Soft Target Based Intelligent Controller for a Changing Environment System

Yougen Chen[1], Seiji Yasunobu[1]

[1]Department of Intelligent Interaction Technologies,
University of Tsukuba, Ibaraki 305-8573, Japan
chen_yougen@edu.esys.tsukuba.ac.jp

Abstract: Human's action decision is based on wide targets and can respond flexibly under different situations. However, flexible adaptation to a dynamic changing environment is difficult but important for an autonomous control system. In this paper, a soft target based fuzzy predictive intelligent controller is proposed. Here, the 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 changing environment to realize situation self-adaptation and target self-regulation like human. The simulation and actual experiment results indicate the validity of the method.

Keywords: Soft Target, Fuzzy Predictive Control, Changing Environment.

1. 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 environment to respond flexibly under different situations.

In many control systems, the situations always change with the constraints 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 environment changed, recalculation of new target is necessary and the recalculation is costly and time lagged.

Therefore, the problem that autonomous control systems respond a changing environment flexibly like human is considered in this paper. We proposed a method of developing an intelligent controller based on soft target and predictive fuzzy control to realize a situation self-adaptation and target self-regulation system with dynamic environment.[2)]

2. 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 situation? The reason is that they control the system according to its internal characteristics and the external environment synchronously. The decision process is shown in Fig.1, which 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 environment information into account. The wide targets can be regarded as a "soft target" set and the best alternative is selected with the changing of situation. 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 environment.

2.1 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 constraint 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.[3, 4)]

It is expressible as shown in Fig.2, and can be expressed by the membership function of enumeration type.

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 formula (1) in state c_n of the object. Here, $\widetilde{T_n}$ is the

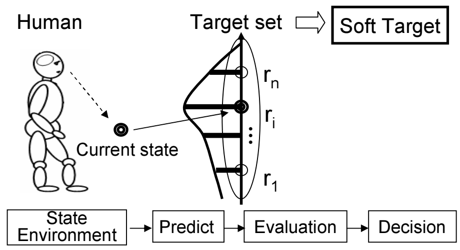

Figure 1: Process of Human Decision

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

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

As shown in Fig.3, target setting knowledge can be expressed as set cluster which correspond with different situations. 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.[5)]

By using soft target, it is possible to construct an intelligent controller for a system with dynamic environment without recalculation of new target.

2.2 Intelligent control system design based on soft target

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

Detector part This part detects the state variables and the environment information and judges the attainment degree to the preset target and the contact degree

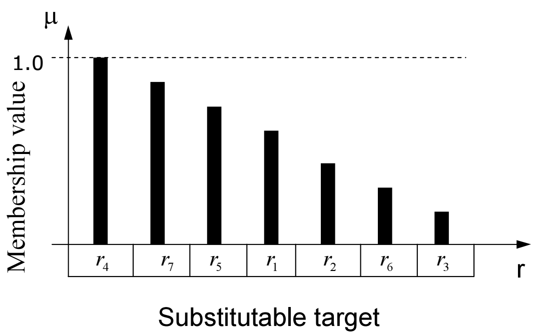

Figure 2: The Soft Target

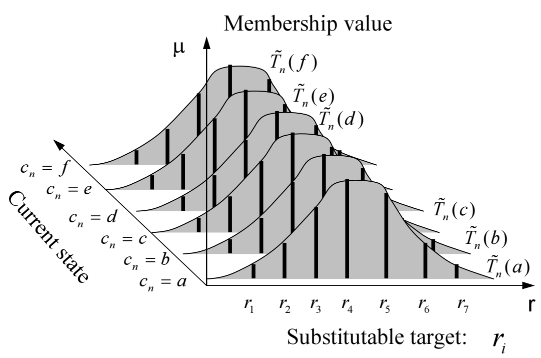

Figure 3: Target Setting Knowledge

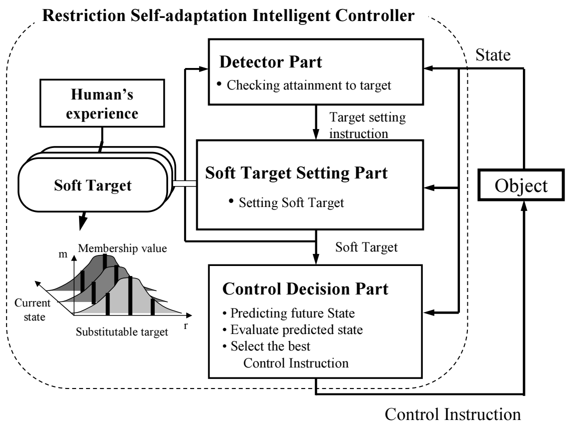

Figure 4: Outline of System Based on Soft Target

to the constraints. When the constraints make it difficult to reach the preset target, target setting instruction is outputted to the soft target setting part.

Soft target setting part When target setting instruction is received, the soft target setting part sets new target according to the current state and environment by the acquired target setting knowledge based on the preset target and constraint information in advance.

Control decision 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 for each target is calculated. Next, the future state of object is foreseen by using all the 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 system based on soft target is realized.

3. Application to pendulum system with dynamic environment

As a typical nonlinear system, the pendulum system is widely used for verifying the new control method. In this research, we take the dynamic constraints as changing environment to construct the pendulum intelligent controller based on soft target.

3.1 Characteristic of inverted pendulum

The model of the inverted pendulum system is shown in Fig.5, and its parameters are listed in Table 1.

The equations of motion are shown as below.

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

Table 1: 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 limit position
$-x_R[m]$	:	Left limit position

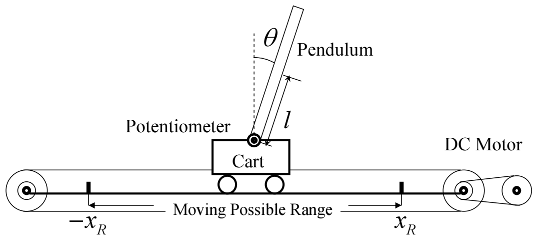

Figure 5: Model of Inverted Pendulum

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

Here, position of cart $x \in (-x_R, x_R)$. The changing environment is defined as the dynamic moving of the limit positions in the right (x_R) and left ($-x_R$). When the x_R is changed, the moving possible range of cart 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.

3.2 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 limit positions is not took into account for the controller. In order to ensure the safety, hardware protection is adopted, and generally the pendulum had to be pushed to the middle of the rail to begin swinging up. In this research, we proposed an intelligent controller based on soft target with regard to dynamic changing constraint to realize the swing up at any position and cart position self-regulation either in the process of swinging up or stabilization.

We constructed the intelligent control system of inverted pendulum based on soft target and human's experiences as shown in Fig.6. The system is composed of target setting part, state detector part and control decision part.

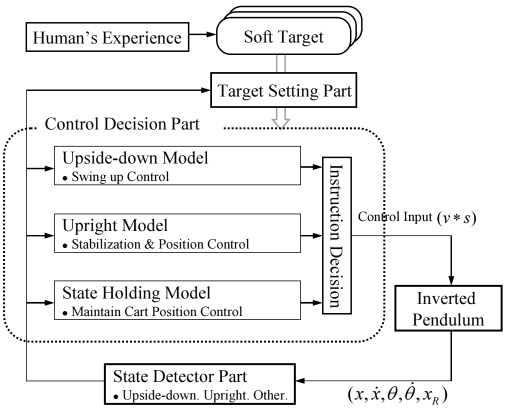

Figure 6: Outline of the Control System

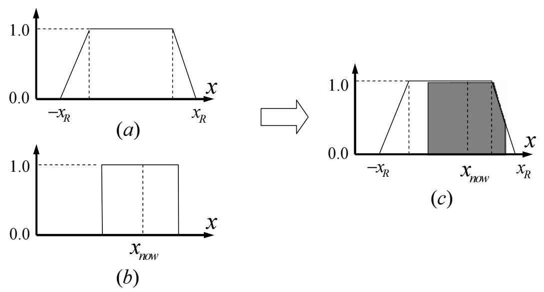

Figure 7: Target Setting Knowledge of Swing up

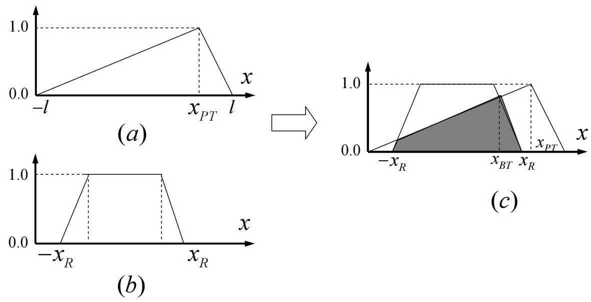

Figure 8: Target Setting Knowledge of Stabilization

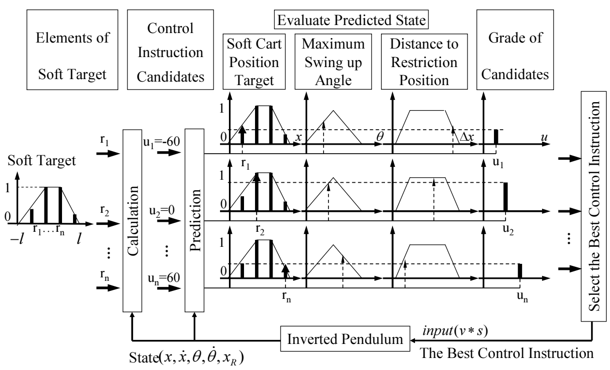

Figure 9: Detail of the Swinging up Control Part

3.3 Target setting knowledge

Target setting knowledge is acquired based on the current state and the preset target by the human's experiences. Fig.7 and Fig.8 are the Target setting knowledge of swing up and stabilization respectively. For swing up, the target is set as the intersection of the near domain of current position and the constraint set when pendulum is about upside-down. For stabilization, it is set as the intersection of preset target set and constraint set when pendulum is about upright. The available alternative target set is showed as the shadow part. 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. For the state holding part, the target is set as the previous cart position.

The available cart position target is set real-timely based on these knowledge according to its current position and the limit positions.

3.4 State detector part

In this part, the state $(x, \dot{x}, \theta, \dot{\theta}, x_R)$ is detected, and the minimal distance from cart to limit positions is calculated. By judging the state, the soft target setting instruction is outputted to the target setting part.

3.5 control decision part

This part is used to decide the control instruction according to the current state. It is composed of three parts: swing up control part, stabilization & position control part and maintaining cart position control part.

Swing up control part The swing up control is done when the pendulum is about in the upside-down state. 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.9. 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.

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

Firstly, the maximal swing up angle of pendulum and cart's position are predicted at the angle predict fuzzy model (shown as Table 2 and Fig.10) acquired from human experiences and position order model respectively by using all the candidates corresponding with the soft target set.

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

Table 2: 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

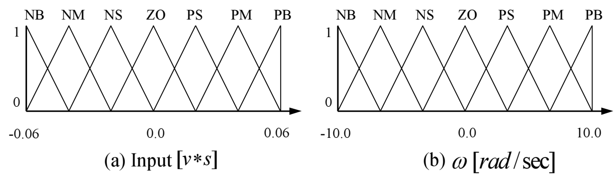

Figure 10: Membership Function of infering $\theta_{\max}$

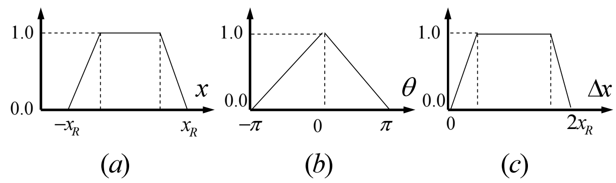

Figure 11: Evaluation Function of Swing up

The membership functions for fuzzy multipurpose evaluation is shown in Fig.11. (a) is cart position evaluation function, (b) is the angle evaluation function, (c) is the distance evaluation function. As the limit position is moving dynamically, the position and distance evaluation function are variable universe fuzzy function.

Stabilization & position control part It 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 limit position.

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.

4. Simulation and experiment

In order to confirm the validity of the constructed control system based on soft target, we carried out the

Table 3: Control Processes of Simulation & 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

simulation and actual experiment respectively with the same parameters.

4.1 Simulation by Matlab

In the simulation, the initial position of cart is set as 0.8m. The preset target position of cart is 0.6m. Considering the length of cart, the margin from cart to restriction is set as 0.1m. Limit positions move from $\pm 1m$ to the middle of rail continuously until it reaching $\pm 0.5m$.

The simulation results is shown as Fig.12 and Fig.13. From the cart position curve, it is confirmed that the cart is moving to the left while swinging up with the left moving of the right restriction position. The distance between cart and restriction is always kept in the safe range.

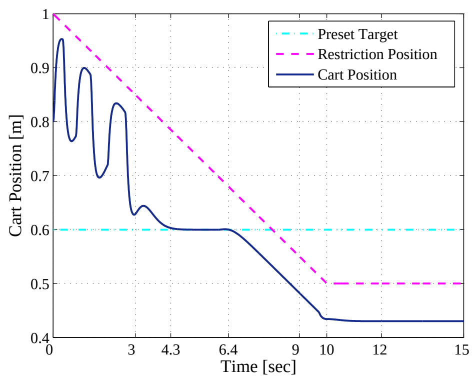

Figure 12: Cart Position of Simulation

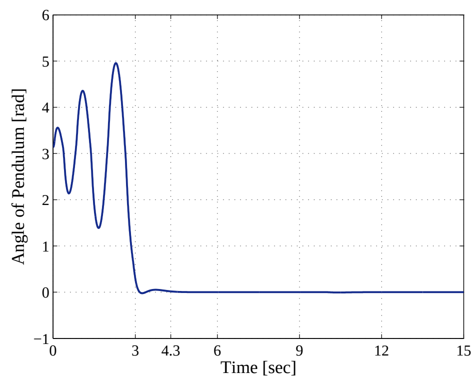

Figure 13: Angle of Pendulum of Simulation

4.2 Actual Experiment

Based the simulation, we carried out the actual experiment with pendulum system. The limit position is detected online by a linear potentiometer. The scene of the pendulum system used for this experiments is shown in fig.16.

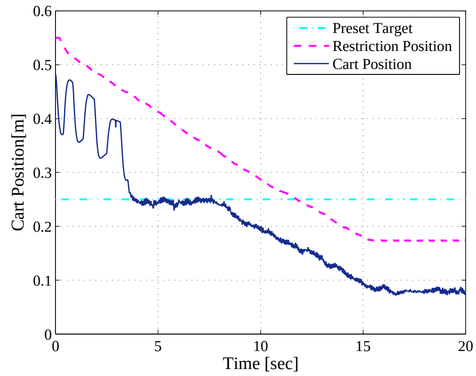

Figure 14: Cart Position of Actual Experiment

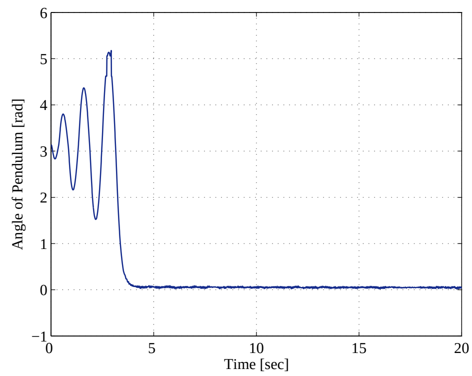

Figure 15: Angle of Pendulum of Actual Experiment

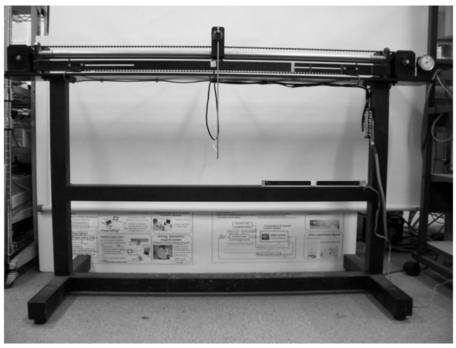

Figure 16: Experiment Device of Pendulum System

Here, the limit 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.14 and Fig.15 which are about the same as the simulation, and proved the validity of this method farther.

The control processes of simulation and actual experiment are shown as Table 3.

From these results, we can confirm that the cart can move flexibly with changing environment 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.

5. Conclusions

In this paper, an intelligent control system based on soft target is proposed and applied to the control of inverted pendulum with dynamic environment. The soft target is acquired based on the preset target and constraint 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 environment without seeking and calculating 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 environment was realized.

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