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Fuzzy Optimization Control: From Crisp Optimization

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Abstract

This section shows interesting contents from the development results of author's past crisp optimization combustion control concerning real boilers of fossil power plants to the upper and lower separation new fuzzy optimization control system plan. The fuzzy decision-type optimization is for elevators and the fuzzy table-like control with zero is for a single-element level control of one tank model. In addition, other researchers' recent researches concerning other applications are introduced to maintain fairness and balance.

Keywords: crisp optimization control, fuzzy optimization control

1. Introduction

In section 1, the section hierarchy and abstract of this chapter is introduced. Moreover, sometimes, abstract of many studies on many kinds of fuzzy optimization control systems are also introduced and discussed. Current interests [1] are mathematically steady and will become active in the future, whereas Mandani type fuzzy control is comprehensible and has been installed already to a marketing personal computer control system for a coupled tank level [2].

In section 2, the composition of the optimizing control system, which the author and the colleagues of an enterprise had developed [3] and the recent evolution of optimization part are introduced. The first real process application version consisted of the optimal search part with the restriction by an upper computer, a usual cascade control by decentralization digital control system and various input parts and an interface part for them. The optimization search

method was developed from some general nonlinear programming to an integer programming that combined a local search and a boundary search using a simple pattern. Afterward, the optimization part has been enhanced to methods using the double patterns with more evaluation cells [4] and to methods in many books for optimization technique [5–7] except for boundary pattern search. In addition, the concept of cellular automata [8] and the technique of Q learning [9] were taken and it has been enhanced in the three universities and an institute of technology.

Zhang, Maeda, and Kawachi [10] presented an optimization model in order to allocate irrigation of water, which is withdrawn from a river, to paddy field blocks in irrigation system. A fuzzy linear programming is employed in order to solve the fuzzy decision-type optimization in the model formulation for dealing with uncertainties due to randomness of hydrologic and hydraulic parameters and fuzziness in management goals.

Multi various patterns and the other concept for optimization are introduced in a literature by the author [11].

Then, recent literature by Fujita, Tani, and Kawamura et al. [12] on fuzzy optimum control theory based on fuzzy maximization decision method of built structure are introduced.

In Section 3, a single input single output (SISO) feed-forward and feedback control system with a Table Base Controller with Zero (TBCZ) as one of Table Base System (TBS) is proposed using crisp number, which is expected to provide some advantages.

There, a feed-forward controller refers to an inverse transfer function of the controlled object.

It is proposed that a control table for three inputs of PID and three types of membership functions are not in fuzzy sets, but rather in crisp sets in expectation of the some advantages:

Some simulation results and evaluations are also shown there.

In Section 4, a fuzzy decision method based on crisp numbers with not only 1D-2D fuzzy evaluation membership functions and 1D-2D fuzzy restriction membership functions but also 3D description of their membership functions with overview plan, and a search method on the overview plan is proposed as a kind of fuzzy optimization part.

2. Examples of crisp and fuzzy optimization control systems

2.1. A crisp example in real plants

The optimizing control is divided into three parts, the optimization part in the upper system, the digital control part in the lower system, and the interface part where they are connected to former two parts. The method of the search for the combination pattern of the local search part and the boundary search part [4] was used as an upper system.

Figure 1 shows a system block diagram of the optimum combustion control system (MHI Operation Support System), which is a real example of crisp optimization controls [3]. The output chart of optimization part is shown in **Figure 2** [3] and control logic part is shown in **Figure 3** [11]. The patent [11] has more information on the optimization control.

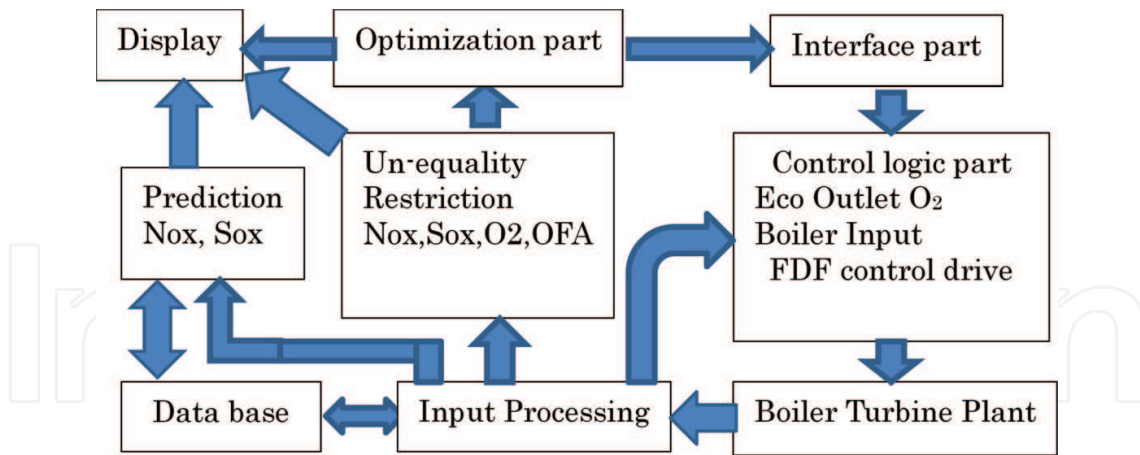


Figure 1. System block diagram of an optimization control.

This example is very important, for horizontally developing the optimizing control with the three-layer structures in the future, and as an example of applying a real machine of the optimizing control in a thermal power generation process that is a multivariable system with large changes though it has not arrived at “fuzzy” optimizing control yet.

However, the initially developed artificial intelligent language and the detail search algorithm of the local search agent and the boundary search agent could not open for secret of know-how. Then, the author has developed a new evolutionary cellular automata algorithm using

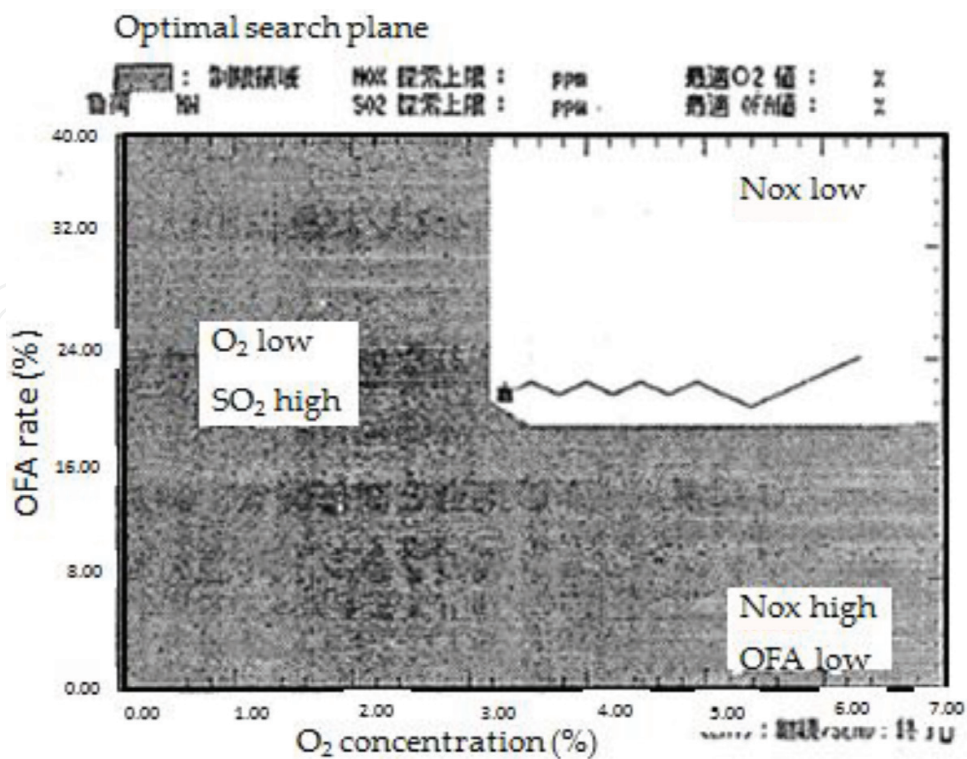


Figure 2. An example of optimization search for maximizing a boiler efficiency in OFA rate and O₂ concentration plane.

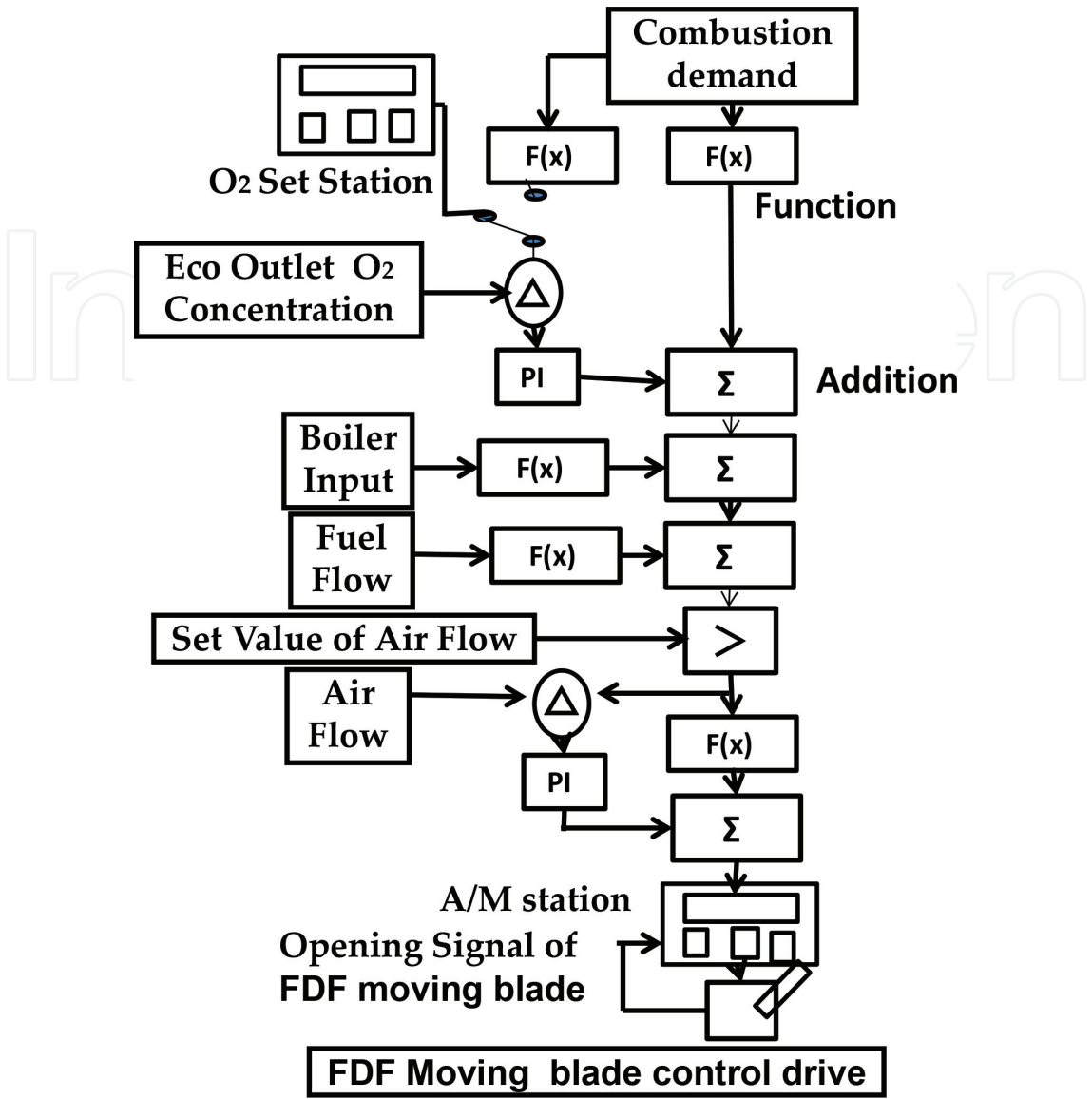


Figure 3. Eco outlet O₂ feedback control logic with optimization signal.

different patterns to low cost squares in the upper optimization control system though they are cost up. They are introduced in the next paragraph.

2.2. A crisp evolutionary algorithm for hybrid optimization control

In this paragraph, a crisp evolutionary algorithm for hybrid optimization control by multiagents is shown, because reliability and adaptability of the above hybrid optimization must be needed to increase and open.

Figures 4 and 5 show the cellular (remaining to use fuzzy number) structure of local search agents to search for the peak in the boundary line and boundary search agents to search for the peak out of the boundary line. Moreover, increasing reliability and adaptability of these search methods are shown [8].

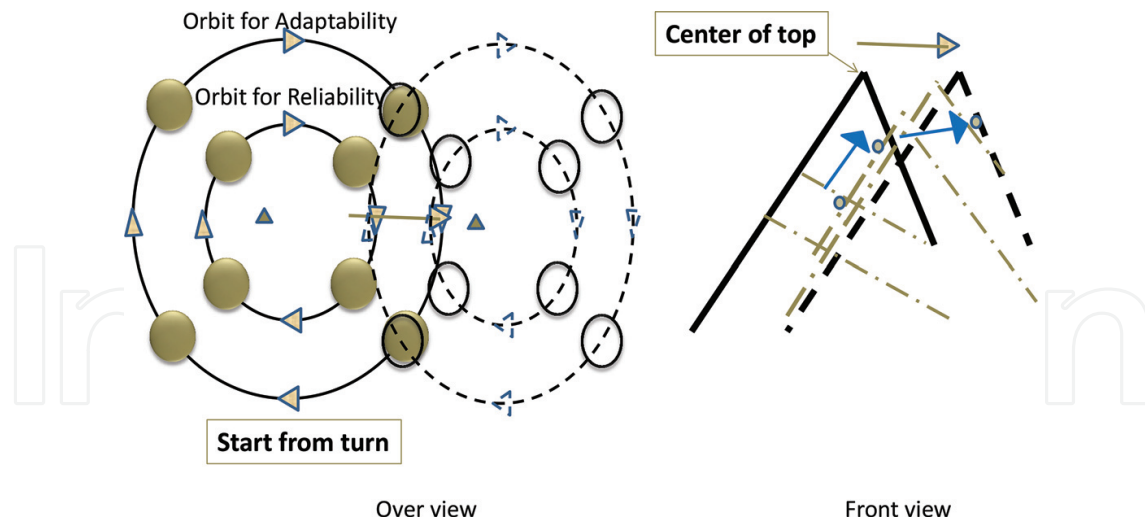


Figure 4. Cellular structure of local search agents for reliability and adaptability.

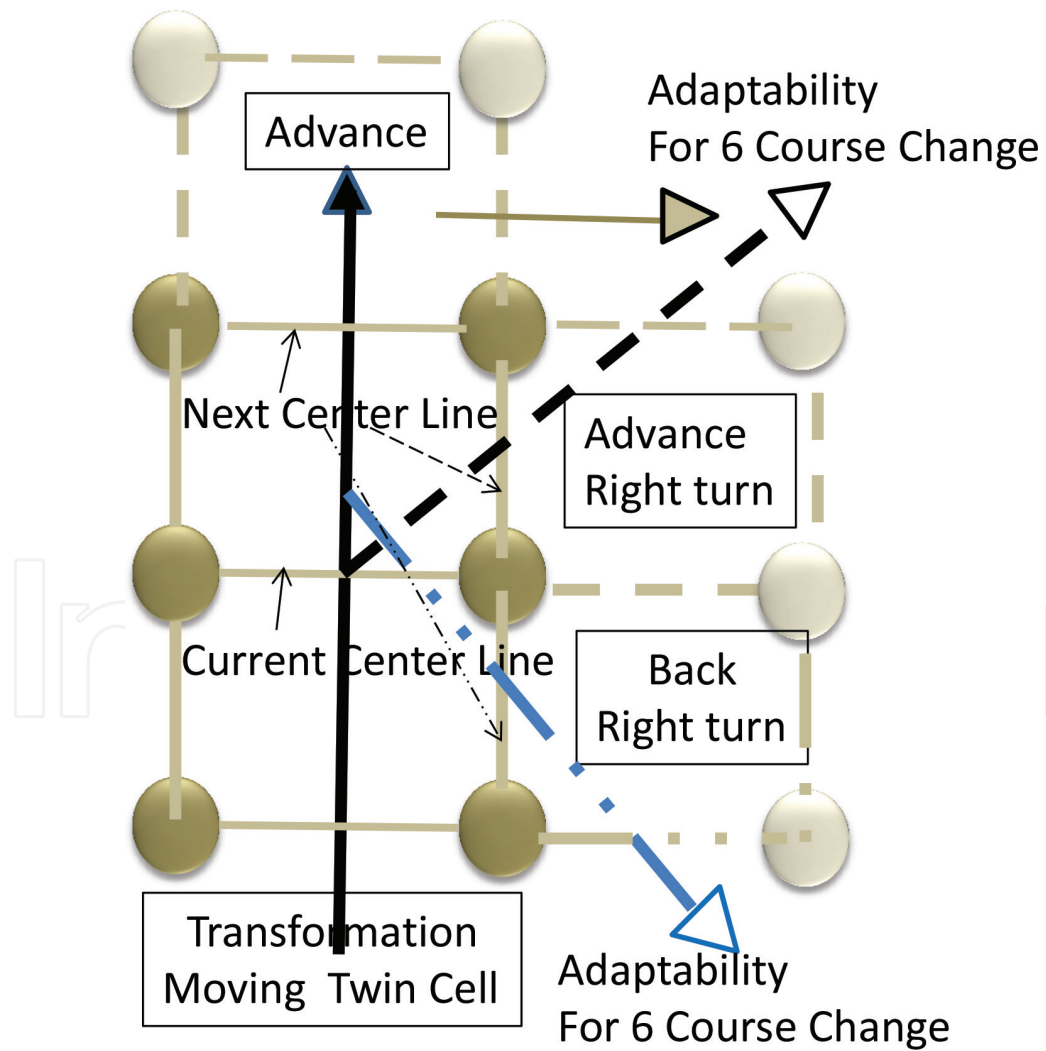


Figure 5. Cellular structure of boundary search agents for reliability and adaptability.

The following features are obtained by using eight cells group in an agent for evaluation of double circles as rotated machines as shown in **Figure 4**.

1. Adaptability to movement of mountains
2. Evaluation to continuous values
3. Application to multipeak

The following features are obtained by using six cells group in an agent for evaluation of double squares as moving cars with six wheels as shown in **Figure 5**.

1. Decrease of derailment probability
2. Evaluation to discrete values
3. Application to bifurcated boundary by using agents with different priority evaluation order

Oppositely, there are the following features in the quadrangle (square) agents adopted with an initial real system.

1. It is easy to develop because algorithm is easy.
2. There is a room to enlarge fuzzy circle.

Figure 6 shows local and boundary search algorithm using cellular automata.

The cellular automata algorithm has the following features.

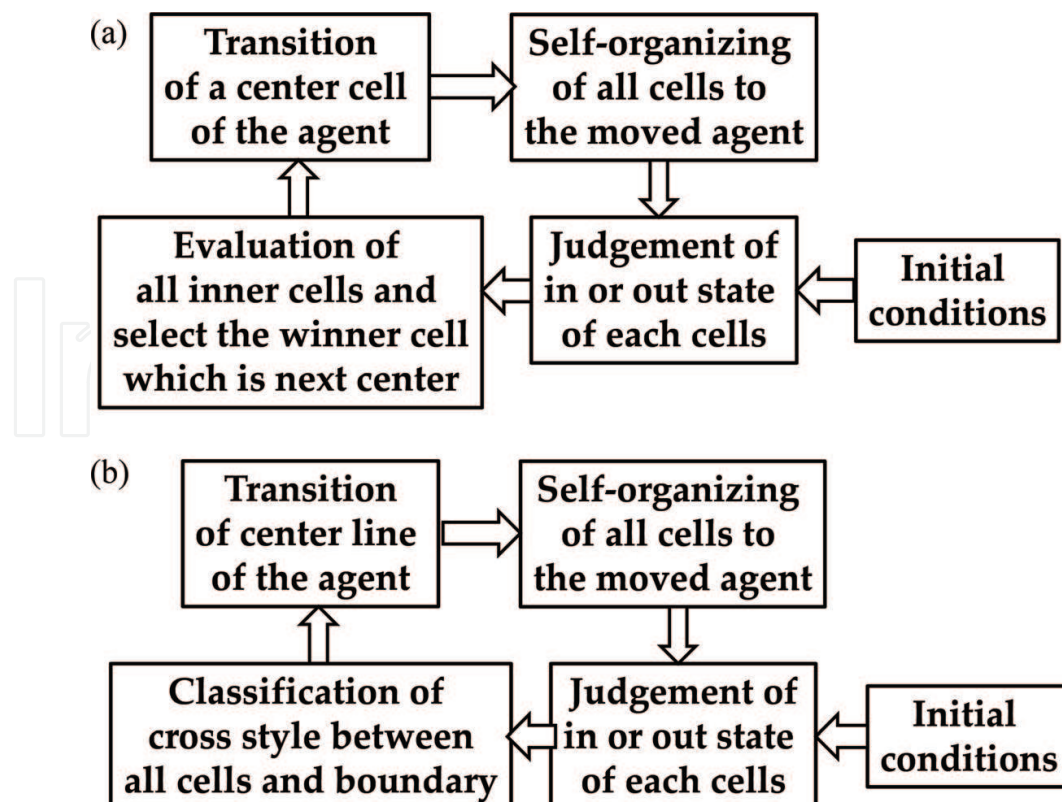


Figure 6. Cellular automata algorithm for local and boundary search algorithm. (a) Local search. (b) Boundary search.

1. Multistart points can set to any positions.
2. Four steps of center transition, self-organization of all cells to the moved agent, in or out state judgment, are repeated.

In the case of four-cell agents like four wheel cars in **Figure 2**, center line must be replaced to front line in automata (b) of **Figure 6**.

2.3. A fuzzy example of built structure

On the other hand, Fujita, Tani, and Kawamura et al. at Kobe University [12] execute fuzzy optimum control theory based on fuzzy maximization decision method (target conditions and restriction condition are expressed by fuzzy membership functions) to built structure, and it is called intelligent active control. Not only target response displacement and target control power but also structure identification values obtained from the responses of the structure and earthquake vibration forecast obtained from earthquake input measurement were used for the structural response forecast.

They decided the parameters using the fuzzy maximization decision method. Then, the effect of controls were examined by experiment and simulation about two methods for addition of control power added the feedback only of the ground vibration input acceleration power and the relative acceleration power's from base of structure.

They reported that the feedback control with optimal coefficients can improve the rate of improvement by 30% higher or more.

This report feels the difficulty for execution of fuzzy optimization control though it can encourage the execution.

In the following section, a table base controller with zero (TBCZ) is introduced for easiness of tuning of membership functions more than conventional fuzzy control.

3. A fuzzy-like table base PID controller with zero

The purpose of this section is to design and evaluate a Table Base Controller with Zero (TBCZ) as one of Table Base System (TBS) [13].

3.1. Table base controller with zero

3.1.1. TBCZ configuration

In this paragraph, we propose the following SISO feed-forward and feedback control system with a TBCZ in **Figure 7**, which is expected to provide the following advantages:

1. Fast start up
2. Small overshoot
3. Easy maintenance using the tuning knowledge of the conventional PID control

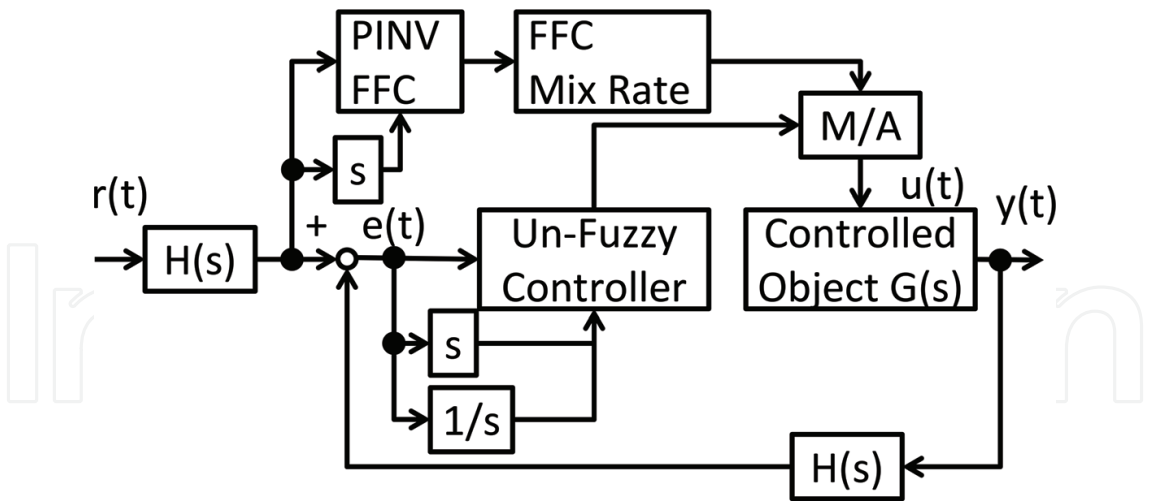


Figure 7. Configuration of a TBCZ.

Moreover, M/A means a manual/auto switch station, s means a differential operator, and $1/s$ means an integral operator in Figure 7.

3.1.2. Table of TBC

Figure 8 shows a table of TBCZ and rectangular membership functions instead of usual triangle membership functions. Here, SUMi contains not only the proportional scaling factor SF_p and the differentiation scaling factor SF_d but also the integrator scaling factor SF_i . Finally, the scaling factor of the input SF_u must not be overlooked.

The rectangular membership functions are easy on computation because they are crisp.

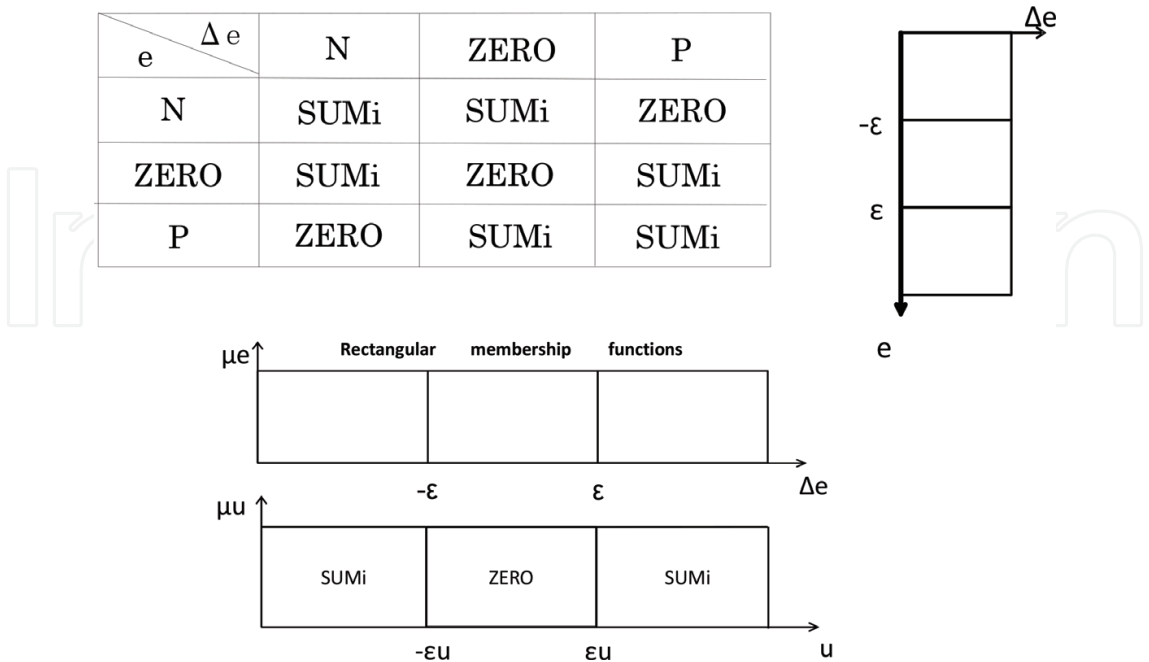


Figure 8. A table of TBCZ and membership functions.

3.2. Modeling, parameter tuning, and evaluation

Here, assumed characteristic of up-down symmetry without hysteresis, and neglected pump with long nose tube reached in water of tank and PWM control dynamics, which is sufficiently fast.

Then, we modeled the control using the following simple linear transfer functions:

$$G(s) = \frac{Ke^{-Ls}}{Ts + 1}; K = 30, T = 20, L = 2 \quad (1)$$

$$H(s) = \frac{K_s}{T_s s + 1}; K_s = 1, T_s = 0.1 \quad (2)$$

3.2.1. Parameter tuning

3.2.1.1. Scaling factor in the TBCZ

The followings are examples of scaling factors in the TBCZ.

$$\begin{aligned} P &= \frac{1}{SF_p}, \quad D = \frac{1}{SF_d}, \quad I = \frac{1}{SF_i}, \quad \varepsilon_0 = 0 \\ \frac{1}{SF_p} &= 0.15, \quad \frac{1}{SF_i} = 0.0091, \quad \frac{1}{SF_d} = 0.1 \end{aligned} \quad (3)$$

3.2.2. Performances of 3×3 and 2×2 tables of TBCZ

An evaluation of the mean integral square error and input (MISEI) was compared for various values of the terminator ε in **Figure 9**.

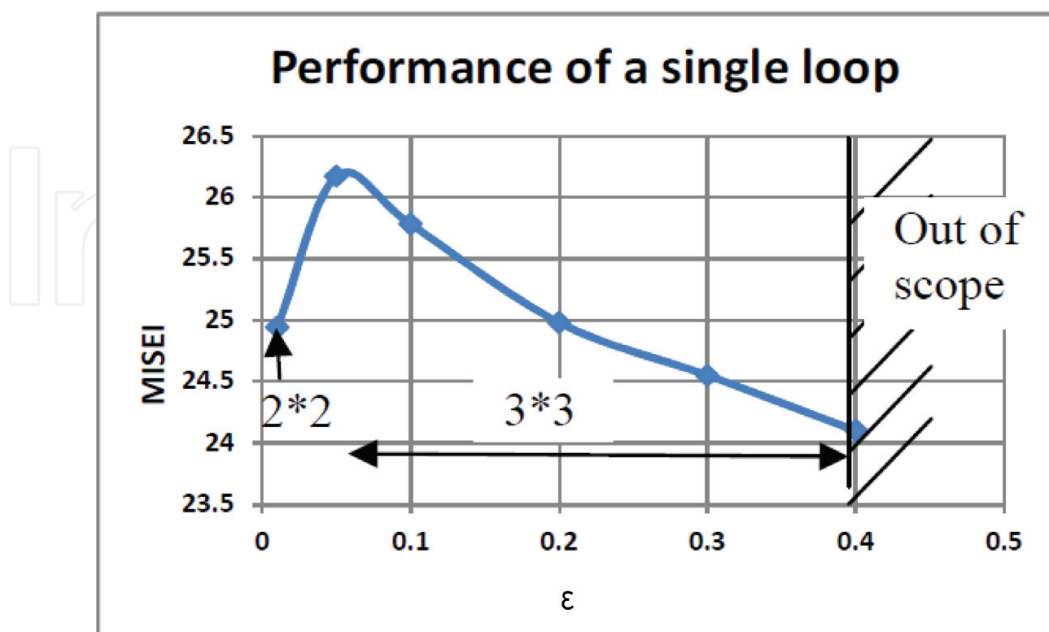


Figure 9. MISEI vs. ε (in a table of TBCZ).

The performance of $\varepsilon = 0.01$ is considered to be equivalent to that of the 2×2 table of TBCZ, it is one point except for line from 0.1 to 0.4 in **Figure 9**. Thus, the 3×3 table of TBCZ is superior than the 2×2 table of TBCZ since this table allows superior performance tuning. If performance is valued, then a larger table is better, although this results in high-cost and increased complexity. Performance of MISEI is superior in the case of smaller Center ZERO. There is a minimum point of MISEI on the edge of out of scope.

3.3. Other considerations to TBCZ

The robust modification of the experimental PID tuning method of Ziegler Nichols could be used here. **Figure 10** shows performance MISEI of a double loop.

The FFC mix rate in the double loop case must be less than half that in the single loop case.

The decoupling [14] study is omitted in this paragraph, then refer to in reference [13].

3.4. Subconclusion

A new concept of a TBCZ with rectangular membership functions based on crisp sets, which was featured by ZERO's in the rule table like the fuzzy-like control table as one of TBC and a feed-forward control line were proposed, and simulation results are presented for a tank level control as an example. Then, superior evaluation based on MISEI and performance was obtained.

The membership functions of the proposed TBCZ were able to easily tune only terminators, which mean the size of ZERO's through the evaluation of MISEI.

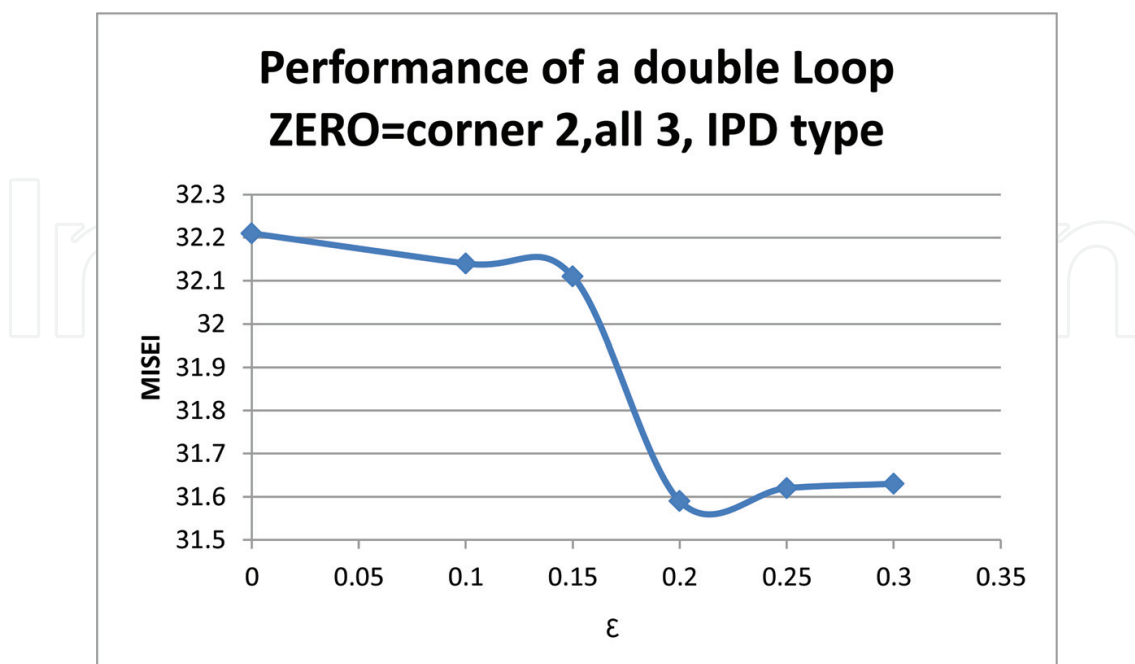


Figure 10. MISEI vs. ε (in a table of TBCZ).

Making and tuning of the controller are easier than in conventional fuzzy control because the membership functions are rectangular without common parts in crisp sets, and the only control rules are ZERO and SUMi in a 3×3 control rule table.

The development of a robust compensator of integrator for no-overshoot property is a future theme. The readers can find the literature [15] on conventional system.

4. Fuzzy decision-type optimization

It proposes a fuzzy decision-making type optimization technique in this paragraph as an example of the problem on elevators.

Wada and Kato propose an optimization technique of fuzzy rules according to the situation by using behavior acquisition based on emotional memory that uses fuzzy sets on pleasantness and unpleasantness of a robot. And the robot is made to acknowledge pleasantness and unpleasantness by using a source of light and an experiment toward a comfortable goal evading the obstacle is done [16].

The fuzzy decision-type optimization for an elevator is proposed firstly in ordinary 2D membership description [17]. In this paragraph, it is enhanced to 3D description.

The other fuzzy optimization studies [18–22] are interesting for this study.

4.1. Maximizing decision probability methods

In this paragraph, firstly, the problem of fuzzy decision-type optimization (maximization) with subjects is defined generally.

Assuming that x_1 and x_2 are fuzzy numbers, membership functions μ_1 and μ_2 are introduced according to x_1 and x_2 and λ is a scalar for λ -cut.

$$\begin{array}{ll} \underset{x \in X}{\text{maximize}} & \min\{\mu_1(x_1), \mu_2(-x_1)\} \Leftrightarrow \\ \underset{x \in X}{\text{maximize}} & \lambda \\ \text{subject to} & \alpha_1 x_1 + \beta_1 \geq \lambda, -\alpha_2 x_2 + \beta_2 \geq \lambda, x \in X \end{array} \quad (4)$$

This technique can be used for fuzzy deciding. For example, it is decided using this technique whether an “almost crowded” elevator should pass over a certain floor with “long queuing length”. These two fuzzy sets “almost crowded” and “long queuing length” are described by using fuzzy numbers of passengers in the elevators and queues in the floor.

x_1 is defined to the number of passengers ride on an elevator, and x_2 is defined to the number of queuing in an elevator lobby of a floor. An example of detail equations and measurement method of person numbers can be referred to the literature [23].

The fuzzy decision method is called to maximizing (min-max) decision because it is optimize when the product (minimum) of two membership functions is max as in **Figure 11**.

where

$$\lambda_{\max} = \max_{\{z_1^0, z_2^0\}} \min_{\{z_1^0, z_2^0\}} \{\mu(x_1), \mu(-x_2)\}$$

$$\lambda_c = \frac{1}{3} \lambda_{\max}, \quad \lambda_0 = 0 \quad (5)$$

The notation of the trapezoid membership function is described by the three terms set $[[left_terminator, center, right_terminator]]$ as same as the triangle membership function (center means the position of grade 1, and terminator means the position of grade 0) and is inserted the end point of right and left terminator by infinity mark $\infty, -\infty$ as the following G and C . Then, the product (minimum calculation) D of G and C is described, if you devise it as multiplying the scalar corresponding the max value $\mu_D(x^*)$; x^* means center of D , then you can write as follows.

$$G = [g_1, g, \infty], \quad C = [-\infty, c, c_2] \quad (6)$$

$$D = \mu_D(x^*) [g_1, x^*, c_2] \quad (7)$$

where $x^*, \mu_D(x^*)$ can be obtained easily because they are coordinate values of a cross point of two lines in the case of triangle or trapezoidal membership functions.

In multiobjective decision-making, generally it is common to narrow down to the only optimum solution by using preference function from among plural noninferior Pareto solutions, and depending on the shape of this preference function, decision maker's preference is divided into whether it is risk avoidance type, risk-oriented type, or risk neutral type.

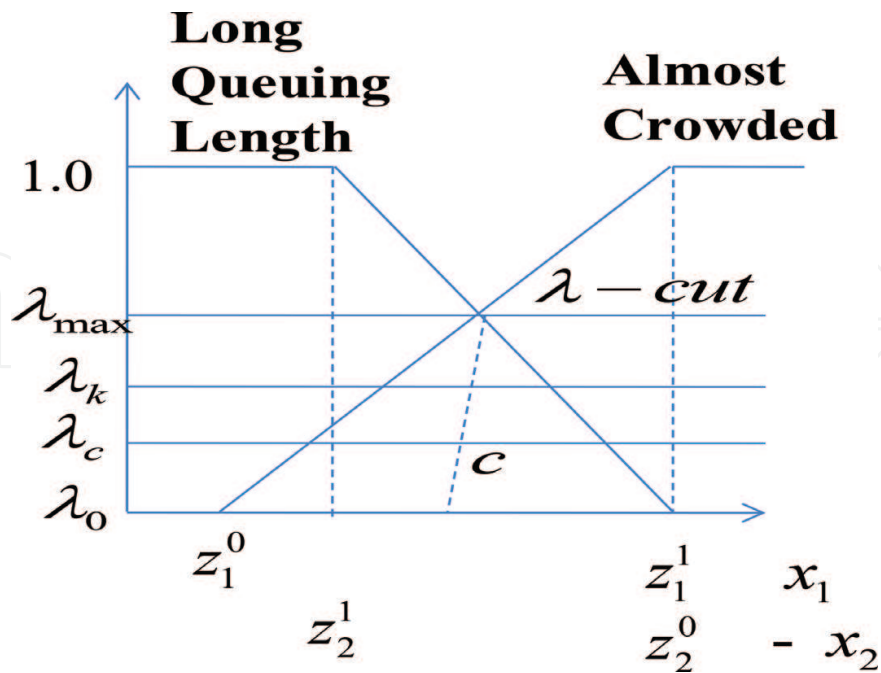


Figure 11. Membership functions of fuzzy sets “Almost crowded” and “Long Queuing Length” with a variable λ -level on fuzzy passage decision of “Maybe Pass a Waiting Floor”.

When the preference function is convex, the case is the risk avoidance type. When it is concave, the case is the risk-oriented type.

When the case has multipurpose G_i ($i = 1, \dots, n$) and numerous restrictions C_j ($j = 1, \dots, m$), their common set D is defined equally as follows.

$$D = G_1 \cap G_2 \cap \dots \cap G_n \cap C_1 \cap C_2 \cap \dots \cap C_m \quad (8)$$

When getting a minimum of the respective membership function μ_{G_i} , μ_{C_j} , the membership function of D is found as μ_D .

$$\mu_D = \mu_{G_1} \wedge \mu_{G_2} \wedge \dots \wedge \mu_{G_n} \wedge \mu_{C_1} \wedge \mu_{C_2} \wedge \dots \wedge \mu_{C_m} \quad (9)$$

When adopting notation like Eq. (7), it can be written as follows.

$$D = \mu_D(x^*) [\{ \min x, s.t., \mu_D(x) = 0 \}, x^*, \{ \max x, s.t., \mu_D(x) = 0 \}] \quad (10)$$

Here, about $(x^*, \mu_D(x^*))$, because they are the coordinates of an intersection point of two straight lines, they can be found easily when finding the set of which D is composed. About both end points, the finding method is like the same.

4.2. Expendability of the proposed method

4.2.1. 3D description

Figure 11 with only a front view becomes **Figure 12** with a front view, a side view and an over view when elevator passenger number x_1 and queuing line number x_2 is selected as independent logically double axis if three view description is adopted in this fuzzy optimization. This change may be increase possibility of fuzzy optimization approach.

The following **Figure 12** comes next **Figure 13** not making the independent double axis of regular axis and reverse axis like **Figure 11** but making psychological one axis by describing variable X_3 (the underside is unpleasant and the upper side is pleasant) in addition to physical two axis by describing variables X_1 and X_2 .

Here, "Almost Crowded" and "Long Queuing Length" are unequality conditions and "Passenger pleasure" is an objective function. It is the fuzzy decision-making method that "pass of an elevator to a floor" is done by maximizing decision method using min-max of three member ship functions (a blue point by minimax method). Whereas it is the crisp decision-making that the decision-making is done at the grey point of which pleasant degree is higher slightly in grey area which grade of all membership functions are one. It's a problem that the comfort level of the waiting line isn't considered against the comfort level of the passenger in this fuzzy decision-making area. Though the comfort level of the passenger is sacrificed, it can be said that the comfort level of the waiting line is considered in the crisp decision-making area.

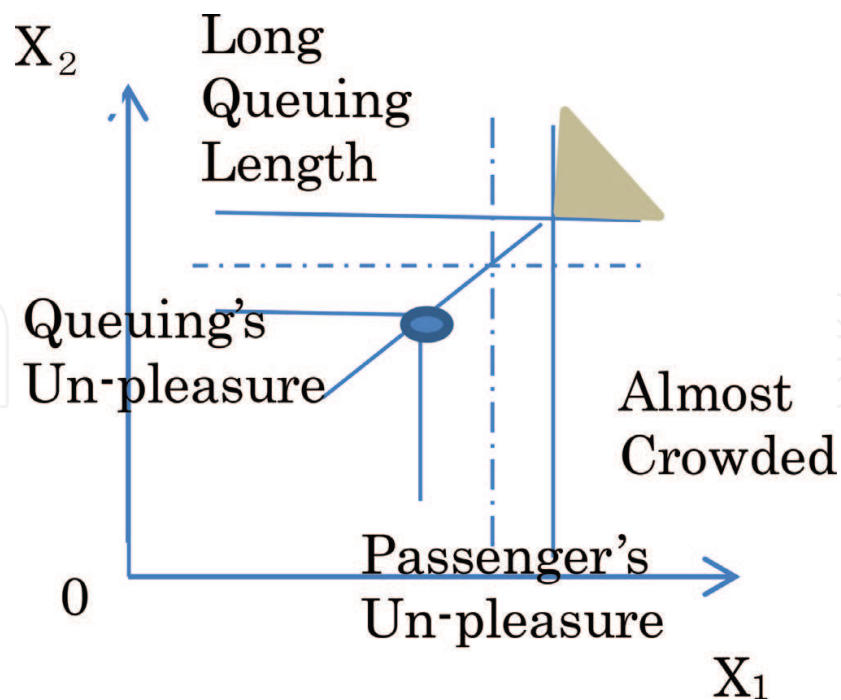


Figure 12. Over view plan on passengers' un-pleasure caused by almost crowded and queuing's unpleasure caused by long queuing length for a fuzzy optimization problem.

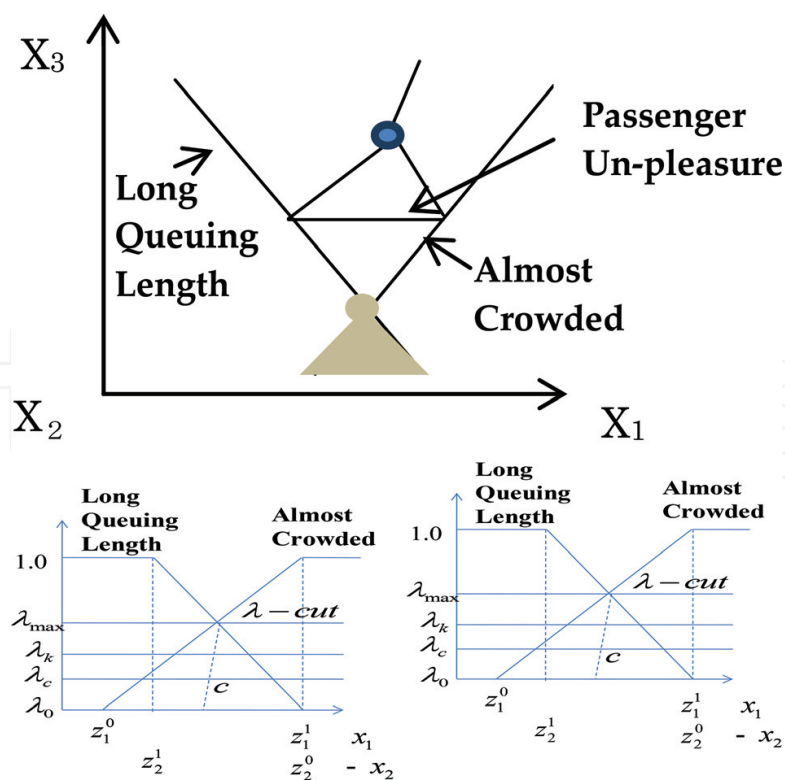


Figure 13. Three side plan in physics and psychological crossing at right angle axis of two dimensions on a fuzzy optimization problem.

The three side of plans (over view, front view and side view) are described like **Figure 13** instead of the above plan like **Figure 12** when X_2 and X_3 out of the three axes are changed like **Figure 13**. Usually, only front view plan is indicated as **Figure 11** and others are omitted for economy and maximum decision policy. Here, overview plan is also indicated because minimum decision policy in overview plan is better than the maximum decision policy as understand if you see.

These plans permit two kinds of optimization methods, minimizing in overview plan and maximizing in front plan.

4.2.2. Search on overview plan

For searching minimum point on overview plan less than grade 1 such as **Figure 14**, mobile method of freely writing lines and circles like dance on the plane in order to evaluate grade values using the following equations with the rotation matrix is proposed here. This is a discrete mobile model which generates left and right double velocities v_L and v_R of interval d .

$$v_G(k) = v_L(k) + v_R(k); r = 0.5d \quad (11)$$

$$\omega_G(k) = \frac{1}{r} (|v_R(k)| - |v_L(k)|) \quad (12)$$

$$\Delta\theta_G(k) = h\omega_G(k); \theta_G(0) = \theta_{G0} \quad (13)$$

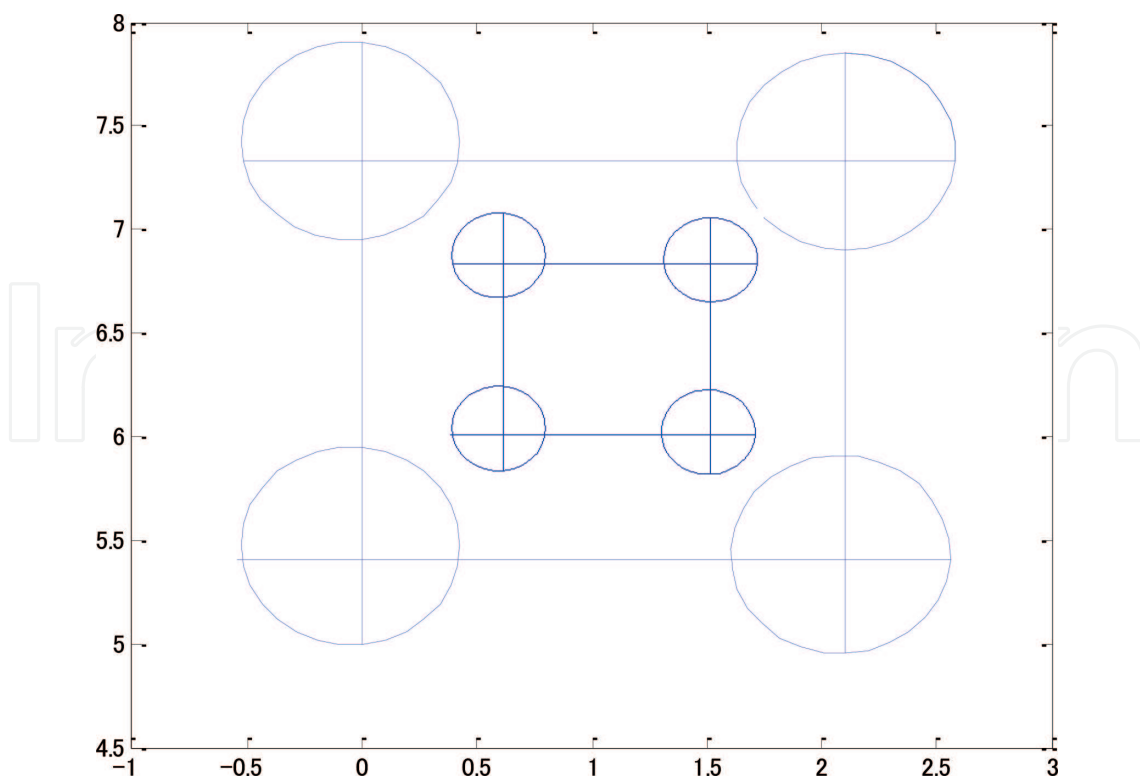


Figure 14. An example pattern of searched course for reduced repeat by a discrete mobile agent.

$$\theta_G(k+1) = \theta_G(k) + \Delta\theta_G(k) \quad (14)$$

$$v_G(k+1) = \begin{bmatrix} \cos \Delta\theta_G(k) & -\sin \Delta\theta_G(k) \\ \sin \Delta\theta_G(k) & \cos \Delta\theta_G(k) \end{bmatrix} v_G(k) \quad (15)$$

$$p_G(k+1) = p_G(k) + hv_G(k+1); p_G(0) = p_{G0} \quad (16)$$

where suffix G means center of the mobile object, suffix L means left, suffix R means right, p means position, ω means angle velocity, θ means angle from x -axis, and h means sample time.

Figure 14 shows an example pattern by a mobile agent and the reduced inner copy for design of searched course in the plane.

Addition of inverse kinematics will make easier the process of drawing figures filled in the canvas.

4.3. Action mode, effective, influence, yield analysis (AMEIYA)

A table on action mode effect, influence, yield analysis (AMEIYA) may be obtained by imitating reasoning methods from left-column action mode to right-column effect, influence and yield things.

A Q&A table used to obtain the above table on AMEIYA may also be made by readers referred to Ref. [23].

In the future, new strategic systems for fuzzy optimization control on elevators will expect to born from these tables.

5. Conclusions

In this chapter, a fuzzy optimization control system by combining fuzzy decision-type optimization parts and a fuzzy-like table base PID controller parts was proposed separately instead of the conventional united crisp optimization control system.

Double future themes on fuzzy optimization, which may be used in fuzzy optimization control, were also presented. One is three side plans with an overview plan, which omitted conventional studies. The other is a new search method on a plane using a new simple discrete mobile model, which generates left and right double vector velocities.

These two separate parts are expected to be united and to be evaluated. Moreover, optimization based on fuzzy numbers and calculations may be used for absorbing uncertainty of sensors output and digitalizing of input to computer.

Moreover, some idea of strategic systems on fuzzy optimization control was provided for readers in the future.

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