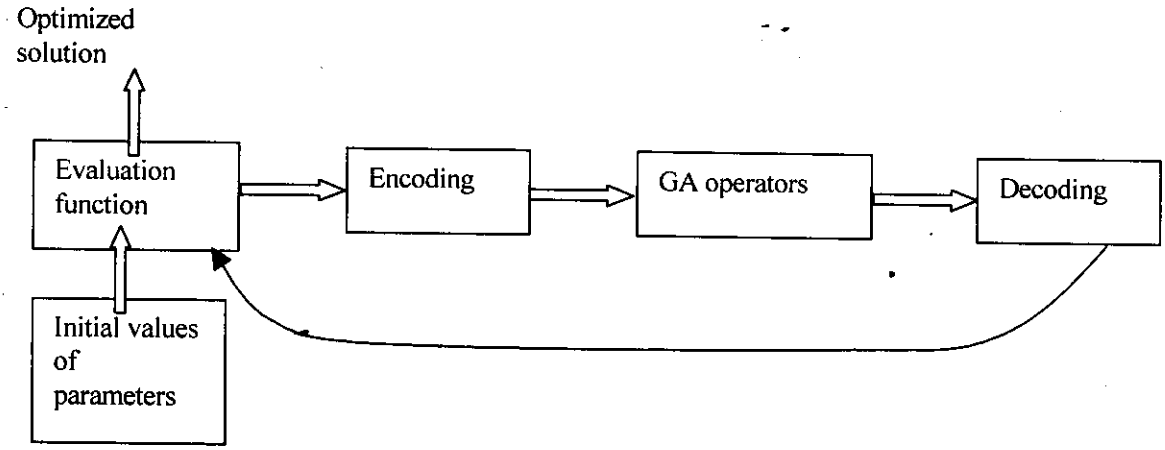

Fig. 1: GA operation scheme

chances to differ from their parental solutions.
Both components intend to give children chances to differ from their parents, and hope that some of the children can be closer to the optimal destination than their parents. Crossover can be one-point, two-point and uniform. One-point crossover was inspired by biological processes, it has some drawbacks among which one of the most important is that one-point crossover cannot combine certain combinations of features encoded on chromosomes. It occurs when parts of two parent chromosomes are swapped after a randomly selected point, creating two children.
Using two-point crossover one can avoid some of the disadvantages that occur in one-point crossover. The two-point crossover is shown below.

101|1011|101   1010011101
110|0011|010 => 1101011010

Like crossover, mutation is another way to cause chromosomes created during a reproduction to differ from those of their parents. There is a mutation rate associated with the operator. The lower the rate is, the less chance the chromosomes of the children differ from those of their parents. The operator is applied to a bit string which represents a chromosome, it sweeps down the list of bits, replacing each bit by a randomly selected bit if a probability test is passed. In other words, for each bit in the bit string, the operator generates a random number between zero and one. If the random number is smaller than the mutation rate, then the operator replaces the bit by a randomly generated bit (either zero or one).
Modelling: The modeling of the control system synthesis with PID controller is carried out. GA operators are used to choose PID controller parameters Kp, Kd and Ki. As a example the control object described by the following differential equation is considered.

$$a_0y^{(2)}(t)+a_1y^{(1)}(t)+a_2y(t)=b_0u(t) \qquad (3)$$

where $a_0 = 6.3$ min^2, $a_1=11.2$ min, $a_2=1$, $b_0=5.1°C/(kgf/cm^2)$; here y(t)- regulation parameter of object, u(t)- neural controller's output.
By using GA learning the development of PID controller for given control object is performed. During tuning of the coefficients values roulette selection, two-point crossover and mutation operations are applied. In the result of learning corresponding values of the coefficients of the PID controller are determined: Kp= 0.99, Kd=0.034, Ki=0.0488. The learning process is continued 10 second and carried out in computer IBM Pentium-II.

Using determined values of the coefficients the time response of control system with PID controller is defined. In Fig. 2 the time response of the control system with PID controller for control of object (3) is shown.

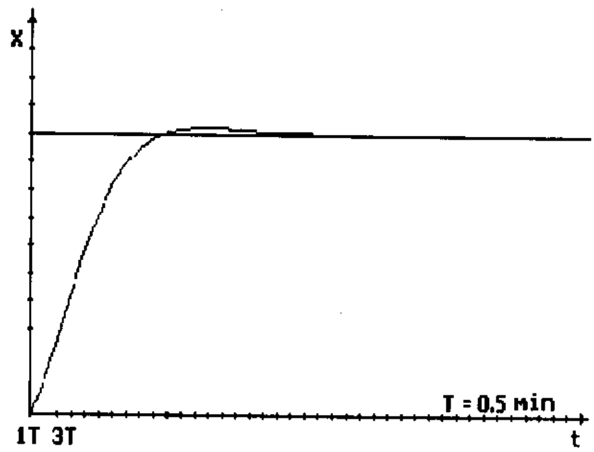

Fig. 2: Time response characteristic of control system with PID controller

The results of simulation and experimental analysis of the automatic control system with GA show its efficiency.
Controller based of recurrent neural network : By increasing complexity of the technological processes, uncertainty of an environment where technological processes take place the model of control system becomes very complicated. For these object the control algorithms developing on base of traditional approach are complex and their implementation is difficult. In addition, the frequently changing of the environmental conditions in the form of unusually disturbance forces to apply artificial intelligence methodologies with self-training and adapting capability. One of these technologies is a neural network. Application of neural network for constructing control system allows us to increase their computation speed validity, self-training and adapting capability.
Number of functions and possibilities of living organisms are realized by some neural structures. By modeling operation principle of these structures one can get adequate mathematical models of the technological processes. Neural networks have such characteristics as:

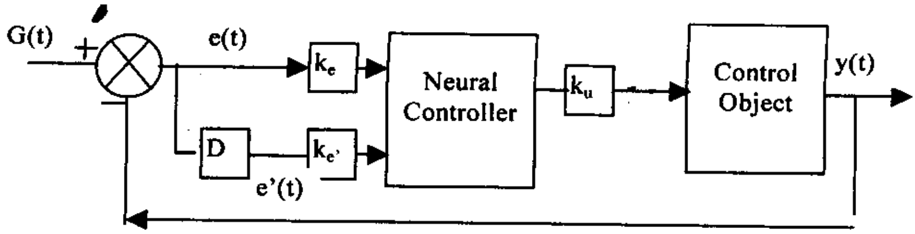

Fig.3. Structure of neural control system.

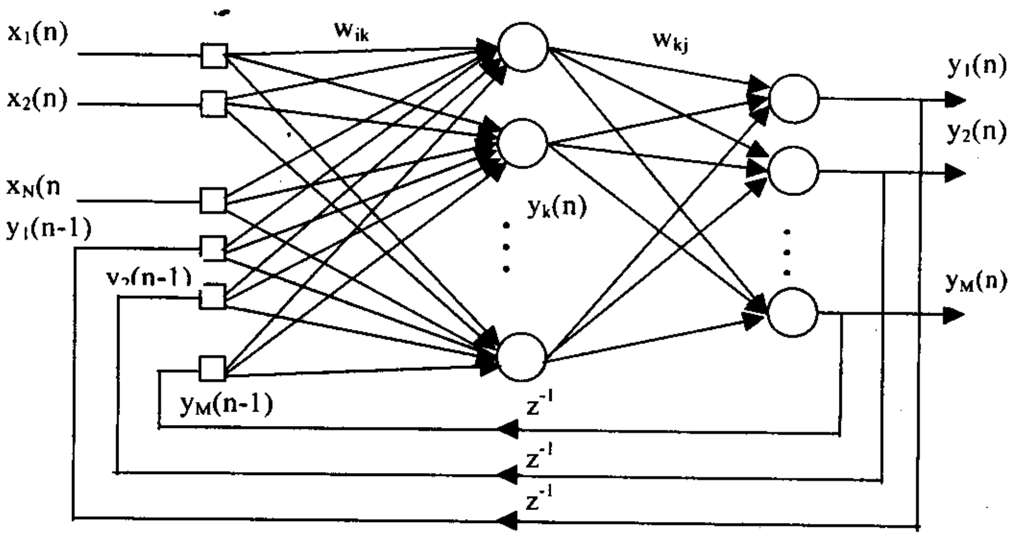

Fig. 4: Recurrent nural network structure

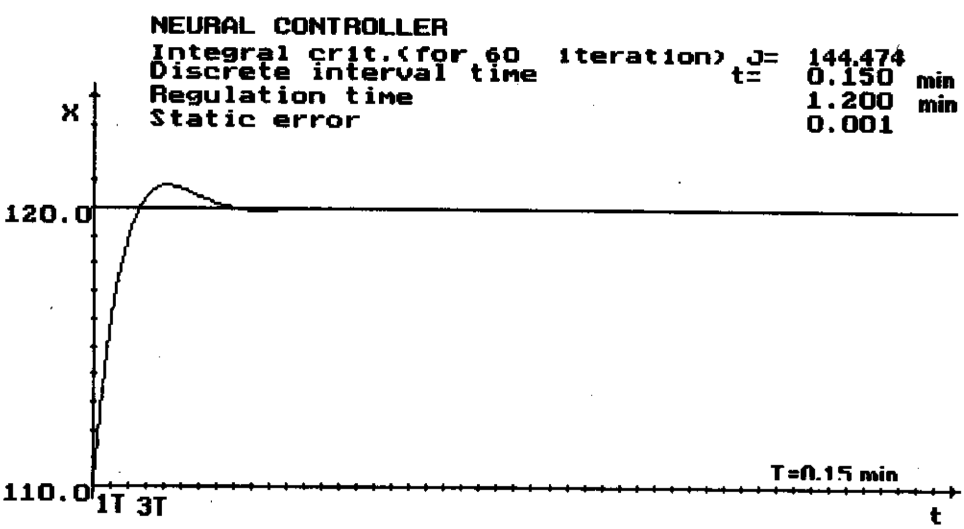

Fig. 5: Time response characteristics of control system based on recurrent neural network

vitality, parallelism of computations, learning and generalization abilities, analytic description of linear and non-linear problems etc. Due to these characteristics neural network becomes great of importance for application in such areas such as artificial behavior, artificial intelligence, theory of control and decision making, identification, optimal control, robotics etc.
The development of control system on the base of recurrent neural network (RNN) is considered. RNN has more computational strength than feeedforward network. The use of RNN provides powerful representations of nonlinear characteristics of dynamics of the process.
Assume that control object is described by the following differential equation

$$\sum_{i=1}^{n} a_{n-i} y^{(i)}(t) + c\varphi(y(t)) = \sum_{j=1}^{m} b_{m-j} u^{(j)}(t) \qquad (4)$$

where a_i ($i=\overline{1,n}$) and b_j ($j=\overline{1,m}$) are unknown parameters of control object, c is unknown non-linear parameter, m<n.
The problem consists in constructing the controller for control of object (4) that would provide the target characteristic of system.
In Fig. 3 the structure of neural control system is shown. The output signal of the control object y(t) is compared with the target signal G(t) of the system and the value of the error signal e(t) is determined. The error signal e(t) is passed to the differentiator D. The output signal of differentiator e'(t) and error signal e(t) after multiplying to the scaling coefficients k_e and $k_{e'}$ are entered to the neural network input. The network output is input of the control object. The synthesis of neural controller includes the determination of the scale coefficients and parameters of the neural network (NN). In the controller synthesis processes the main problem is learning of the NN coefficients. Assume there is target behaviour for the constructed control system. It is necessary to determine the values of parameters- weight matrix w_{ij} and scale coefficients k_e, $k_{e'}$, k_u using of which in control system for object (4) would allow to achieve time response which provides target step response of the system.
Recurrent neural network's model: Assume that input signals applied to the network at time n are $x_i(n)$ (i=1..N) (Fig.4). Output signals of the network are $y_j(n)$ (j=1..M). N and M number of neurons in the input and output layers, correspondingly. The input layer of the network is formed by the external input signals $x_i(n)$ and one step delayed output signals $y_j(n-1)$ of network. The network is fully interconnected with $w_{ik}(n)$ and $w_{kj}(n)$ weight coefficients. Here $w_{ik}(n)$ are weight coefficients between input and hidden layers, and $w_{kj}(n)$ are weight coefficients between hidden and output layers. The output signals of network are defined by the following equation.

$$Y(n)=f(X(n),Y(n-1),W(n)) \qquad (5)$$

Here X(n) and Y(n-1) are external input and one step delayed output vectors correspondingly, f is activation function. In the work the Gaussian activation function is used. The input layer of the network is used to allocate the input signals. Number of signals in the input layer is N+M. The output signals of the hidden layer are calculated as

$$y_k(n) = \frac{1}{1+\exp(-s_k(n))} \qquad (6)$$

Here k=1...K. K is number of neurons in the hidden layer. The values of $s_k(n)$ are calculated as

$$s_k(n) = \sum_{i=1}^{N} w_{ik}(n)x_i(n) + \sum_{l=1}^{M} w_{(N+l)k}(n) y_l(n-1) \qquad (7)$$

The output signals of the network are determined as

$$y_j(n) = \frac{1}{1+\exp(-s_j(n))} \qquad (8)$$

where $s_j(n) = \sum_{k=1}^{K} w_{kj}(n) y_k(n)$.
This recurrent neural network structure is used in neural control system synthesis.
Modelling of neural control system: Using GA operators the learning of the recurrent neural network is carried out in neural control system (Fig.3). In neural controller the number of input neurons are three and output is one. During synthesis neural controller as a evaluation function the inverse of the Integral of Absolute Error is taken (2). The optimal parameters values correspond to the small value of the IAE.
Learning of the neural network coefficients is carried out according the algorithms described above in GA operation scheme. During learning the weight coefficients of neural network are represented by the chromosomes. The encoding block transforms the decimal values of coefficients to binary codes. To represent network coefficients the long chromosomes are used. The tuning of chromosomes is carried out by the selection, crossover and mutation operations. After correction the coding processes (transformation from binary to decimal) is performed and the value of the Integral of Absolute Error in control system is estimated. The learning is continued until the IAE was acceptable small.
The computer simulation of the neural control system is performed for control object described by the following differential equations:

$$a_0 y^{(2)}(t) + a_1 y^{(1)}(t) + a_2 y(t) = b_0 u(t) \qquad (9)$$

where $a_0 = 0.072$ min^2 , a_1=0.56 min, a_2=1, b_0=60°C/(kgf/cm^2); here y(t)- regulation parameter of object, u(t)- neural controller's output.
The development of neural controller for given control object is performed. Using GA learning the corresponding values of neural network coefficients are determined. In Fig.5 the time response of neural control system for control of object (9) is shown.
The results of simulation of control system with recurrent neural network show that static error of time response characteristics of the system is absent (zero), transient overshoot is also absent. The results of simulation and experimental analysis of the automatic control system with recurrent neural network show its efficiency.

References

D.E.Goldberg. 1989. Genetic algorithms in search, optimisation, and machine learning. Addison-Wesley, Reading, Massachusetts.
R.A.Aliev, R.H.Abiev, R.R.Aliev. 1994. Automatic control system synthesis with the learned neural network fuzzy controller. Texnicheskaya kibernetika, Moskva, N3, (Russian).
R.A. Aliev,F.T.Aliev, R.H.Abiev,R.R. Aliev. 1994. Industrial neural controllers.//EUFIT'94, Elita foundation, Promenade 9, 52076 Aachen, Germany.
R.H.Abiev. 2001. Controller Based on Softcomputing Elements.//Electrical, Electronics & Computer Engg. Symposium, NEU-CEE 2001, Turkey, May 23-25.
R.H.Abiev. 1995. Controllers based on neural networks//Uchenie zapiski, AzGNA, pp147-152.(Russian)
R.H.Abiev,G.Mustafaeva. 1997. Synthesis of neural controller for control of technological processes by using genetic algorithms. Higher Military See School, N1, pp88-97 (Russian).