Soft Target Based Intelligent Controller for a System with Dynamic Restriction

Chen Yougen
Doctoral Program in Graduate School of
System and Information Engineering
University of Tsukuba
Ibaraki 305-8573, JAPAN
E-mail: chen_yougen@edu.esys.tsukuba.ac.jp

Seiji Yasunobu
Department of Intelligent Interaction Technologies
University of Tsukuba
Ibaraki 305-8573, JAPAN
E-mail: yasunobu@iit.tsukuba.ac.jp

***Abstract*— Human's action decision is based on wide targets and can respond flexibly under different situations. However, flexible adaptation to the situation with dynamic restriction is difficult but important in autonomous control system. In this paper, a method of developing intelligent controller based on soft target is proposed. Here, soft target is defined as a target set which includes many target elements with different satisfaction grade and is converted into target setting knowledge by soft computing. And this controller is applied to the control of inverted pendulum system with dynamic restriction to realize situation self-adaptation and target self-regulation in the process of swinging up and stabilization. The simulation results show the validity of the method.**

I. Introduction

Human have a remarkable capability to perform a wide variety of physical and mental tasks without any measurements and any computations. Underlying this capability is brain's crucial ability to manipulate perceptions and remarkable capability to operate on and reason with, perception-based information which are intrinsically vague, imprecise and fuzzy [1]. Human's action decision is based on wide targets and can self-regulate the target with the changing of restriction to respond flexibly under different situations.

In many control systems, the situations always change with the restriction conditions or disturbances. Responding flexibly to the dynamic environment change in the external world like human is very necessary but difficult for an autonomous control system. A conventional control method usually sets the only and the best control target beforehand based on the control purpose. Thus when restriction condition changed, recalculation of new target is necessary if the best target becomes unavailable because of the restriction or disturbance. And the recalculation is costly and time lagged.

Therefore, the problem that autonomous control systems respond a changing restriction flexibly like human is considered in this paper. We proposed a method of developing an intelligent controller based on soft target to realize a situation self-adaptation and target self-regulation system with dynamic restriction.

II. Soft target control method

Since human's action decisions need not any precise measurements and calculations, how can they control a system flexibly even with dynamic changing situation? The reason is that they control the system according to its internal characteristics and the external restrictions synchronously, their decisions are based on wide targets and the best alternative target is selected real-timely based on experiences by predicting and evaluating the state of the object with taking dynamic restriction into account. The wide targets can be regarded as a "soft target" set and the best alternative is adjusted dynamically with the changing of restriction.

Therefore, we proposed the concept of soft target based on which an intelligent controller can be constructed and applied it to the control of inverted pendulum system with changing restriction positions.

A. Outline of soft target

In this paper, soft target is defined as a target set and is converted into target setting knowledge by soft computing. It is constructed by fuzzy logic based on the preset target and restriction information, and can be expressed as a control target set defined by fuzzy set, which includes many alternative candidates. Each candidate has its membership value defined as satisfaction grade in the range from zero to one [2].

It is expressible as shown in Fig.1, and can be expressed by the membership function of enumeration type.

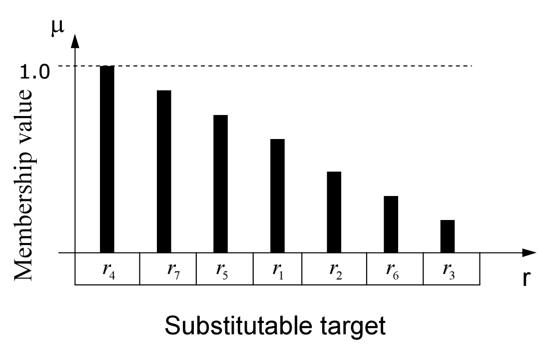

Fig. 1. The Soft Target

The total set of the target is assumed as R. Soft target $\widetilde{T_n}$ assumed to be a control target can be defined by the following expression in state c_n of the object.

$$\widetilde{T_n} = \int_R \mu_{\widetilde{T_n}}(r_i)/r_i, \qquad r_i \in R. \tag{1}$$

Here, $\widetilde{T_n}$ is the soft target set and $\mu_{\widetilde{T_n}}(r_i)$ is the membership value of alternative r_i corresponding with the state c_n.

As shown in Fig.2, target setting knowledge can be expressed as set cluster which correspond with different restrictions. According to different current state c_n (a ~ f), the target is set as $\widetilde{T_n}$ (a ~ f) respectively. Once the target is set, it is possible for the system to select the best alternative candidate instruction corresponding with one of the substitutable target element r_i by predictive fuzzy control method [3].

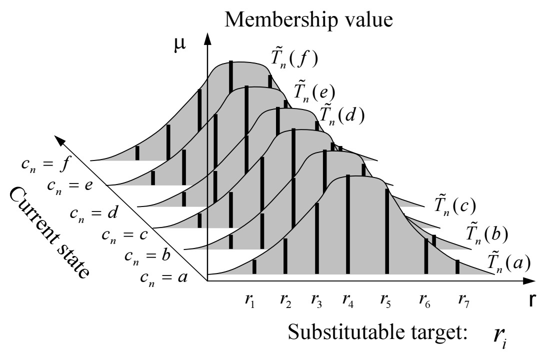

Fig. 2. Target Setting Knowledge

By using soft target, it is possible to construct an intelligent controller for a system with dynamic restriction to realize the restriction self-adaptation and target self-regulation without recalculation of new target.

B. Intelligent control system design based on soft target

The system's structure based on soft target can be outlined as shown in Fig.3. It is composed of three parts: state detecting part, soft target setting part and decision making part [4][5].

1) Detector part: This part is detecting the state variables and the restriction information, judging the attainment degree to the preset target and the contact degree to the restriction. When the restriction makes it difficult to reach the preset target, the target setting instruction is outputted to the soft target setting part.

2) Soft target setting part: When target setting instruction is received, the soft target setting part sets new target based on the soft target set according to the current state from the acquired target setting knowledge based the preset target and restriction information in advance.

3) Control decision part: In this part, the control decision is made as following process. Firstly, each element of soft target is assumed as the control target, and the operation instruction candidate to each target is calculated. Next, the future state of controlled object is foreseen by using all the

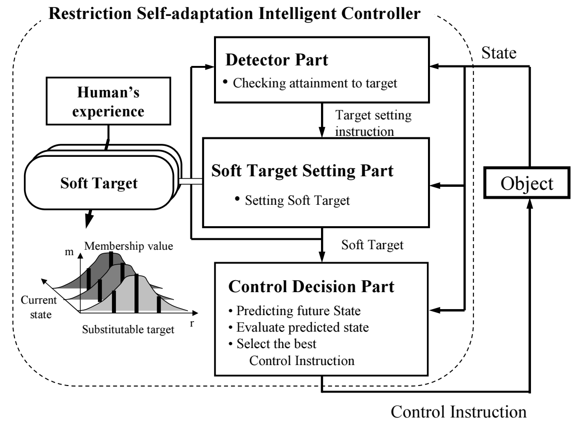

Fig. 3. Outline of the Proposed System Based on Soft Target

operation instruction candidates in parallel. Then the future state is evaluated by fuzzy inference, and the evaluation value of the operation instruction candidate is calculated. Lastly, the operation instruction candidate with the highest evaluation value is selected and given to the object as a control instruction.

These operations are repeated in the whole control process. Thus, the intelligent control of system based on soft target is realized.

III. Application to Invented Pendulum System with Dynamic Restriction

As a typical nonlinear system, the pendulum system is widely used for researches of control. In this research, we take the dynamic changing restriction into consideration to construct the pendulum intelligent controller based on soft target.

A. Characteristic of inverted pendulum

The model of the inverted pendulum is shown in Fig.4, and its parameters are listed in Table I.

The equations of motion are shown as below.

$$(M+m)\ddot{x} - ml\sin\theta\cdot\dot{\theta}^2 + ml\cos\theta\cdot\ddot{\theta} + F\dot{x} = au \tag{2}$$

$$(J+ml^2)\ddot{\theta} + c\dot{\theta} - mgl\sin\theta + ml\cos\theta\cdot\ddot{x} = 0 \tag{3}$$

Here, position of cart $x \in (-x_R, x_R)$. So when the restriction x_R is changed, the moving possible position range of cart

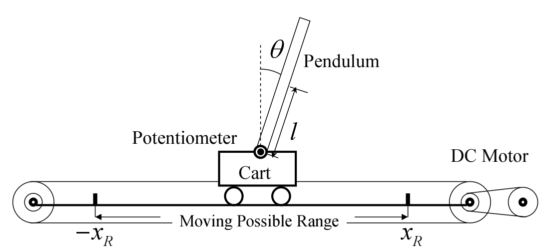

Fig. 4. Model of Inverted Pendulum

TABLE I
PARAMETERS OF INVERTED PENDULUM

$x[m]$	:	Position of cart
$M[Kg]$	:	Mass of cart
$F[Kg/s]$	:	viscous friction coefficient
$u[V]$	:	Input voltage of amplifier
$a[N/V]$	:	Gain of torque
$l[m]$	:	Half length of pendulum
$\theta[rad]$	:	Angle from vertical axis of rail
$m[Kg]$	:	Mass of pendulum
$J[Kg*m^2]$	:	Moment inertia of pendulum
$c[Kg*m^2/s]$	:	Viscous friction coefficient of axis
$g[m/s^2]$	:	Acceleration due to gravity
$x_R[m]$	:	Right restriction position
$-x_R[m]$	:	Left restriction position

is changed too. Thus, we have to control the cart position flexibly so that it moves in the allowable range in the process of swinging up and stabilization.

B. Control strategy of inverted pendulum

The control strategy of inverted pendulum can be acquired by human as moving the cart left and right.

When the pendulum is about in the upside-down state, operators enlarge the angle of pendulum to swing up it by moving the cart left and right with taking the restriction position into account. They decide the motor's voltage and rotary direction by predicting the cart position and the maximal angle of pendulum. When the cart is close to the restriction position, the contrary voltage is outputted to ensure the cart in the safe range with the moving of restriction at all times. Thus, the relationship between the angle and the power moving the cart is studied and can be changed into swinging up knowledge as experiences based on which the pendulum can be swung up to the upright state.

Once the pendulum is about upright, the cart is moved in the direction that can maintain the pendulum stable in the upright state exactly until the motor voltage is close to 0. Moreover, if the position of the cart is different from the target position of the cart, the cart is push to the direction of the target position to approach the preset target while maintaining the stabilization of pendulum. And if the preset target becomes out the range of restriction with the moving of restriction position, the cart is set tracing the restriction position automatically by target self-regulation to maintain it is at the nearest position to the preset target.

After acquired these experiences of swinging up and stabilization, we can construct the intelligent controller based on them.

C. Outline of system

Until now, many intelligent methods have been applied to the pendulum system, such as the evolutionary control, predictive fuzzy control and adaptive fuzzy control [6][7]. But in all of them, the restriction position is not took into account for the controller. In order to ensure the safety, the pendulum had to be always pushed to the middle of the rail to begin swinging up. In this research, we constructed an intelligent controller based on soft target with regard to dynamic changing restriction to realize the swing up at any position and cart position self-regulation either in the process of swinging up or stabilization.

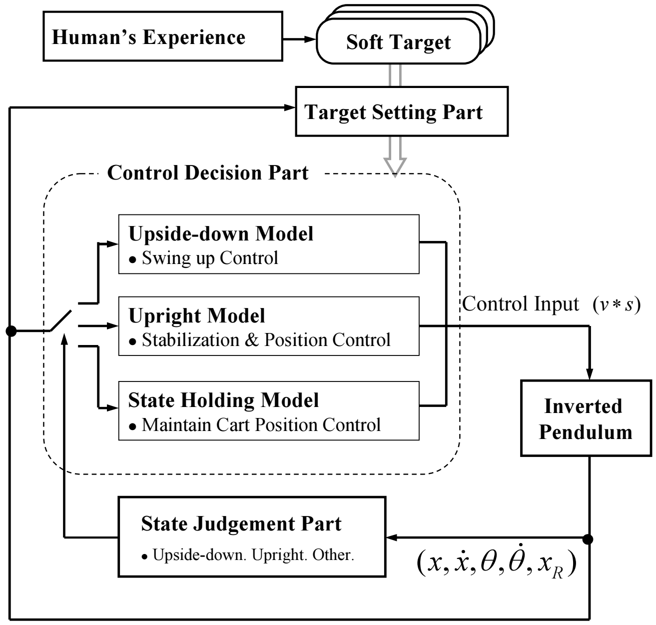

Fig. 5. Outline of the Control System

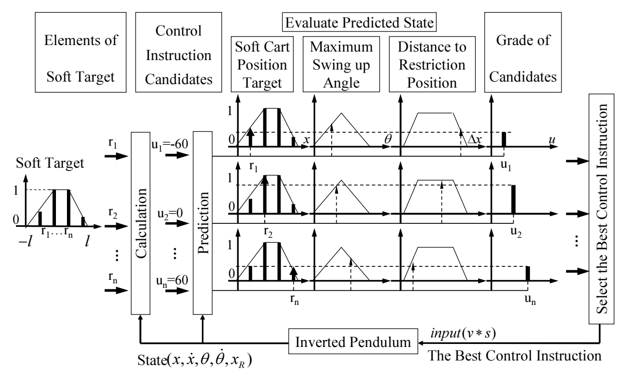

Fig. 6. Detail of the Swinging up Control Part

We constructed the intelligent control system of inverted pendulum based on soft target and the acquired experiences as shown in Fig.5. The setting of soft target is integrated into the control decision part. The system is composed of state judging part, swing up control part, stabilization & position control part and maintaining cart position control part.

1) State Judging Part: The state is judged according to the angle and angle velocity of pendulum as follows.

- The pendulum is in the upside-down state (the angle of pendulum θ is about π).
- The pendulum is about upright (θ is small [within $\pm 0.5rad$] & $\dot{\theta}$ is middle [within $\pm 10rad/s$]).
- Other than the above-mentioned.

After judging the state, the different control model is selected according to the current state.

2) Swing up Control Part: The swing up control is done when the pendulum is about in the upside-down state. It is necessary to consider the cart moving in the restriction position while the pendulum swinging up without regard to the preset target in this process. In this part, the value of the control input is determined by the predictive fuzzy control. The detail of swing up control part is shown in Fig.6. Here, the control input is defined as the length of time ($inputtime$)to give motor a constant voltage, the value of which is calculated by the following formula. The cart is moved right and left by controlling the sign of motor voltage.

$$input = 10[v] \times inputtime[s] \tag{4}$$

Firstly, the maximal swing up angle of pendulum and cart's position are predicted at the angle predict fuzzy model (shown as Table II and Fig.7) acquired from human experiences and position order model respectively by using all the candidates corresponding with the soft target set.

TABLE II
ANGLE PREDICTIVE MODEL

$\theta_{max}(rad)$		$\omega(rad/sec)$						
		NB	NM	NS	ZO	PS	PM	PB
$Input$ $time$	NB	0.1	0.8	2.0	2.5	2.8	3.0	3.1
	NM	1.0	1.5	2.7	2.8	2.9	3.2	3.2
	NS	2.1	2.1	3.0	2.9	3.0	3.4	3.5
	ZO	2.4	2.2	3.1	3.1	3.1	3.5	3.8
	PS	2.7	2.9	3.1	3.2	3.3	4.3	4.8
	PM	3.0	3.0	3.5	3.4	4.3	5.2	5.7
	PB	3.1	3.1	4.0	3.6	5.0	6.0	6.2

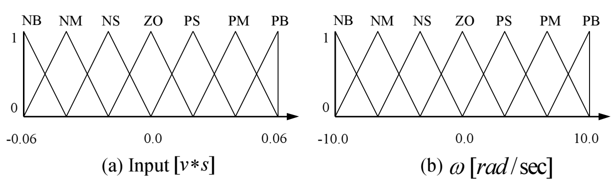

Fig. 7. Membership Function of $\theta_{\max}$

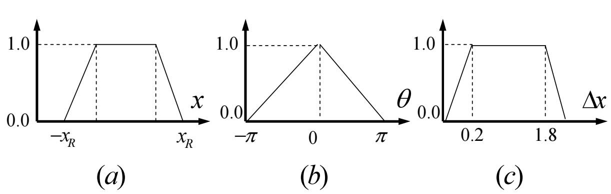

Fig. 8. Membership Function of Swing up

Then, the swing up control part carries out the multipurpose fuzzy evaluation for the predicted maximum swing up angle of pendulum, cart's position and the minimum distance from cart position to the left and right restriction position. It calculates the evaluation values of all candidates and selects the candidate with the highest evaluation value as a control instruction.

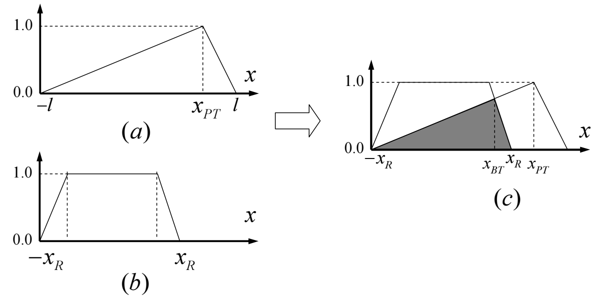

Fig. 9. Membership Function of Stabilization

The membership functions for fuzzy multipurpose evaluation is shown in Fig.8. (a) is the soft target set of cart position, (b) is the angle evaluation function, (c) is the evaluation function of distance to the restriction position. As the restriction position is changing dynamically, the position evaluation function is a dynamic function, too.

3) Stabilization & Position Control Part: The stabilization & position control part is executed when the pendulum is about upright to make the pendulum be upright and approach to the preset target when the preset target is in the range of restriction or to the self-regulation target when the preset target is out the range of restriction. The control input is determined by the fuzzy inference which uses the predicted cart position and the restriction position as shown in Fig.9. Here, x_{PT} is the preset target position of cart after stabilization, x_{BT} is the best alternative selected as control target which has the highest grade. (a) is the acquired target set of cart position based on preset target, (b) is the possible position set of cart with considering restriction $\pm x_R$, and (c) shows the possible alternative set which is the intersection of (a) and (b) as the shadow part.

4) Maintaining Cart Position Control Part: The control system selects the maintain cart position part in situations other than upright-down and upright. This part maintains the position of the cart so that it will not move in large scale and waits for the next time swing up.

IV. SIMULATION AND EXPERIMENT RESULTS

In order to confirm the validity of the constructed control system based on soft target, we carried out the simulation in MATLAB and the actual experiment with pendulum system. Table III is a summary of values of pendulum system's parameters. These parameters are the same as that of actual pendulum.

A. Simulation on Computer

1) simulation conditions: The simulation conditions and initial values are shown as below.

- Initial position of cart is 0.8m.
- Preset target position of cart is 0.6m.

TABLE III
VALUE OF PARAMETERS

$M[Kg]$	:	3.1169
$F[Kg/s]$	:	23.0467
$a[N/V]$	:	11.1000
$l[m]$	:	0.1150
$m[Kg]$	:	0.1000
$J[Kg * m^2]$	:	0.0026
$c[Kg * m^2/s]$	:	0.0021
$g[m/s^2]$	:	9.8000

- Considering the length of cart, the margin from cart to restriction is set as 0.07m.
- Restriction position moves from $\pm 1m$ to the middle of rail continuously until it reaching $\pm 0.5m$.
- The simulation time is 15s.

2) simulation results: The simulation results is shown as Fig.10 and Fig.11. From the cart position curve, it is confirmed that the cart is moving to the left while swinging up with

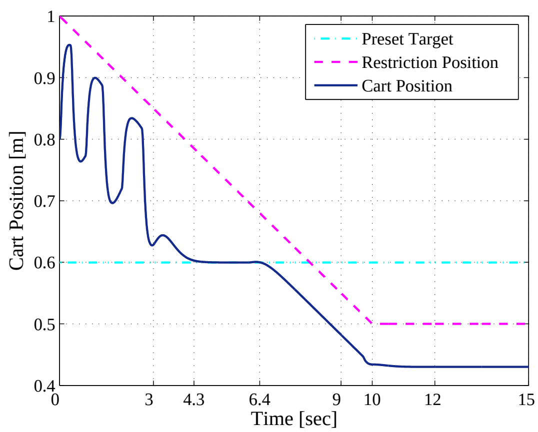

Fig. 10. Cart Position of Simulation

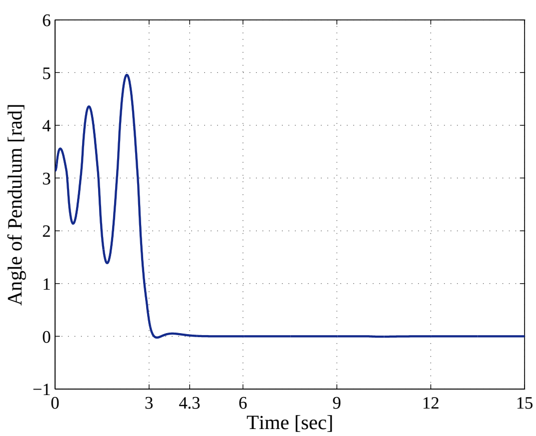

Fig. 11. Angle of Pendulum of Simulation

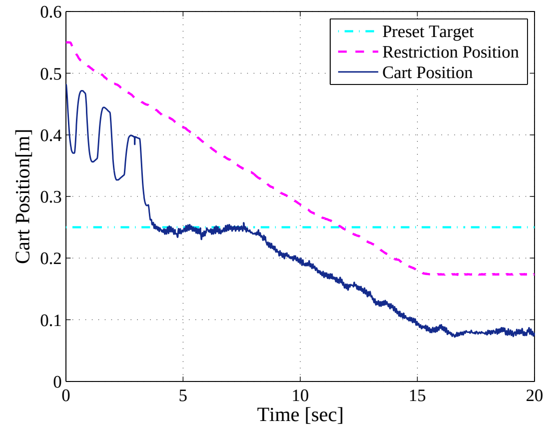

Fig. 12. Cart Position of Actual Experiment

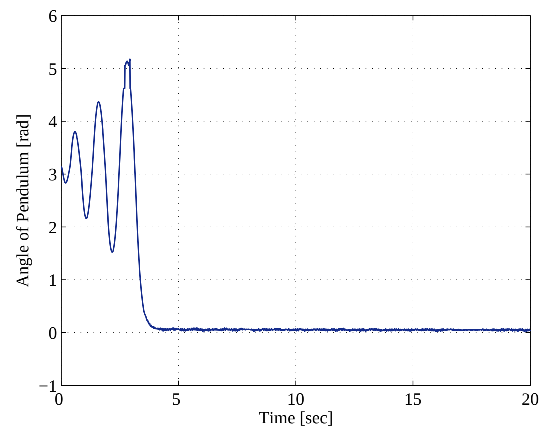

Fig. 13. Angle of Pendulum of Actual Experiment

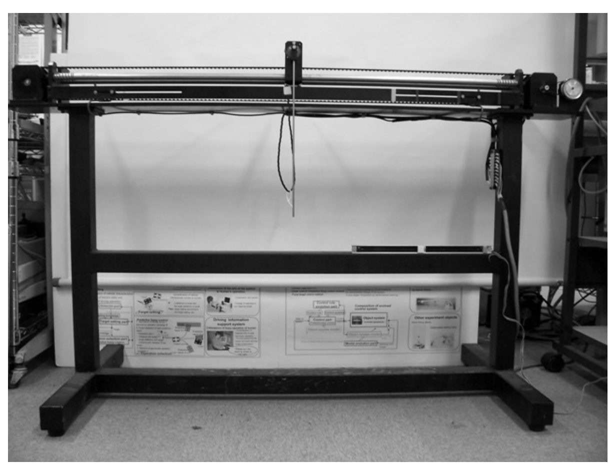

Fig. 14. Experiment Device of Pendulum System

TABLE IV

CONTROL PROCESSES OF SIMULATION AND EXPERIMENT

Process	Simulation	Actual experiment
Swing up	0~3.0s	0~3.5s
Upright	3.0~4.3s	3.5~4.2s
Stable at x_{PT}	4.3~6.4s	4.2~6.9s
Stable at x_{BT}	6.4~10.0s	6.9~15.3s
Stable near x_{R}	10.0~15.0s	15.3~20.0s

the left moving of the right restriction position. The distance between cart and restriction is always kept in the safe range. It means that the cart position is regulated real-timely with the moving of restriction position to ensure it in the safe range while the pendulum swinging up.

B. Experiment Using Actual Pendulum

Based the simulation, we carried out the actual experiment with pendulum system. The restriction position is detected online by a linear potentiometer. The scene of the pendulum system used for this experiments is shown in fig.14.

Here, the restriction position is in the range of -0.55~0.55m. The preset target of cart is 0.25m. The initial position of cart is 0.5m. The experiment results is shown as Fig.12 and Fig.13 which are about the same as the simulation. It proved the validity of this method farther.

The control processes of simulation and actual experiment are shown as Table IV. From these results, we can confirm that the cart can move flexibly with changing restriction whether in simulation or actual experiment in the process of either swinging up or stabilization. The target position of cart is adjusted as the best target or the best alternative candidate appropriately in all these processes. We can guarantee the safety wherever the pendulum begins swinging up at the rail by this method.

V. CONCLUSIONS

In this paper, an intelligent control system based on soft target is proposed and applied to the control of inverted pendulum with dynamic restriction. The soft target is acquired based on the preset target and restriction information. By integrating it with predictive fuzzy control method, the target of cart position is adjusted dynamically based the evaluation of the predicted state. The simulation and actual experiment results indicated that the system using a soft target based intelligent controller can respond flexibly to the dynamic changing restriction without seeking the target again. And the cart position can be guaranteed in the best target or the best alternative candidate all the times. A situation self-adaptation and target self-regulation system with dynamic restriction was realized.

REFERENCES

[1] L. A. Zadeh. From Computing with Numbers to Computing with Words – From Manipulation of Measurements to Manipulation of Perception, *IEEE Transactions on Circuits and Systems*, Vol. 45, No. 1, pp. 105-119, 1999.

[2] S. Yasunobu and T. Matsubara. An Intelligent Controller Based on Fuzzy Target and Its Application to Car Like Vehicle, *Proc. of SICE Annual Conference 2005 in Okayama*, pp. 2489-2494, 2005.

[3] S. Yasunobu and S. Miyamoto. Automatic train operation by predictive fuzzy control, *Industrial Application of Fuzzy Control (M. Sugeno, Ed.), North Holland*, pp. 1-18, 1985.

[4] R. E. Bellman, L. A. Zadeh Decision-making in Fuzzy Environment, *Management Science*, Vol. 17, No. 4, pp. B-141-164, 1970.

[5] T. Matsubara and S. Yasunobu. Acquisition of Fuzzy Target by Reinforcement Learning and Its Application to Four-wheeled Vehicle Control, *The 5th International Symposium on Advanced Intelligent Systems (ISIS2004)*, pp. 1-6, 2004.

[6] S. Yasunobu, H. Yamasaki. Evolutionary Control Method and Swing up & Stabilization Control of Inverted Pendulum, *IFSA2001*, pp. 2078-2083, 2001.

[7] R. Ordonez, J. Zumberge. Adapitive Fuzzy Control: Experiment and Comparative Analyses, *IEEE Transactions on Fuzzy Systems*, Vol. 5, No. 2, pp. 167-188, 1997.