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Design Fuzzy Controller for the Ball Positioning System Based on the Knowledge Acquisition and Adaptation

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Abstract

Industrial processes are normally operated by skilled humans who have the cumulative and logical information about the systems. Fuzzy control has been investigated for many applications. Intelligent control approaches based on fuzzy logic have a chance to include human thinking. This paper represents modeling approach based upon operators knowledge without mathematical model of the system and optimize the controller. The experimented system is constructed for sending a ball to the goal position using wind of two DC motors in the predefined path. A vision camera to mimic human eyes detects the ball position. The system used in this experiment could be hardly modeled by mathematical methods and could not be easily controlled by conventional manners. The controller is designed based on the input-output data and experimental knowledge obtained by trials, and optimized under the predefined performance criterion. And this paper shows the data adaptation for changeable operating condition. When the system is driven in the abnormal condition with unconsidered noise, the new optimal operating parameters could be defined by adjusting membership functions. Thus, this technique could be applied in industrial fields.

Key Words : Knowledge acquisition, fuzzy logic, intelligent control, optimization.

1. Introduction

During the last several years, fuzzy controllers have been investigating to improve manufacturing processes [1], [2]. Conventional controllers need mathematical models and cannot easily handle nonlinear models because of the incompleteness or uncertainty. On the contrary, intelligent control approaches based on fuzzy logic can include humans inference mechanism without information of the systems complex dynamic equations. Therefore, we can make control rules without exact quantification [3]. The controller for the experimented system in this paper is designed based on the empirical knowledge because of the feature of the used system. The fuzzy singleton method is employed for the consequent part.

2. Ball Positioning System

As shown in Fig. 1, the experimental tested system consists of independent two fans operated by two DC motors. The purpose of this experiment is that a ball is sent to the final goal positions using two fans. This system contains non-linearity and uncertainty caused by the aerodynamics inside the path. In this experiment, the wind flowed from DC motors will crash to surface of the inner path and it makes an eddy change strength of wind and makes the difference of the wind strength at each position. Therefore, the ball is not moved as the power is applied to the each path because of the uncertainty. Analysis of effects caused by the wind is difficult and modeling of the system is also not easy because of the much changeable phenomenon. Therefore, the goal of this experiment is that the fuzzy controller is initially designed by operators knowledge and optimized itself after playing with the system [4].

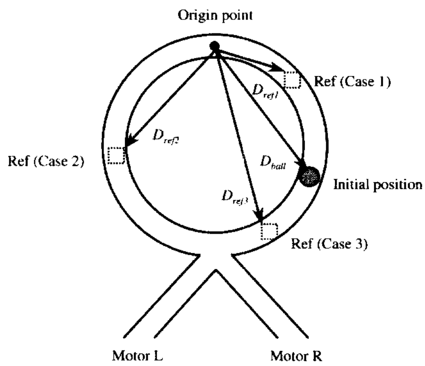

Fig. 1. Ball positioning system used in this experiment.

3. Image Processing

Real images are transmitted to a computer by a CCD camera and a frame-grabber. The two-dimensional ball position is recognized from the captured image. In this case, colors of ball, plant, and predefined path are

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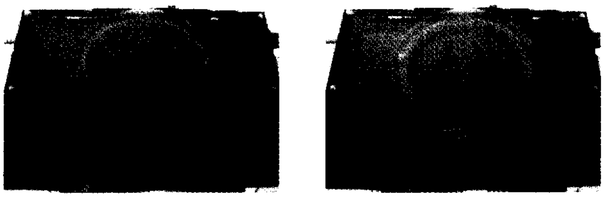
different one another: the background color is black, the path color is green, and the ball color is yellow. Black and green colors have low red value compared with yellow color. The difference of each image is measured for finding moving ball position. The difference coding reduces the effect of environment mixed with similar colors. In the image processing, the center of ball is obtained by difference values of two images that stored in arrays. The threshold process is employed to eliminate noise after getting the difference values of images. If the value of a pixel is higher than required threshold value, one is assigned otherwise zero is assigned to that pixel. Finally, the center of area is used for measuring the ball center point [5]. It is obtained by the following equations.

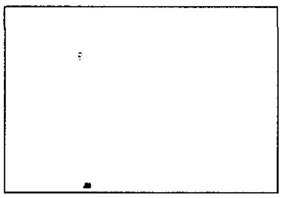
$$A = \sum_{i=1}^{n}\sum_{j=1}^{m} B[i,j] \tag{1}$$

$$\bar{x}\sum_{i=1}^{n}\sum_{j=1}^{m} B[i,j] = \sum_{i=1}^{n}\sum_{j=1}^{m} jB[i,j], \quad \bar{y}\sum_{i=1}^{n}\sum_{j=1}^{m} B[i,j] = \sum_{i=1}^{n}\sum_{j=1}^{m} iB[i,j] \tag{2}$$

$$\bar{x} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} jB[i,j]}{A} \qquad \bar{y} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} iB[i,j]}{A} \tag{3}$$



(a) Initial ball position (b) Final ball position



(c) Finding ball position

Fig. 2. Image processing for finding the ball position.

Following window is main control window. It is to adjust the condition of control environments. In other words, we can set the parameters for the initial conditions and check changed values while the system is operating.

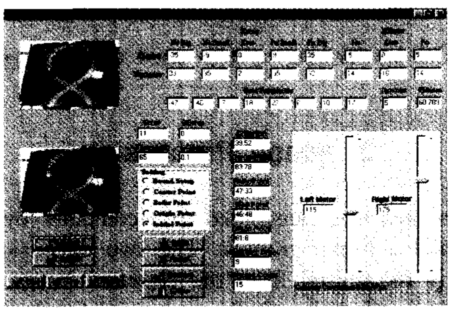


Fig. 3. Control main window for control environment.

The Fig. 4 is the block diagram for the system control. Firstly, CCD camera captures the ball position using a frame grabber that is equipped in a computer and then information of the ball position is sent to the controller. In the next step, the center point of a ball is found by the image processing. If the ball position is found, then we can obtain the error value by the error equation that is defined by the distance between the ball and the goal position. When the error value is measured, the control command could be determined. This control command is sent to a microprocessor, which is to make PWM (Pulse Width Modulation) signal and communication between the computer and the processor. And then a motor driver is operated by the PWM signal, which is generated by the microprocessor. Both motors are driven by the commanded PWM signals and then the ball is moved to new position.

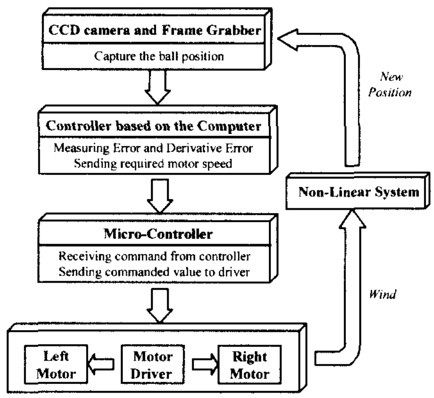


Fig. 4. Flowchart for operating the system.

4. Fuzzy System

4.1 Measuring Error Value

Equation of error values is required for evaluating. Error values are defined by the difference of distance between the final goal and the present ball position. In this experiment, error and derivative of error are used for inputs. Input voltages of motors are calculated by the membership functions in the consequent part. The direction of error values has *plus* or *minus* sign by the distance measure. If the ball is locating at the opposite direction of the goal position, the error value should be bigger. The following equation is to measure error values.

$$e(t) = \sqrt{(B_x - O_x)^2 + (B_y - O_y)^2} - \sqrt{(R_x - O_x)^2 + (R_y - O_y)^2} \tag{4}$$

where B, O, and R indicate a ball position, an original position, and a goal position respectively.

4.2 Fuzzy Rules and Membership Function

Gaussian functions are used for membership functions of a premise part and five singleton values are used for the consequent part. As shown in Table 1, the skilled human could define how to handle or control the system. This is called the operators knowledge. Fuzzy rules are constructed based upon operators knowledge as shown in Table 2 that is used to control the system.

Table 1. Operators knowledge for controlling both motors.

	Initial Ball Position: Right side	
Ball Condition	Higher than Goal	Motor R: Speed down slightly Motor L: Speed up quickly
	Opposite Side	Motor R: Speed down quickly Motor L: Speed up quickly
	Lower than Goal	Motor R: Speed down slightly Motor L: Keep speed

Table 2. Fuzzy rules obtained by operators trials.

Right Motor

Δe \ e	PB	PS	ZE	NS	NB
N	NS	ZE	ZE	PB	PB
Z	NB	NS	ZE	ZE	PS
P	NB	NS	NS	PS	PS

Left Motor

Δe \ e	PB	PS	ZE	NS	NB
N	PS	PS	PS	NS	NS
Z	PB	PS	ZE	NB	NB
P	PB	PB	PS	NB	NB

4.3 Inference and Defuzzification

The Mamdani fuzzy inference system was proposed for controlling system with a set of linguistic rules from experienced operators and min-max composition is used for inference [6], [7]. In Mamdani fuzzy model, center of areas or mean of maximum is used for defuzzification. In this paper, fuzzy singleton is applied. It is a special case of the Mamdani fuzzy inference system [8], [9]. Consequent membership functions are specified by fuzzy singleton [3]. The fuzzy singleton is free of computation works. Therefore, it is suitable for real time applications.

5. Optimization

The system condition is changed each experiment due to different environment conditions. Therefore, the adjustment of parameters in the membership functions is necessary. In this paper, two types of optimization methods are applied for searching good parameters. The eight parameters for error and derivative error membership function are adjusted by an optimization. Each membership functions is symmetrically constructed, therefore adjusted parameters are reduced. In this experiment, hybrid genetic algorithm and simulated annealing are implemented for the optimization.

5.1 Genetic Algorithm

A genetic algorithm is a global optimization method to find the required solutions. The GA obtains new populations using reproduction, crossover, and mutation [10]. In this paper, 8bits are composed for searching each parameter. Therefore, total 64bits genes are used. Reasonable ranges of each parameter are determined by operators knowledge. If a proper range is used in a GA decoding process, high quality solution can be obtained without much population and generation. This is suitable for this plant. And it could not break the fuzzy linguistic reasoning due to keeping the regular range.

In GA, a search space is digitized by its resolution R_i for the parameter x_i with Libits. It could be formulated as a following equation.

$$R_i = \frac{UB_i - LB_i}{2^{L_i} - 1} \tag{5}$$

If it is increased by kbits, R_i is increased by 2^k times and search space is increased by $(2^k)^n$ times. Hybrid genetic algorithm is the method that a GA and Nelder-Meads simplex method are combined [11]. The hybrid approach yields the fast convergence rate without sacrificing the accuracy of the solution. Therefore it can reduce the computational cost.

5.2 Simplex Method

The geometric figure formed by a set of n+1 points in n-dimensional space is called a simplex. When the points are equidistant, the simplex is said to be regular. Thus in two dimensions, the simplex is a triangle and in three dimensions, it is a tetrahedron.

The basic idea in the simplex method is to compare the values of the objective function at the n+1 vertices of a general simplex and move this simplex gradually towards the optimum point during the iterative process. This method was originally given by Spendley, Hext and Himsworth and later developed by Nelder and Mead [12]. The movement of the simplex is achieved by three operations known as reflection, contraction, and expansion.

5.3 Simulated Annealing

Simulated annealing is a derivative free optimization method that recently drawn much attention for being as suitable for continuous as for discrete optimization problems. The most important part of SA is the annealing schedule, which specifies how rapidly the temperature is lowered from high to low values. This is usually application specific and requires some experimentation by trial and error. In this paper, the algorithm starts at a high starting temperature and it is declined gradually while iterations are repeated.

6. Experiment Result

6.1 Performance Criterion

Performance criteria are necessary to evaluate the performance. Several types of criteria are used for this

Table 3. Parameters of membership functions for experiments.

	Error M.F.										Derivative Error M.F.					
	NB		NS		ZE		PS		PB		NE		ZE		PO	
	CE	VA	CE	VA	CE	VA	CE	VA	CE	VA	CE	VA	CE	VA	CE	VA
A	-40	20	-20	10	0	10	20	10	70	40	-10	5	0	3	10	5
B	-40	30	-15	15	0	5	15	20	80	50	-4	5	0	5	4	5
C	-50	35	-10	20	0	8	10	20	50	25	-4	5	0	3	4	5
D	-50	25	-20	10	0	10	20	10	50	25	-4	5	0	4	4	5
E	-30	20	-15	10	0	10	15	10	30	20	-4	4	0	3	4	4
F	-35	25	-18	10	0	8	35	25	30	20	-2	2	0	2	2	2

Table 4. Results of the operators trials using the parameters of the Table 3.

	Goal: Left Upper						Goal: Right Upper					
	1	2	3	4	5	Ave.	1	2	3	4	5	Ave.
A	41.81	13.95	14.24	32.20	12.36	22.91	15.49	17.77	33.32	31.35	35.16	26.62
B	16.69	8.59	30.74	13.72	13.02	16.55	57.27	36.32	39.63	16.54	29.17	35.78
C	17.21	14.08	34.44	18.40	17.42	20.31	43.25	43.55	38.39	60.82	46.39	46.48
D	19.83	13.19	12.72	12.34	9.37	13.49	31.14	34.74	44.83	30.90	27.07	33.73
E	10.44	8.60	9.20	27.11	9.63	12.99	43.80	35.45	13.43	31.79	13.09	27.51
F	18.09	19.33	19.64	19.88	18.24	19.04	27.89	26.03	28.13	24.84	15.07	24.39

work. In this paper, the combined performance criterion is defined as following which considers a convergence time and error values simultaneously.

$$f(e)=\alpha\sum_{t=t_1}^{t_2} t|e(t)|+(1-\alpha)\sum_{t=t_1}^{t_2}|e(t)| \quad (6)$$

where is contributed coefficient, and t1 and t2 are the period time of measurement error.

6.2 Operator's Trials

In an operators experiment, convergence rates and error values are measured for comparing the performance. It is achieved by the performance criterion so called the objective function and fuzzy rules are fixed based on the empirical knowledge. Fig. 6 is shown the error value while the system is operating. Initial value is very high. Error value is reduced to low level gradually by iteration. There are some oscillations but the controller removes that. Finally, the value is converged to zero.

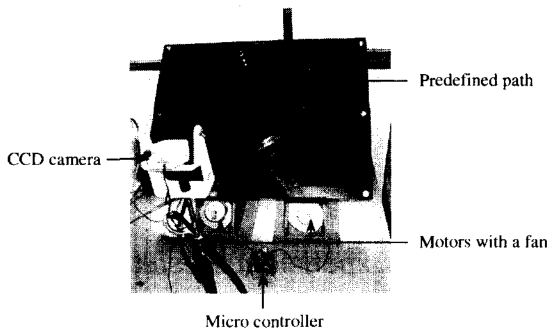


Fig. 5. The experimented system and components.

In operators test, random parameters are firstly selected and parameters are adjusted by evaluated performance. This is much important information for the optimization. Results of the test are shown in Table 3 and Table 4.

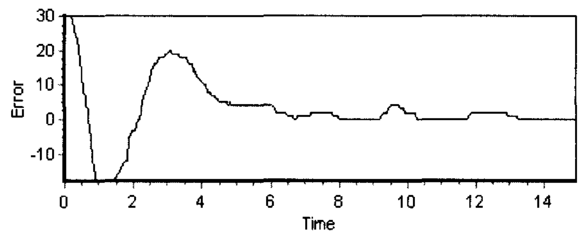


Fig. 6. Error graph with respect to time.

6.3 Condition of the Optimization

For optimization, we set the two condition of the system. First one is in the condition that has external disturbance and the other is in the condition that has no disturbance. Following Table 5 is shown the classified condition. In both conditions, we use two optimization methods. One is Hybrid genetic algorithm and the other is simulated annealing. Especially, we test sequential condition of the system. Firstly, the system is operated without the disturbance, secondly, operated with the disturbance, and finally, operated without the disturbance again. It is for experiments that the system can be adapted at the changed condition of the system. And we want to find which optimization method is the fittest method for the system optimization.

Table 5. Condition of the system for the optimization.

	Used Optimization Method		
	W/O Disturbance	With Disturbance	Sequential Condition
Step 1	Hybrid GA	Hybrid GA	Hybrid GA (W/O Disturbance)
Step 2	SA	SA	SA (With Disturbance)
Step 3	×	×	SA (W/O Disturbance)

6.4 Without Disturbance

6.4.1 Hybrid Genetic Algorithm

30% of crossover and 1.5% of mutation rate are implemented for genetic algorithm in this test. And elitism is used for storage and transfer of the population. It could improve the optimization performance. The first graph of Fig. 8 represents the performance with respect to each membership functions.

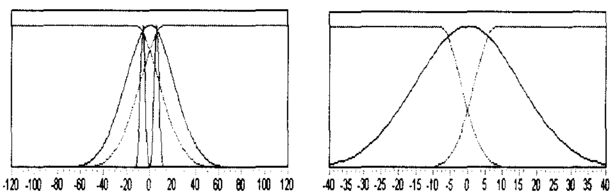


Fig. 7. Optimized fuzzy membership functions in the Hybrid GA.

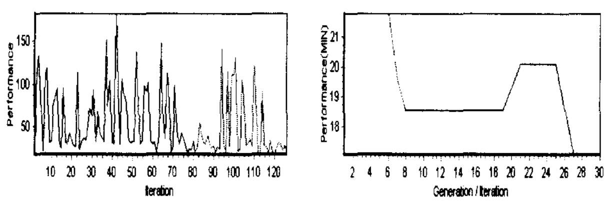


Fig. 8. Performance of the experiment in the case of the Hybrid GA.

The performance values jump to worse value once in the middle of a graph, but it could be declined gradually with iteration. Shapely changed values are eliminated at the consequent part. After processing of GAs, the performance represents a worse value than previous values in the simplex method as shown in the second graph of Fig. 8 because the difference of the performance exists in real experiments even though the same membership functions are used. This phenomenon could occur due to features of the system or uncertainty of wind. Another reason is that the best performance values are kept continuously in GA and then it will transfer to the next generation. In other words, all parameters transferred from GA are used for operating the system and then performances are evaluated again in the simplex method, so little bits gap could exist. But the performance values get lower finally as shown in the second graph of Fig. 8.

6.4.2 Simulated Annealing

As shown in Fig. 10, couple of graphs represents results of SA algorithm. In the initial part of the second graph of Fig. 10, the performance value is dropped much and then it get lower to better values while iteration is repeated. SA can search good solutions fast even though repeated iteration times are less than that of GA. When SA is used for the optimization, to select initial values is very important. In this experiment, SA starts with searched parameters by operators trials. A high computation cost is avoided by known initial parameters. Initially a high temperature coefficient is selected for the global search and then it is improved gradually during the processing for the local search. The optimized solution is searched through this processing. Fig. 9 shows the optimized fuzzy membership function by simulated annealing.

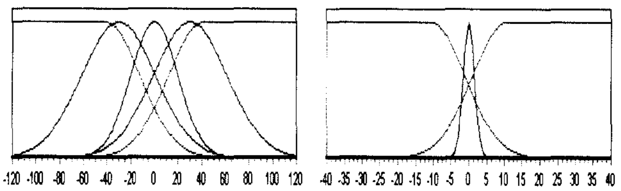


Fig. 9. Optimized fuzzy membership functions in the SA.

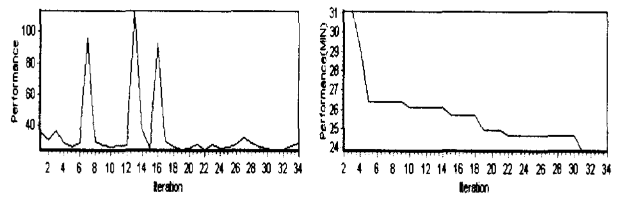


Fig. 10. Performance of the experiment in the case of the SA.

6.5 With Disturbance

In this section, we test the system in the special condition that has external disturbance. We punch the three holes on the cover of the plant. It causes the outflow of wind from the predefined path. And a ball is forced to rush into the holes. If a ball is in this condition, the controller could not control the ball position easily. So we need to change the control rules or to adjust parameters of fuzzy membership functions for the system adaptation. In this paper, the latter manner is used.

6.5.1 Hybrid Genetic Algorithm

In this case, outflow of wind causes the difficulty to control the system. As shown in Fig. 12, there are large numbers of oscillations in the whole range. The reason why performance results are oscillated is that moving a ball is influenced by the outflow of wind. The trend of the moving a ball is very sensitive. Therefore, we have to adjust the parameters of fuzzy membership functions for controlling the system properly. It is easier than the method to change the control rules.

In final step, the performance is improved as shown in the right graph of Fig, 12. But reducing magnitude is smaller than the case that has no artificial disturbance in the initial part of the performance of the test results. Fig. 11 shows membership functions, which are optimized by hybrid GA.

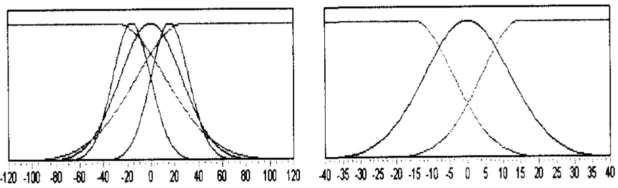


Fig. 11. Optimized fuzzy membership functions in the Hybrid GA.

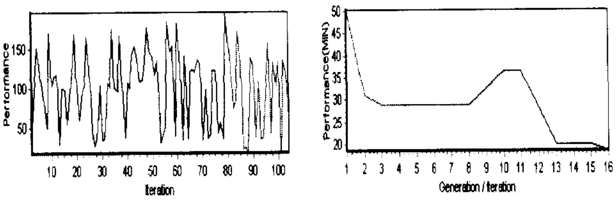


Fig. 12. Performance of the experiment in the case of the Hybrid GA.

6.5.2 Simulated Annealing

In this optimization approach, the improving speed is slow. It means that the improvement of the performance is difficult, when disturbance is got into the system. Especially,

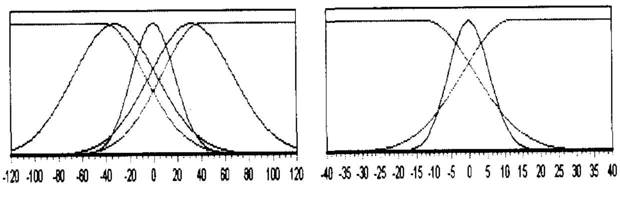


Fig. 13. Optimized fuzzy membership function in the SA.

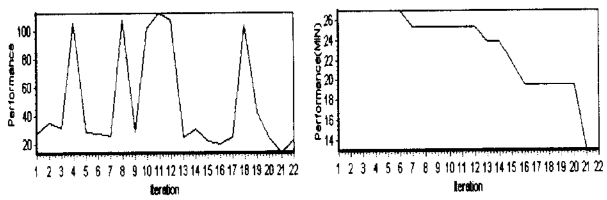


Fig. 14. Performance of the experiment in the case of the SA.

the performance values are very bad values in the starting part. Because the initial point of simulated annealing is selected by the operators knowledge with hand-operated tests. But as shown in Fig. 14, performance is getting better. With these results, we can say when disturbance is come into the system, without new initial step or reconstruction of control rules the system can be controlled well.

6.6 Sequential Condition

We can have the experience of effect of disturbance while driving the system. In this case, we need to do diagnosis and then to solve problems. There are many methods for this kind of matter. In this paper, special sequential condition is constructed for the natural operating situation. In the first step, the system is operated without disturbance and optimized by hybrid genetic algorithm. And secondly, disturbance is got into the system. In this condition, simulated annealing method optimizes the system. In the final step, the system has no disturbance again and optimized by simulated annealing.

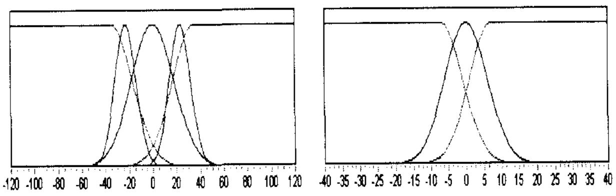


Fig. 15. Final fuzzy membership functions in the first step.

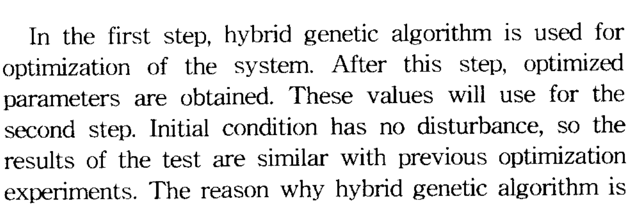


Fig. 16. Performance of the experiment in the case of the Hybrid GA in the first step.

In the first step, hybrid genetic algorithm is used for optimization of the system. After this step, optimized parameters are obtained. These values will use for the second step. Initial condition has no disturbance, so the results of the test are similar with previous optimization experiments. The reason why hybrid genetic algorithm is used for the first step is that genetic algorithm can search solutions broadly and globally. Solutions of the system are found by first optimization approach, which is genetic algorithm, and then mode is changed to simplex method, which is local search method.

In the second step, holes are opened for the situation of disturbance. Simulated annealing method is used for the optimization. For initial point, optimized values by previous hybrid genetic algorithm in the first step are used. In spite of the fact that optimized parameters are used for the system control, the system could not be controlled well because conditions in the system are changed. Thus we have to adjust parameters for the proper control.

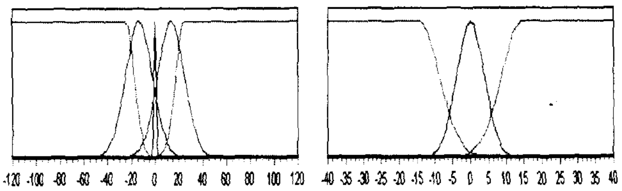


Fig. 17. Optimized fuzzy membership functions by SA in the second step.

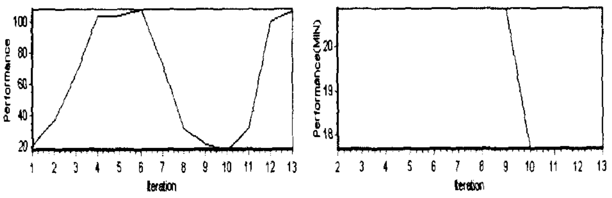


Fig. 18. Performance of the experiment in the case of the SA in the second step.

When we consider the graph in Fig. 18, optimization processing is achieved by simulated annealing. It means that optimized parameters are changed due to the disturbance. There is very big merit that it is much easy way for optimization with changeable condition. If we want to make new control rules, we must spend much time and effort for adaptation of the system. If this kind of situation is occurred in the practical area, this approach fit for field engineers.

Fig. 17 is changed fuzzy membership functions by simulated annealing. When we compare between the fuzzy membership function of the first step and the second step, both of them are much different because of the influence of the disturbance. As shown in Fig. 18, simulated annealing is one of the fast optimization methods, when initial points are selected properly. In the simulated annealing, time scheduling is much important. Generally, high value is chosen in the initial point. While repeating iteration, temporary value is reduced gradually.

In the final step, we remove disturbance and drive the system. It is the same condition with the first step but

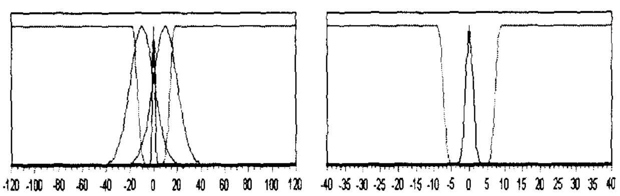


Fig. 19. Optimized fuzzy membership functions newly in the last step.

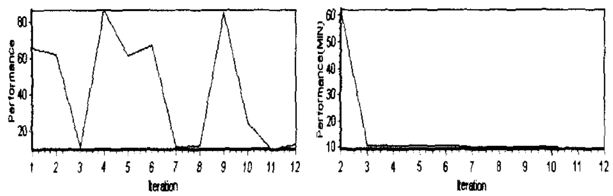


Fig. 20. Performance of the experiment in the case of the SA in the last step.

used the optimization method is different. Simulated annealing method is used because global search is not necessary. We just want to explore the boundary of the near old optimized values and then find good parameters for new changed situation. The results of this approach are suitable for the condition as shown in Fig. 20.

7. Conclusion

The primary goal of this paper is to design and optimize a fuzzy controller based on the operators knowledge and running process. It uses characteristics of the fuzzy controller that it can control systems using fixed rules without mathematical models. In this paper, Gaussian functions are employed for fuzzy membership functions and 8 functions are used for error and derivative error. Thus, total 16 parameters are optimized. The hybrid approach combined a GA with a stochastic variant of the simples method is implemented and applied for the alleviating computation cost. Also, SA is tested as the optimization method. Operators knowledge is used for finding reasonable ranges in the hybrid GA and initial parameters in SA. In this paper, both of them are compared considering convergence rate and accuracy. SA is better than hybrid GA with considering convergence rate. But it is difficult to decide which one is the best optimization method. It is depends on the situation of the systems. We just regard that SA is a more proper approach for this system because its behavior is more similar to human being. Fig. 21 is shown the full processing block diagram. It starts with knowledge acquisition, which is achieved by operators. Main issue of this paper is the knowledge adaptation using some kinds of the optimization methods. It could be considered as a real situation of the industrial field.

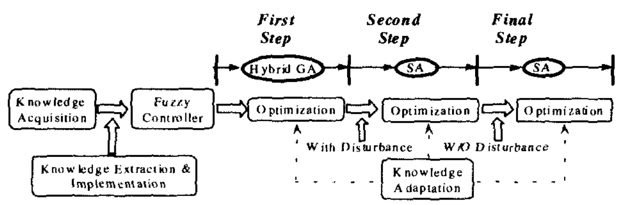


Fig. 21. Block diagram of the system optimization.

We can make a decision that the system with changeable condition can be handled by the optimization. And simulated annealing is better way to be applied in the real system because operation speed is fast and basic technique is similar with human beings behavior.

Reference

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