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# Predictive Fuzzy Control and its Application for Automatic Container Crane Operation System

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**ABSTRACT:** A predictive fuzzy-logic control that uses rules coached in terms of desired states is applied to automatic container crane operation (ACO) systems.

The predictive fuzzy-logic controller selects the most likely control command based on both a prediction of control results and direct evaluation of the control objectives. The control rules are described as follows; "If ( u is C → x is A and y is B ) then u is C".

The proposed fuzzy controller is applied to ACO systems for controlling container cranes with a focus on four principal performance characteristics: the evaluation of safety, stop-gap accuracy, minimum container sway and carrying time. The results of a field experiment using a real container crane with the ACO system confirm that an un-skilled operator can handling more than 30 containers every hour which is the same degree as is possible with a skilled operator.

**KEY WORDS:** fuzzy control, container crane, automatic crane operation, predictive control

## 1. Introduction

In recent years, automatic controllers using a micro-computer instead of a human operator have been developed for plants, transportation systems and so on. In many cases, a computer control gives quick response and accurate control, but inferior quality of control than a skilled operator. A fuzzy logic[1] control method which can make up an algorithm from control know-how of a skilled operator by fuzzy sets, is proposed by Mamdani[2], and applied to a cement kiln[3], a water treatment[4] and so on[5]. By these controllers, operations considering the desired states of a system are difficult.

To solve this problem, a predictive fuzzy controller which predicts the result of each candidate control command and selects the most likely control rule based on a skilled human operator's experience have proposed.[6] The predictive fuzzy controller is applied to automatic train operation systems, by which a train can be started, kept to a limited speed and stopped at a target position of a station. This controller is currently being applied to Sendai-city subway system's automatic train operation system.[7]

Container cranes for handling the cargos between ships and wharves must operate efficiently and smoothly to meet the increasing size and speed of container ships as well as the growing volume of containerized transportation.[8] Presenting, most cranes are still operated by skilled human operators.

Therefore, an automatic container crane operation (ACO) system is in strong demand. One conventional method proposed the incorporation of a linearlized control algorithm with target velocity patterns of the trolley and wire rope on the crane.[9] Controlling the crane for practical use is difficult, however, because it is very hard to realize container position and sway control exactly using only trolley velocity control.

This paper explains the predictive fuzzy controller and the ACO controller developed based on the previously reported controller. Field tests using a real crane have been conducted to assess the efficiency of the developed controller with that of human crane operation.

## 2. Application of Fuzzy Logic to Control

### 2.1 Situation of fuzzy control

A fuzzy logic control aimes to realize a skilled operator's intellectual action using a computer. There are proposed two approaches based on human consideration process as follows; (1)Stare evaluate fuzzy control: A control command is decided from experiences and states of the present time, (2) Predictive fuzzy control : A control command is selected from the control command will be satisfy desired states and objectives.

There are situated at Fig.1 which has two axies, complicacy of system and control purposes. The state evaluate fuzzy control is suitable for a complex system which is difficult to modeling. But in the control rules, control objectives are not appered. The predictive fuzzy control predict objectives in future and/or the present time, and evaluate these multi-objectives. The prediction of these objectives are used partial experience modeles. These two fuzzy control scheme are not contrary, and able to conbined effectively according as application to approach for a control of skilled human operator.

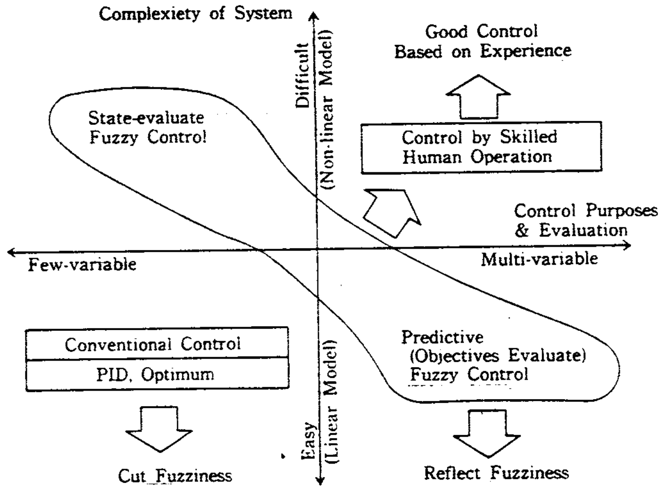



Fig.1 Situation of fuzzy control

2.2 States evaluate fuzzy control

The fuzzy control applied to a cement kiln by Holmblad[4] decides a control action $u^*$ from the set of control rules Ri, which is described as "If x is Ai and Bi, then u is Ui". This fuzzy control evaluates the system state, which is described as "if part: X is A' and Y is B'", and decides $u^*$ from these values. "If the temperature is high and the pressure is slightly high, then the fuel is decrease." is a typical example of process control rules.

2.3 Predictive (objectives evaluation) fuzzy control[6,7]

A skilled human operator has extensive experience through many experiments with the system's operation. And he can perform high-quality control satisfying the system objectives. However, the above-mentioned fuzzy control cannot evaluate the system objectives.

In order to overcome this problem the predictive fuzzy controller which decides a control action $u^*$ from the objectives evaluation of the control results by the control actions has been proposed. The algorithm of the predictive fuzzy controller is as follows:

In the predictive fuzzy controller, a value of control command is limited to a discrete number u (u = C1,C2,...,Cn), and x and y are assumed to be performance indices for control. Evaluations of x and y, for example "good" or "bad", are defined by fuzzy sets which are characterized by membership functions $\mu Ai(x)$, $\mu Bi(y)$. A fuzzy controller periodically evaluates the efficiency of linguistic control rules such as " If the performance index x is Ai and index y is Bi, when a control command u is decided to be Ci at this time, then this control rule is selected and the control command Ci is decided for output of the controller ". The above linguistic control rule is formulated as follows:

Ri: " If (u is Ci — x is Ai and y is Bi ) then u is Ci "

"When the control notch is not changed, if the train stops in the predetermined allowance zone, then the control notch is not changed." is a typical example of train operation rules. Fig.2 illustrates graphically the control sequence.

The process to produce the fuzzy logic controller is as follows.

(step-1) Describe human operator's strategies of the system operation

(step-2) Define the meaning of linguistic performance indices

(step-3) Define models to predict the results of an operation

(step-4) Convert the linguistic human operator's strategies into the predictive fuzzy control rules

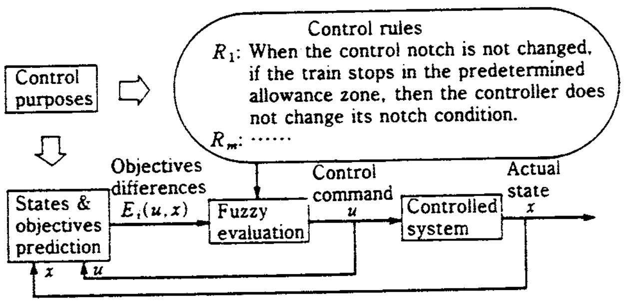



Fig.2 Predictive fuzzy control sequence[7)]

3. Outline of Container Crane Operation

Recently, almost all container cranes are still operated by skilled human operators. The operations themselves are divided into two simultaneous functions. One is the trolley operation, which commands the trolley target velocity, and moves and stops the trolley at the pre-determined position. The other is the wire rope operation, which commands the container hoisting or lowering target velocity, and regulates the rope length.

As mentioned earlier, the purpose of this paper is to report on an ACO system which realizes crane operation similar to that of a skilled human. As was shown in Fig. 3, human experts operate cranes by evaluating various performance indices such as safety, stop gap, maintained sway and carrying time. Factors affecting operations are the wind, cargo weight, the tide, and so on.

4. Human Crane Operator Strategies

As the first step in applying the fuzzy logic controller to crane operation, the actual operations performed by skilled operators coupled with their accumulated knowledge must be studied. Human container crane operation strategies are described below.

4.1 Operation parameter and container course decisions

Before carrying a cargo from the start point to the target point, the operator must know the obstruction sections and their heights (danger zone) along the way which the cargo must cross safely, based on the ship body structure and on the state of containers piled on the deck. Such operation parameters as maximum trolley speed are decided from the traveling distance and the cargo weight.

4.2 Trolley and wire rope operations

(1) Trolley operation

Trolley movement is divided into the seven domains of, start (P0), acceleration (P1), constant speed control (P2), deceleration (P3), stop (P4), correcting (inching) (P5), and lowering (P6). Furthermore, the operation is divided into two function levels. One is the decision level, in which the present domain of the trolley operation is decided. The other is the activation level, in which the target trolley velocity and the acceleration force are commanded.

(a) Trolley decision level: The domain timing changes are affected by initial sway, the wind and the rope length, which are operated independent of the trolley. These timing changes are given as 7 decision rules. An example of the decision rule is descrived as follows.

(T3) In the constant speed control domain, when the deceleration control is started under these trolley speed, trolley position and rope length conditions, if the trolley is stopped beyond the target position at the small maintained sway, then the deceleration control is started. (P2 → P3)

(b) Trolley activation level: The practice function is determined from the above-mentioned trolley decision level. At this level, each domain is practiced as 7 activation rules. An example of the rules is as follows.

(C3) In the constant speed control domain (P2), the trolley speed is held at the maximum trolley speed.

(2) Wire rope operation

The wire rope operation is similarly divided into two function levels. One is the decision level, in which the target rope length is decided. The other is the activation level, in which the target rope velocity is commanded.

(a) Rope decision level : At this level, the hoisting or lowering of cargo is determined from the cargo (trolley) position. An example of the rules is as follows.

(R2) In the danger zone, the rope length is held at the safe rope length.

(b) Rope activation level : At this level, the target rope velocity is commanded from the present rope length and the determined target rope length, taking the hoist motor capability into consideration.

## 5. Automatic Crane Operation System by Predictive Fuzzy Control

### 5.1 Fuzzy Performance Index Sets

In the second applicational step of the fuzzy logic controller, the meaning of linguistic performance indices have to be defined. From the above-mentioned experience rule, fuzzy performance index sets are defined. (Fig. 3)

(1) Safety performance indices (S) are Height danger (HD), Height safe (HS), Danger zone (XD), Hoisting zone (XC) and Lowering zone (XE).

(2) Stop-gap performance indices (G) are Beyond-target position (XT), Good stop (XG), Badstop (XB) and Zero trolley speed (VZ).

(3) Maintained sway performance indices (W) are Acceleration end (AE), Deceleration end (DE), High trolley speed (VM) and Low trolley speed (VL).

(4) Carrying time performance indices (P) are Start (P0), Acceleration (P1), Constant speed control (P2), Deceleration (P3), Stop (P4), Correcting (P5), Lowering (P6) and Before lowering (<P6).

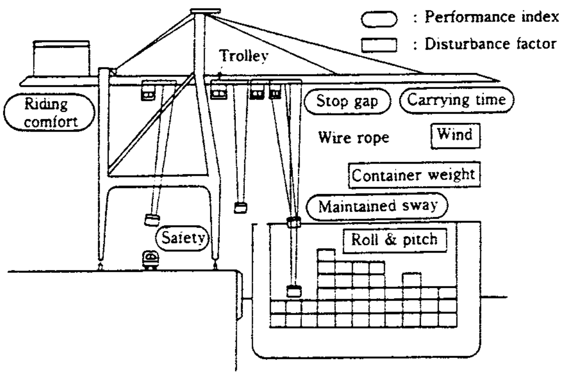



Fig.3 Container crane operation[10)]

### 5.2 Predictive Model

Predictive models for predicting results for index evaluation are defined in the third step. These models enable (1) height clearance calculation and (2) stop position prediction.

### 5.3 Fuzzy Control Rules

In the final step, the above-mentioned rules of operational experience are converted into fuzzy control rules. For example, each phrase of the "experience trolley decision rule" (T3) is rewritten as follows.

· In the constant speed control domain → P is P2.
· The deceleration control is started → t3 = t and t4 = t + Td.
· The trolley is stopped beyond target position → G is XT.
· In the small maintained sway → Fd = Fm,

where t3, t4 are start and end times of the deceleration control(P3), t is present time, Fd is deceleration force, and Fm is a deceleration or acceleration force of a non-swaying load.

These phrases can be summarized as follows.

(T3) If ( P is P2 and (t3 = t and t4 = t + Td and Fd = Fm → G is XT ) ) then t3 = t and t4 = t + Td and Fd = Fm.

The right half of Fig.4 shows these fuzzy rules in shorten form.

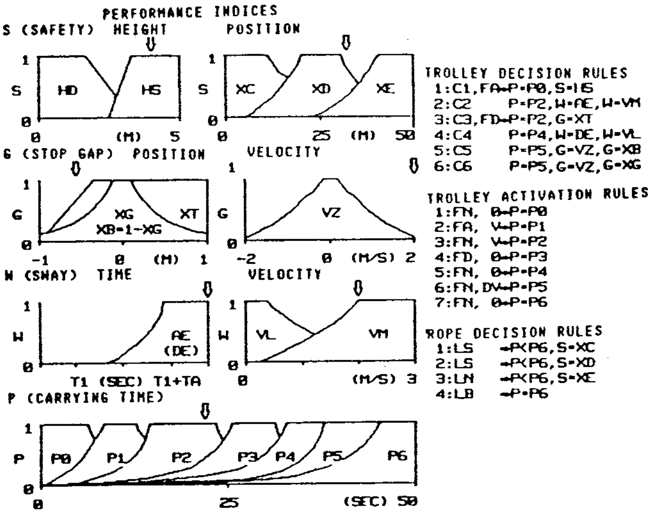



Fig.4 Performance indices and control rules

### 5.3 Realization of fuzzy ACO controller

Figure 5 shows a configuration of ACO system and a container crane in Port of Kitakyusyu-city which is used for field test. The ACO system consists of two controllers with 16-bit microcomputers (HD-68000). They are conected by communication line and watch an accident each other.

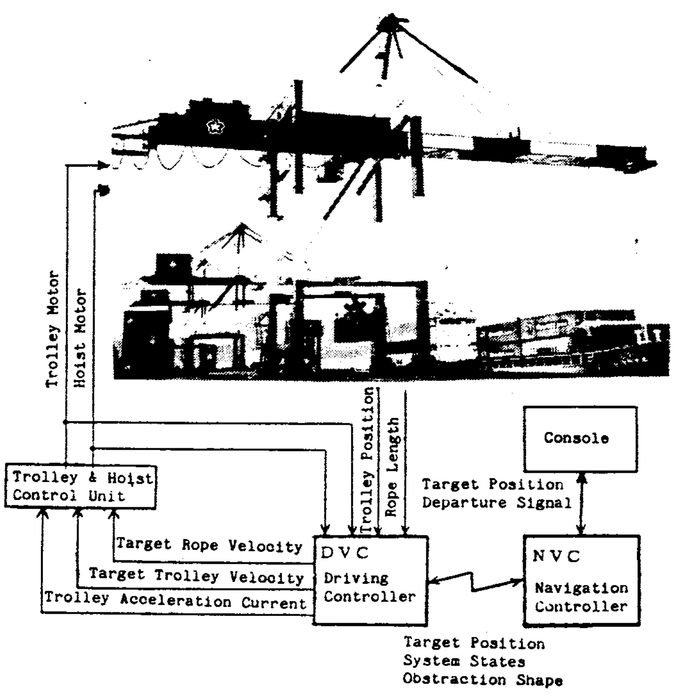



Fig.5 Configuration of ACO and applied container crane Trolley & Hoist

(1) NVC (Navigation Controller)

The NVC which is in an operator room, has a shape of the ship and states of pailed container. A target position and depature signal is entered from a console by an operator. The NVC communicates the target position, obstraction shape and others to the DVC.

(2) DVC (Driving Controller)

The DVC which is in a machine room commands a target trolley velocity, a trolley acceleration current and a target wire rope velocity from a trolley position and a rope length which are detected by rotary encoders, based on the above-mentioned fuzzy control rules. Figure 6 shows a photograph of the DVC.

## 6. Field Test of a Real Container Crane

A field test was performed using an actual container crane as shown in Fig.5. The crane has a height of about 30 m, an outreach of 38.0 m, a span of 16 m and a maximum trolley speed of 125 m/min.

In the field test, a container and a spreder (35.3 ton) travel 32 m across obstractions 15 m high. Figure 7 summarizes the field test in which the spreder is moved from a center of ship to a wharf. The result of field test by a human operator who has the license but un-skill to this crane, shows the average of carrying time is about 62 seconds with large stopping error. So, to finish the operation, he need more a moment.

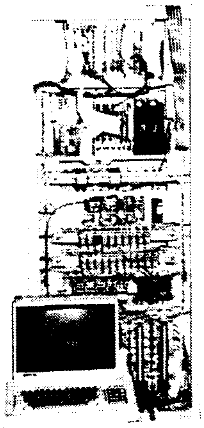


Fig.6 Developed Fuzzy-ACO DVC (Driving controller)

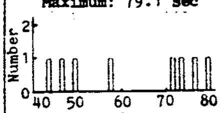
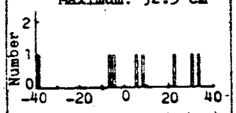
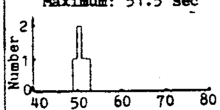
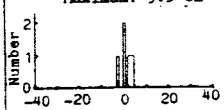
| Item / Method | Carrying Time | Stop Gap (Error) | Maintained Sway |
|---|---|---|---|
| Manual Operation | Mean : 61.7 sec<br>Minimum: 43.4 sec<br>Maximum: 79.1 sec<br><br>Carrying Time (sec) | Mean : 5.7 cm<br>Minimum: -39.0 cm<br>Maximum: 32.5 cm<br><br>Stop Gap (Error) (cm) | Mean 14.0 cm |
| With Fuzzy Control | Mean : 50.3 sec<br>Minimum: 48.5 sec<br>Maximum: 51.5 sec<br><br>Carrying Time (sec) | Mean : 0.5 cm<br>Minimum: -3.0 cm<br>Maximum: 3.5 cm<br><br>Stop Gap (Error) (cm) | Mean 11.5 cm |

Fig.7 Summary of real crane field test results
(From a ship hold to a wharf)

The result of field test using the Fuzzy-ACO controller shows that the Fuzzy-ACO is cappable of carrying a cargo at a constant optimum time (the mean is 50.3 sec) and accurate stop (within ± 3.5 cm). The other result of feld test that the container is carried from the wharf to the center of ship shows that the mean carrying time is 41.3 seconds. So, a cycle time is 91.6 seconds. This means that a total of 39 containers can be loaded every hour. Considering changes of obstraction and a target hold position, however, the actual cargo handling ability is about 30 containers every hour.

To summarize the field test results, with Fuzzy-ACO operation, an un-skilled operator can operate the container crane as skillfully as a veteran operator.

## 7. Conclusion

A predictive fuzzy controller was developed and has been applied to automatic container crane operation (ACO). The proposed Fuzzy-ACO controller was installed in microcomputers, and field tests were performed using a real container crane. The field tests indicate two principal results. First, the Fuzzy-ACO controller is fully capable of operating a crane as safely, accurately and skillfully as a skilled human operator. Second, even an unskilled operater can handle a crane as efficiently as a skillful operator using the Fuzzy-ACO controller.


## 8. Acknowledgements

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