SCIS-ISIS 2012, Kobe, Japan, November 20-24, 2012

An intelligent car driving based on fuzzy target with safety zone

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***Abstract*—We proposed an intelligent control based on the fuzzy target which also put a safety zone into its element. Fuzzy target is composed of alternatives of the target and their membership values which are normalized from 0 to 1. And, a safety zone is a space in a position separate from the final target. A car driving system using the control was constructed. The simulation of parking control was performed by using this system. The effectiveness and feasibility of the proposed control were confirmed.**

I. Introduction

Fuzzy set is a concept that allows machines to handle human subjectivity[1], and applying fuzzy set to various controls is done[2]. This fuzzy control was applied to real systems such as an automatic operation systems of the Sendai-city subway[3]. This system uses predictive fuzzy control which selects a control command by evaluation predicted state of a controlled object. And, this control was applied to a parking control system for a four-wheel vehicle[4]. Car driving system such as parking control system is usually used in environment with much disturbance, so it should control it flexibly in consideration of situation changes by disturbances. This control method sets a single best target based on the control purpose. If the best target becomes unavailable because of situation's change, re-acquiring the new target is necessary if the best target becomes unavailable because of disturbances, as shown in Figure 1(a). So it is inflexible.

Fuzzy target based predictive fuzzy control were proposed [5]. Fuzzy target is composed of alternatives of the target and their membership values which are normalized from 0 to 1. This control sets fuzzy target toward the final target and select a best element as the target. Therefore, if the best element becomes unavailable, another best one is selected in Figure 1(b). So, it operates vehicle flexibly in a fixed space with obstacles or environment with moving obstacles. However, when an obstacle occurs so that to approach the final target is barred, they cannot respond to such a disturbance and may collide with it.

On the other hand, under the environment where such obstacles occur, human does not only progress for the final target, but backs away to a safety zone which is a space away from the final target. In this paper, we propose the intelligent control based on the fuzzy target which also put a safety zone into its element.

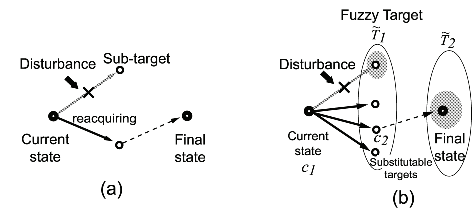


Fig. 1. Correspondence to disturbance

II. Intelligent Control based on fuzzy target with safety zone

A. human decision making based on fuzzy target with safety zone

Human's action decision (Fig.2) is based on multi-targets and can respond flexibly under different situations just based on information which are intrinsically vague, imprecise and fuzzy. The best alternative target is selected in real time based on experiences by predicting and evaluating the state of the object with taking dynamic environment information into account[5].

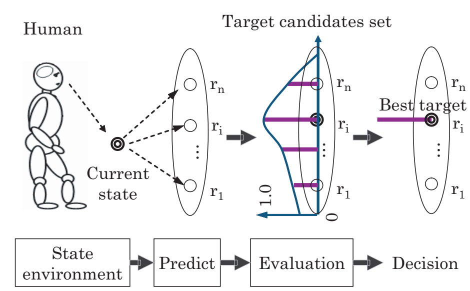


Fig. 2. Decision process of human

In the environment where obstacles occur, at first, human consider the strategy targets which should be passed. And, he reaches the destination by passing along them. When human decides action, he does not only consider a main tactical target and sub tactical targets which are targets in order to reach the strategy target, but considers retreat targets which is in a safety zone which is a space away from the strategy target. And, human regards each target as "the main tactical target is better than sub tactical targets, sub tactical targets are better than retreat targets". Fuzzy target has these targets as elements And,

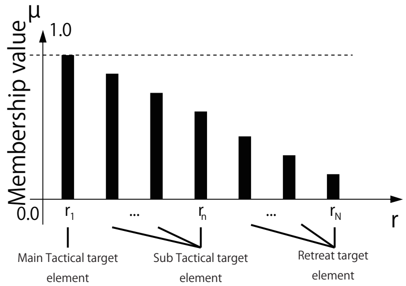


Fig. 3. Fuzzy target

the elements have membership values for fuzzy target. The membership values are the goodness as the target, as described above. They are shown as Figure 3.

Human considers one or two more action for each element For example, he considers five actions for main target element, one action for each sub tactical target element, and one action for retreat target element. Next, he foresees each future state when he selects each element as the target and does each action for it. Then he evaluates them by the degree of satisfaction of some purposes like "deviation with the target is near", "the distance with obstacles is far". Then, he evaluates each element by the evaluation value of future state and the membership value of it. Finally, he selects the element with the highest evaluation as a target, does the action for it. For example, when human drives a car on the mountain path which is narrow and whose passing each other is impossible are shown in Figure 4, he keeps its position in mind as a retreat target element if human find a safety zone such as a wide space where cars pass each other. When an oncoming car doesn't come, he would evaluate higher the main tactical target element and sub tactical target elements than the retreat target and select the main tactical target element. Because he would evaluate that the all future states when he selects elements enough fills the purpose" the distance with obstacles is far" and substitutable targets have relations of " the main tactical target is better than sub tactical targets, sub tactical targets are better than the retreat target". When an oncoming car comes, he would select the retreat target element as the target. Because he would evaluate that the future state when he selects main and sub tactical target elements are hardly fills the purpose "the distance with obstacles is far" and the evaluation would reverse the relations of them. As a result, he would operate a car toward the strategy target when an oncoming car don't come, when an oncoming car comes he would operate a car toward the safety zone.

B. design of intelligent Control

Human foresees the states in the future when he selects an element as the target, and evaluates by vague concepts such as "far". Then, the control machine is designed based on predictive fuzzy control [4]. Figure 5 shows the outline of the control machine designed based on human decision making based on fuzzy target with safety zone.

The controller is composed of three stages.

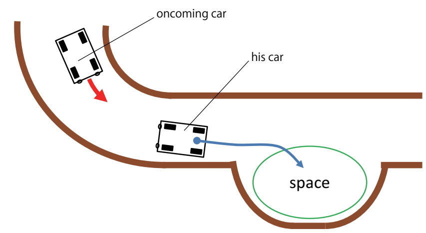


Fig. 4. Driving example a car on a narrow mountain path

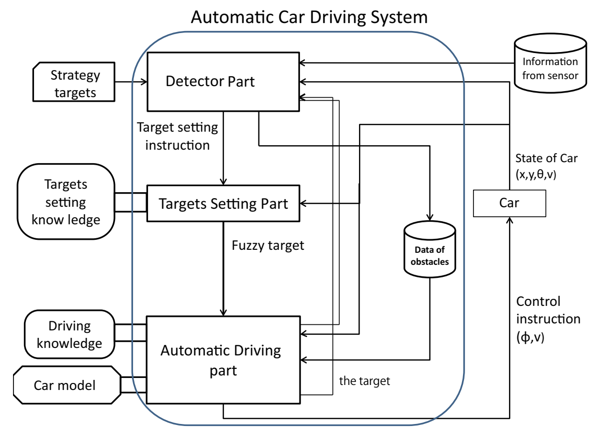


Fig. 6. Outline of the automatic car driving system

1) Calculation the operation candidatesC_m and prediction future states
2) Evaluation the fuzzy target
3) Selection the target and decision of operation instruction

1) The one or two more operation candidates for each element r_n are calculated. And, the future state when an operation candidate C_m is done are predicted based on an object model. 2) The future state is evaluated by its membership values, which is the degree of satisfaction for the purposes. Then, the evaluation value of the pair (r_n, C_m) is calculated by the future state' evaluation and the membership value for fuzzy target of the element. 3) Then, the pair (r^*, C^*) with the highest evaluation value is judged and r^* is selected as the target. Then the operation candidate C^* for it is outputted to the object as an operation instruction.

III. Application of Control to Intelligent Car Driving System

In this chapter, an intelligent car driving system that uses the intelligent control machine designed is constructed. This system is mainly composed of three parts (Detector Part, Target Setting Part, and Automatic Driving Part), and the designed intelligent control machine is built in as an Automatic Driving part. Figure 6 shows the outline of the system.

A car state is defined as position (x, y), direction θ, and speed v. And an operation instruction is defined as (ϕ, v),where ϕ is steering angle. This system is assumed to be able to detect the obstacle up to about seven meters in

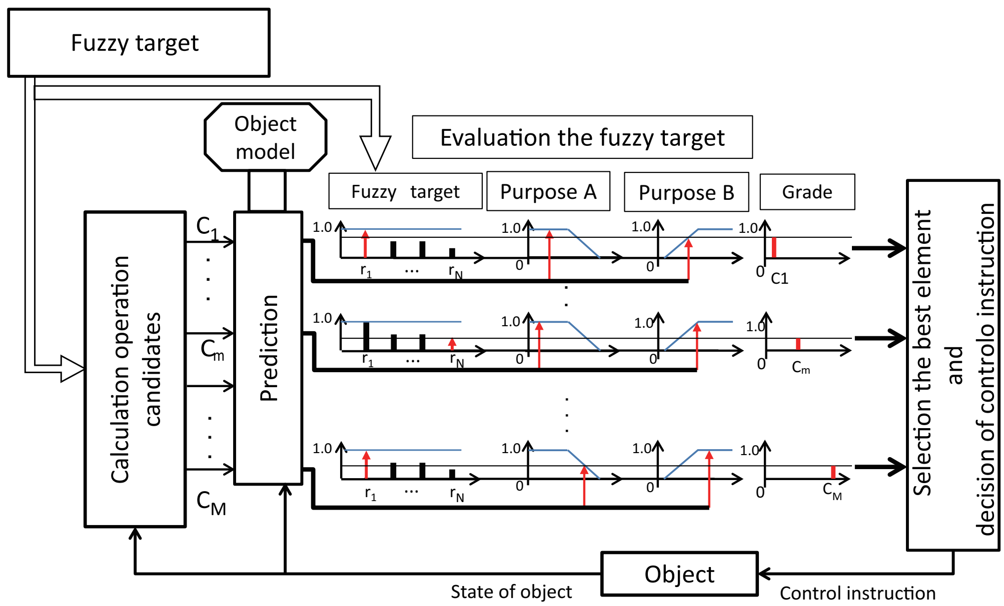


Fig. 5. Intelligent Controller based on fuzzy target with safety zone

surroundings with the sensor. The input to this system is a destination and targets which should be passed from and the initial position to the destination. A destination and targets that should be passed are defined as strategy targets as follows.

$$ST_i = (x_i, y_i, \theta_i, v_i), \quad (1)$$

and

$$i = 1, ..., I. \quad (2)$$

Where,I is number of strategy targets.

A. Detector Part

This part judges the attainment to the strategy target. The target setting instruction is outputted to target setting part if the next strategy target still exists, and if it is not so, the system is ended as a destination attainment. And, the positions of the obstacles in the car surroundings are calculated at the interval of Δt second based on information acquired with the sensor.

B. Targets Setting Part

When the target setting instruction from detector part is received, the strategy target is renewed. At this time, it is impossible to move directly from the state of a present car to the next strategy target in consideration of the dynamic characteristic of the car, this part generates a new target on the way[6]. And the new target is set as next strategy target. This part sets the fuzzy target based on the strategy target and outputs them to automatic driving part. The element r_n of the fuzzy target is defined by the parameter of the position (x_n, y_n), the direction θ_n, the speed v_n as follows,

$$r_n = (x_n, y_n, \theta_n, v_n), \quad (3)$$

and

$$i = 1, ..., N. \quad (4)$$

Where, N is number of elements. In this paper, $N = 4$ and each element is defined as follows, r_1 is main tactical target element, r_2, r_3 is sub tactical target elements and r_4 is retreat target element. And, they are defined by using parameters of ST_i as follows,

$$r_1 = (x_i, y_i, \theta_i, v_i) \quad (5)$$
$$r_2 = (x_i + \sin(\theta_i), y_i - \cos(\theta_i), \theta_i, v_i) \quad (6)$$
$$r_3 = (x_i - \sin(\theta_i), y_i + \cos(\theta_i), \theta_i, v_i) \quad (7)$$
$$r_4 = (x_{i-1}, y_{i-1}, \theta_{i-1}, v_{i-1}) \quad (8)$$

The membership values $\mu(r_n)$ are set as $\mu(r_1) = 1.0$,$\mu(r_2) = \mu(r_3) = 0.5$,$\mu(r_4) = 0.1$ based on their relationship.

C. Automatic Driving Part

This part is inputted the targets from the target setting part and performs followings.

1) Calculates the operation candidates C_m and Prediction future states.
2) Evaluation the fuzzy target

3) Selection the element r^* and Decision of operation instructionC^*

In this paper, this part calculates eight operation candidate. 1)Five operation candidates for a main tactical target are calculated and each one operation candidate for other targets is calculated. (ϕ_{old}, v_{old}) is as the last operation instructions, the operation candidates to r_1 are C_1: going to r_1 directly, C_5: holding (ϕ_{old}, v_{old}) for 10 seconds, then going to r_1, C_6 holding $(\phi_{old} + 0.25, v_{old})$ for 10 seconds, then going to r_1, C_7: holding $(\phi_{old} - 0.25, v_{old})$ for 10 seconds, then going to r_1, and C_8: holding $(\phi = 0, v_{old})$ for 10 seconds, then going to r_1. The operation candidates C_2, C_3 are going to r_2, r_3 directly. The operation candidate C_4 is going to r_4 directly.

The future state of the car is calculated by repeating calculation the future state when the operation candidate carried out for one second and re-calculation of a steering angle 16times. The calculated state is outputted as the future state if car reaches to the target or the distance with the obstacle is below the definite value.

2) The future state is evaluated by the belonging level to the membership function in which the concept of "Deflection with the target is good" or "Deflection with the target is accurate "and "The distance with the obstacle is good" or "The distance with the obstacle is accurate". The evaluation of pair (r_n, C_m) is evaluated based on the evaluation value of the future state and the membership value of its element.

3) The pair (r^*, C^*) with the highest evaluation value is selected as the target and the operation candidate for it is outputted to the car as an operation instruction.

IV. Evaluation by simulation of parking control

The effectiveness of the intelligent control based on fuzzy target with safety zone is confirmed by simulation of using it by the intelligent car driving system in the environment where obstacles occur.

A. simulation's condition

Figure 7 shows the positions and direction of cars and ST. The simulation's condition is shown as follows.

- Map ⊠ 41m41m
- Area can be moved ⊠ $-4.5 < x < 3.5$
- operated car
  - initial state ⊠ $(-2, -20, 0.5\pi)$
  - speed ⊠ 0.5m/s
  - wheelbase ⊠ 2.6m
  - car width ⊠ 1.7m
  - maximum steer angle ⊠ 0.5rad
- other car 1
  - initial state ⊠ $(-8, -10, 0)$
  - movement ⊠ 0.4m/s during 3.0-8.8sec
- other car 2
  - initial state ⊠ $(2, 20, -0.5\pi)$
  - movement ⊠ 0.5m/s during 5.0-60sec
- Strategic targets
  - $(7, 5, \pi, -1)$
  - $(-1, 7, 0.75\pi, 1)$
  - $(2, 1, 0.5\pi, 1)$
  - $(2, -7, 0.5\pi, 1)$
  - $(2, -20, 0.5\pi, 1)$

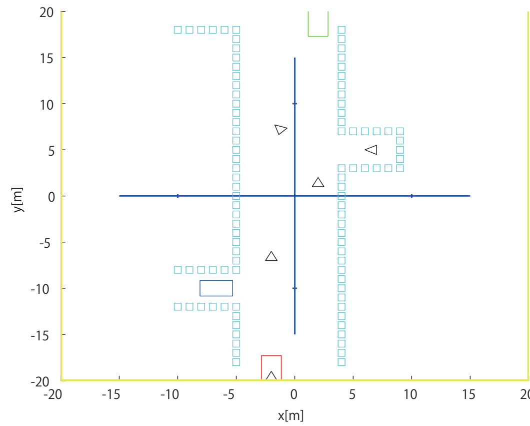


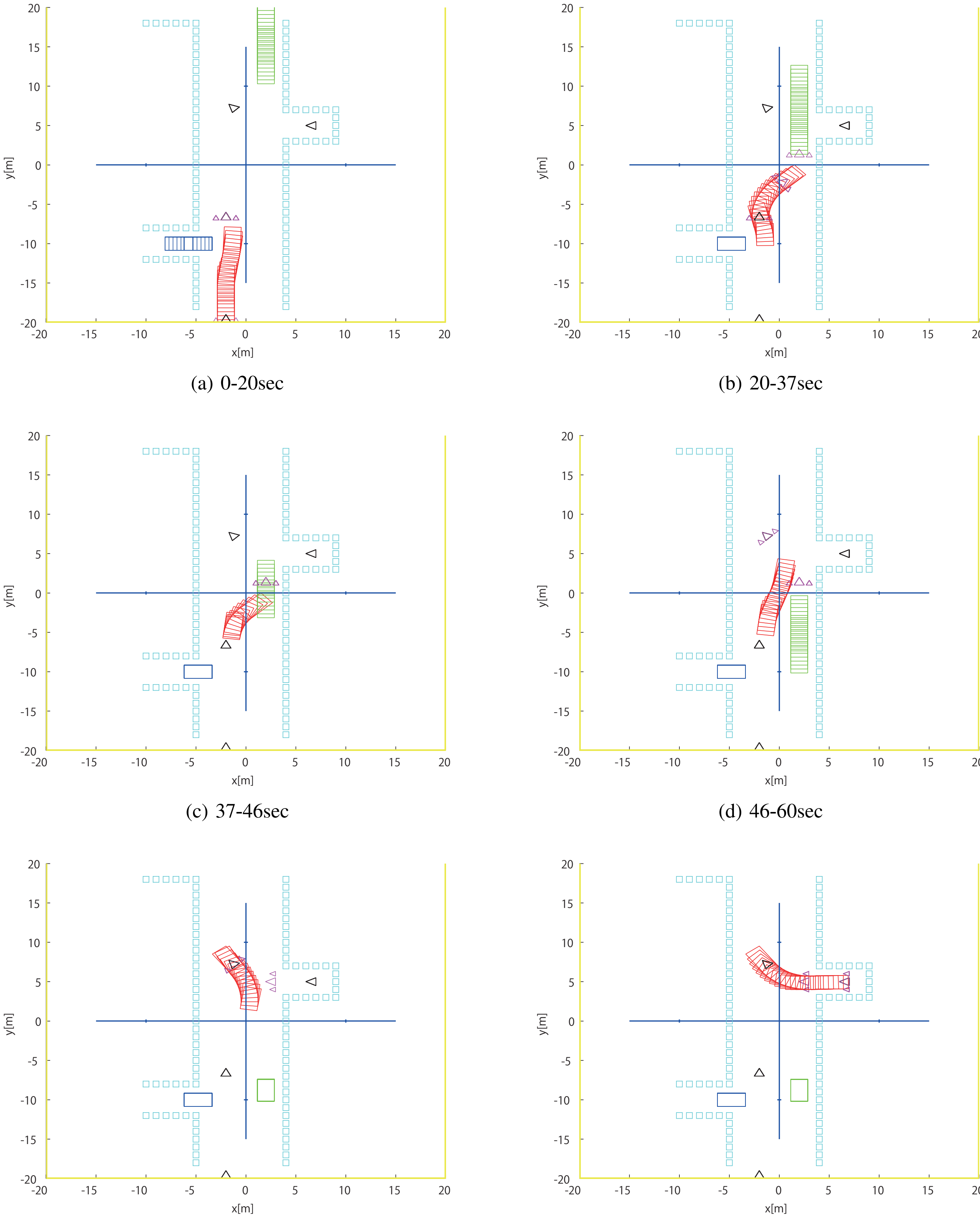
Fig. 7. Initial positions and direction of cars and ST

B. Simulation result and consideration

Figure 8(a)to(f) show trajectory of cars in the simulation. In Figure 8(a) 0-20sec, other car 1 where it had run from the left side as time passes became an obstacle. To occurrence of the obstacle, the operated car changed the course into the right and the collision with the other car 1 was avoided. It is thought that this action was realized by selecting sub tactical target. In Figure 8(b) 20-37 sec, the other car 2 had also been coming from above while the controlled car had been going to the strategy target. It is clear to collide, if they continue advance as it is. However, in Figure 8(c) 37-46sec, the controlled car retreated toward r_4 which is retreat target element. And it avoided a collision as a result. In Figure 8(d) 46- 60sec after the movement, controlled car approached a tactical target after other car 2 moved downward further. At this time, the controlled car did not go to r_1 but went on toward r_3. In Figure 8(e) 60-72sec and Figure 8(f) 72-89, the controlled car passed the strategy target and reached to the destination. Summarizing the above consideration, the intelligent car driving system chose the target flexibly to occurrences of obstacles, when obstacle occurred so that to approach the strategy target is barred, it responded to the disturbance by selecting retreat target element r_4, as a result, it operated the car to the destination without any collision.

V. Conclusion

An intelligent controller based on fuzzy target which also put a safety zone into the element was proposed. Fuzzy target is composed of alternatives of the target and their membership values which are normalized from 0 to 1. It doesn't only have a main tactical target element and sub tactical target elements which are in order to reach the destination, but has retreat



(a) 0-20sec

(b) 20-37sec

(c) 37-46sec

(d) 46-60sec

(e) 60-72sec

(f) 72-89sec

Fig. 8. trajectory of cars in simulation

target elements which are in a safety zone which is away from the destination.

Then, an automatic car driving system uses the proposed control was constructed By simulation of parking control in the environment where obstacles occur, it showed that the system can flexibly respond to obstacle which occurs so that to approach the destination is barred by selecting the retreat target element and operate a car to the destination without any collision in the environment where obstacles occur. As a result, the effectiveness and feasibility of the proposed control were confirmed.

ACKNOWLEDGMENT

This work was supported by JSPS KAKENHI Grant Number 24500272.

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