Design of A Cooperative Auto-driving System Based on Fuzzy Instruction

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Abstract: It is difficult for a traditional control system to support human's operation flexibly by using a best instruction only. In this paper, we propose a control system to cooperate with human based on fuzzy instruction. The fuzzy instruction is control instruction defined by a fuzzy set and is composed of the satisfaction rating with the control instruction candidate. An impedance controller is designed via auto-driving method of four-wheeled vehicle using predictive fuzzy controller. The cooperative control system is constructed and evaluated by experiments that run on narrow/wide road using driving simulator. Experimental results demonstrate the effectiveness of the cooperative auto-driving control system based on fuzzy instruction for the cooperation of the computer with human.

Keywords: Fuzzy Instruction, Impedance Controller, Auto-driving Method, Predictive Fuzzy controller

1. Introduction

In the last few years there has been a lot of interest in the area of human-machine cooperation. This is partly due to the fact that the computer equipments have been closer with human, and human-machine interaction has been required in many applications, e.g. health care for the elderly, domestic robot, entertainment, agriculture, etc. Therefore it is necessary to establish a control system to cooperate with human[1)2)].

When both human and computer execute a single task, human will intervene the control, and because the traditional computer control command is only a single instruction, it is difficult to support the change of the surrounding situations flexibily. Human decides an action consciously or unconsciously by his own sense, knowledge, the experiences, etc. Generally, human maintains two or more action candidates before making decision and will select the best one with high satisfaction rating from those candidates. At this point, human can flexibly correspond to the change of the surrounding situations. If control system can also supply some control instruction candidates, the control system will make decision like human to adapt to the different environment. Fuzzy controller can implement this control target to make decision like human to adapt to the surrounding situation[4)]. In typical fuzzy controller such as sugeno-type methodology, the control instruction was obtained by the known knowledge and fuzzy inference engine. The output of controller is one signal as a control instruction to the object after the result fuzzy set is defuzzified. Yasunobu (1987) has shown that in the predictive fuzzy controller[3)], result fuzzy set can supply control instruction candidates according to operation candidates which are as input set of controller, and based on these control instruction candidates the control system can cooperate with human[5)6)].

In this paper, preliminary aspects of human-vehicle cooperation task are studied, as shown in Fig.1, in which a human and a vehicle which can automatic drive perform a task together. Fuzzy instruction as a fuzzy set which includes many control instruction is calculated according to the current situation, and an auto-driving method is proposed. In this method, reference path is not necessary and tactical targets are made for path planning, and predictive controller is utilized to predict the steering angle according to the current situation. Moreover, dynamic constraints are also considered. We will construct a cooperative system to cooperate with human. When human holds the steering wheel, the cooperative system will do work and support the human's operation. If human releases the steering wheel, auto-driving system will do work.

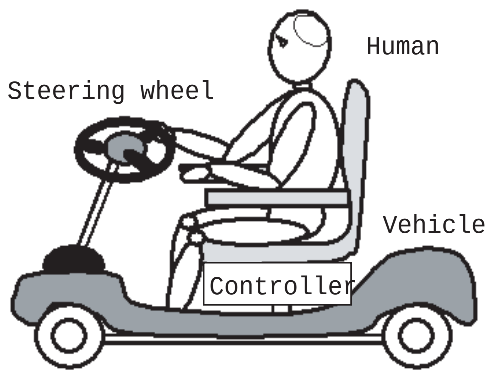

Figure 1: Human-vehicle cooperation

2. Cooperation method with human

2.1 Fuzzy Instruction

The fuzzy instruction is fuzzy set which are composed of the membership value of the control instruction candidates u_i. The discrete control instruction candidates represent the satisfaction rating sr_{u_i} of the control purpose as shown in Fig.2. Fuzzy instruction Φ_n in the

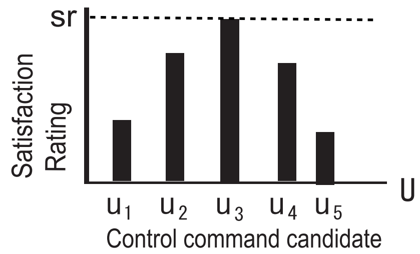

Figure 2: Fuzzy instruction

current state is defined by the following expressions now when the total set of the control instruction is assumed to be U.

$$\Phi_n = \int_U sr_{\Phi_n}(u_i)/u_i \tag{1}$$

Here, $sr_{\Phi_n}(u_i)$ are the membership function of control instruction candidate u_i.

2.2 Dynamic Characteristic of Vehicle

A simple model of the four wheel vehicle dynamics is developed. It is assumed that each wheel rolls without laterally slipping and the generation of the centrifugal force is disregarded when the velocity is very slow, thus with nonholonomic characteristics has the shown geometrical relation in Fig.3. In this case, configuration of four wheel vehicle can be described by the vector of coordinates q=$[x, y, \theta, \phi]$. The state of a present vehicle is shown by coordinates (x, y) of the middle of the rear wheel and angle θ of the x axis and the advanced direction. The front wheel steering angle ϕ is the average of of right angle ϕ_R and left angle ϕ_L, the distance of the front wheel and the rear wheel is L, the average velocity of the front wheel is v, and the rotational velocity of the front wheel is ω. At this time, the dynamic equation of Ackermann-Jeantaud is

$$\frac{dx}{dt} = vcos(\phi)cos(\theta), \tag{2}$$
$$\frac{dy}{dt} = vcos(\phi)sin(\theta), \tag{3}$$
$$\frac{d\theta}{dt} = \frac{v}{L}sin(\phi), \tag{4}$$
$$\frac{d\phi}{dt} = \omega. \tag{5}$$

Therefore, when steering angle ϕ and velocity v are kept constant, present position (x_0, y_0) and angle θ_0 are assumed. In that case, after t second, position (x_t, y_t) and angle θ_t calculate

$$x_t = \frac{L}{tan(\phi)}cos(kt) + x_0, \tag{6}$$
$$y_t = \frac{L}{tan(\phi)}sin(kt) + y_0, \tag{7}$$
$$\theta_t = kt + \theta_0. \tag{8}$$

In this case, k is

$$k \equiv \frac{vcos(\phi)tan(\phi)}{L}. \tag{9}$$

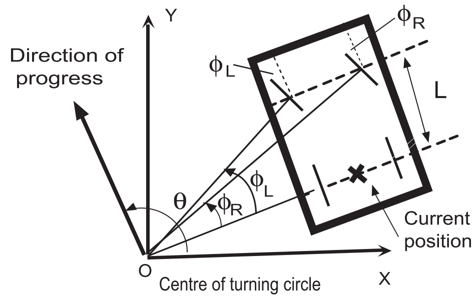

Figure 3: Dynamic characteristic of vehicle

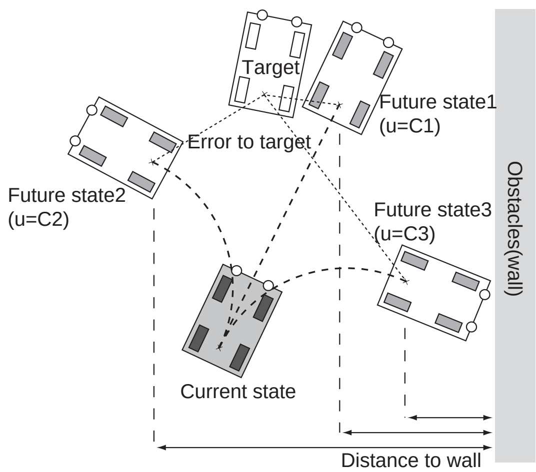

Figure 4: Operation candidates with prediction

2.3 Automatic Driving Method

In application to make a smooth tracking to attain the target, predictive fuzzy control is utilized. The predictive fuzzy controller decides the fuzzy instruction by using the predictive fuzzy control method. At first, operation candidates are assumed such as 'Turn right.' , 'Turn left.', etc. And the controller predicts the future state of each operation candidate during t sencond as

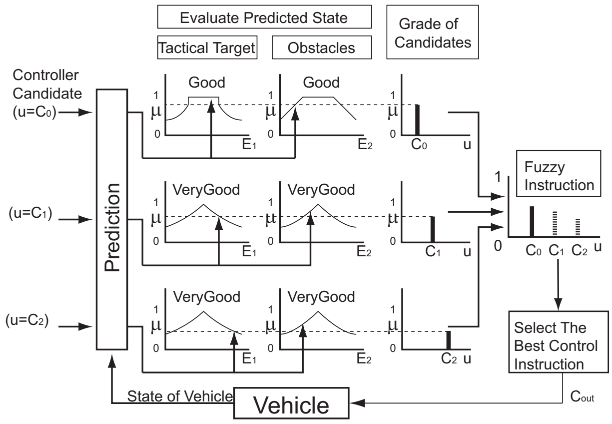

Figure 5: Decision of fuzzy control instruction

Fig.4. The t second is the expectation time to arrive the target. In this case, dynamic characteristic of vehicle is as a simple predict model for predictive fuzzy control. Secondly, fuzzy inference engine based on the knowledge of human's operation is to evaluate the satisfaction rating sr_{u_i} through calculating the distance to the environment constraints. The candidate that has highest grade is assumed the optimal control instruction for the current state. Then the optimal control instruction as next computer instruction operates the direction of the vehicle to run. The process is shown in Fig.5.

2.4 Cooperative Controller Based on Fuzzy Instruction

The vehicle has sufficient autonomy to perform computer command actions without detailed instructions from human, but human can intervene the computer command actions cooperatively by steering wheel. An overview of the system is presented in Fig.6. The human tries to operate the steering wheel by power τ_h from the arm. The power τ_c is decided by cooperative control system and will change along with the increase of steering angle ϕ. The steering wheel was moved finally by necessary torque τ_T and the human will operate the vehicle in steering angle ϕ.

The controller adds power τ_c that shows strength of the will of the computer to the human's operation on there by impedance controller. Impedance control is nonlinear impedance control as shown in Fig.7 and on wide/narrow road the impedance is different. Impedance k_{IC} is decided by satisfaction rating error k_ϕ, the angle error of the optimal operation instructions ϕ_c^* and the human operating steering angle ϕ. The expression is shown as Eq.(10). And the power τ_c can be expressed as Eq.(11).

$$k_{IC} = k_\phi \Delta\phi = k_\phi(\phi_c^* - \phi). \quad (10)$$

$$\tau_c = k_1\ k_{IC} = k_1\ k_\phi(\phi_c^* - \phi). \quad (11)$$

Here, k_ϕ is satisfaction rating error between present

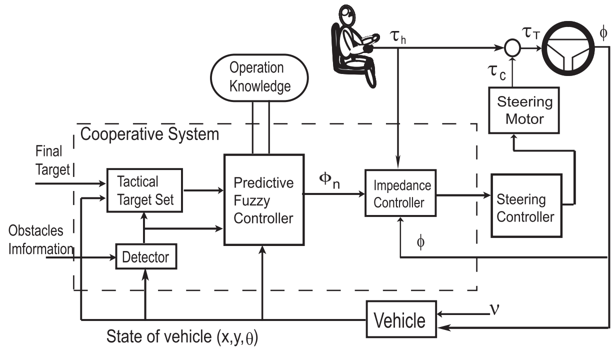

Figure 6: System configuration

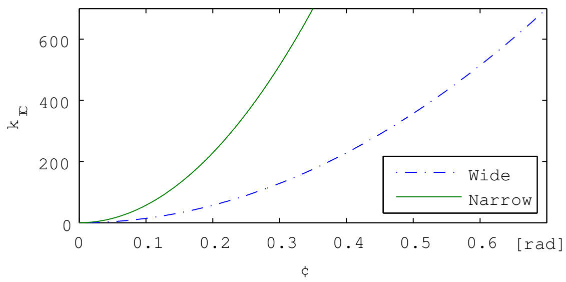

Figure 7: Nonlinear impedance along with the increase of angle error $\Delta\phi$

steering angle and computer command, k_1 is a scaling constant. k_ϕ is decided by fuzzy instruction Φ_n. The controller evaluated satisfaction rating sr_ϕ of the present operator's steering angle ϕ and computer command satisfaction rating sr_c^*. The controller decides k_ϕ from the fellow expression by using each satisfaction rating. The appearance of the decision of k_ϕ is shown in Fig.8.

$$k_\phi = sr_c^* - sr_\phi. \quad (12)$$

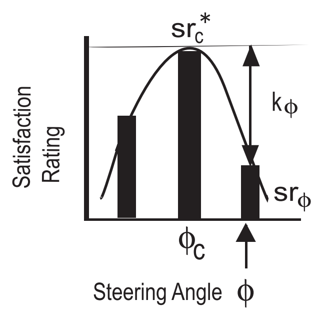

Figure 8: Decision of impedance

3. Experiment

3.1 Experiment Setup

The experimental set-up for the human-vehicle cooperation experiment was as shown in Fig.9. It consists of computer auto-driving simulation system and driving simulator with steering wheel (WingMan FOEMULA GP, Logicool Corp.). The steering wheel is actuated by a servomotor, and the steering angle is sensed by a potentiometer. The power τ_c is sensed by a strain gage (Resistance Value 350Ω) through a reinforcing girder. During cooperation control when a human moves the reinforcing girder, the increase of steering angle error is first sensed. Based on the fuzzy instructions the error of satisfaction rating is calculated. Experiment course was as shown in Fig.10 (width is 8 m). Two different road was assumed. Wide road width is 8 m, and narrow road width is 4 m. Road was from start point (-10m, -10m, $\pi/2$) to goal point (10m, 20m, $\pi/2$). The characteristics of the vehicle is as follows. The wheelbase is 2.6 m, distance between axis and bumper is 0.4 m, width is 1.7 m, the smallest turning radius is 6 m and the velocity is 0.4 m/s.

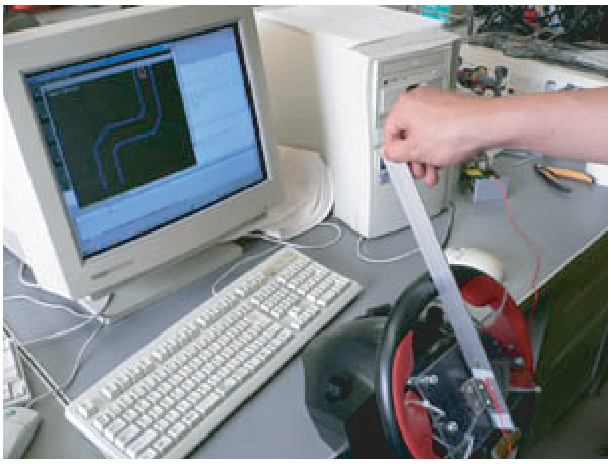

Figure 9: Experimental setup for cooperation experiment. Photograph shows the computer auto-driving simulation system, driving simulator, the reinforcing girder, and a strain gage pasted on the reinforcing girder.

3.2 Experiment in neutral gear state

In order to know the relation of τ_c and angle error $\Delta\phi$ in different road width, we assumed that the vehicle was in neutral gear (velocity is 0) and the vehicle is in the centre of the road, as shown in Fig.11. Through moving the reinforcing girder the relation of τ_c and angle error $\Delta\phi$ was presented. On the narrow road a), the grade of vehicle safety is lower, so the satisfaction rating error is higher, and human could only move the reinforcing girder from -0.25 rad to +0.25 rad. However, on the wide road b), the grade of vehicle safety is high, so the

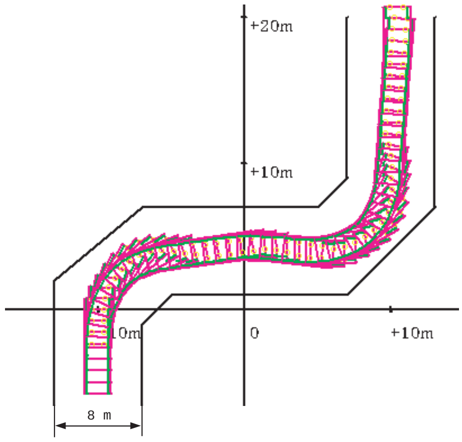

Figure 10: An example of auto-driving trajectory on wide road (width=8m)

satisfaction rating error is low, and the human could move the reinforcing girder from -0.46 rad to +0.46 rad. The strain gage value both is between -0.5 V and +0.5 V. The result is shown in Fig.12.

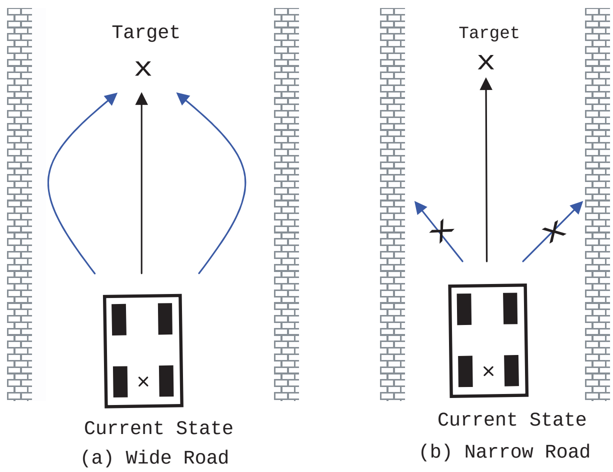

Figure 11: The support of human's operation in different situations

3.3 Experiment in driving state

Now we have known the relation of the τ_c and angle error $\Delta\phi$ when the vehicle was in neutral gear state, the driving experiment is carried out based on the computer auto-driving simulation system to test the different support to human on narrow/wide road. The computer auto-driving simulation system simulates the real-time vehicle and auto-driving system is constructed based on the fuzzy instructions. Fig.10 shows an automatic drive example on wide road (width is 8 m).

The initial state is q_s=[x, y, θ, ϕ]=[-12.0, -10.0, $\pi/2$, 0.0], and final target is q_T=[$x_T, y_T, \theta_T, \phi_T$]=[10.0, 20.0, $\pi/2$, 0.0]. Through setting the tactical target, the vehi-

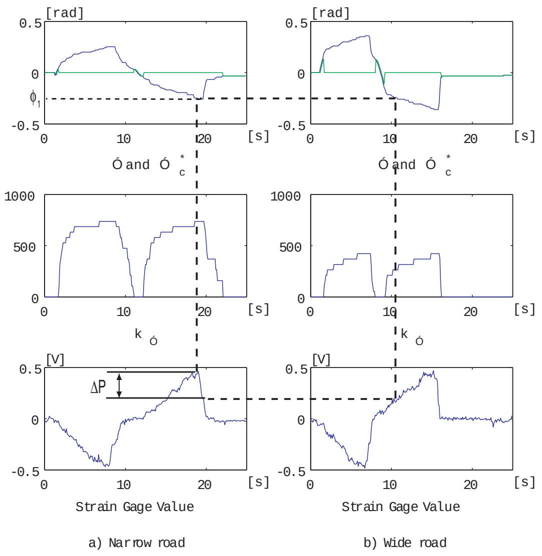

Figure 12: Relation of τ_c and $\Delta\phi$

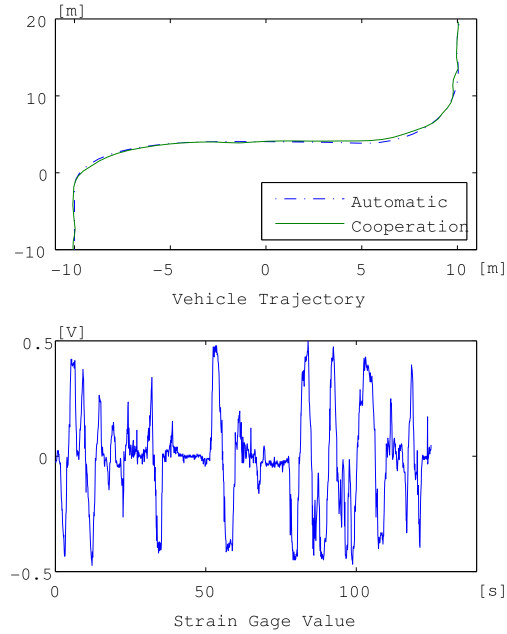

Figure 13: The support on narrow road (width $= 4m$)

cle moves keeping away from the obstacles from initial state to final target. In Fig.10, polylines are shown as the obstacles (e.g. wall). In order to reach the final target, three tactical targets have been setted. The tactical targets list is List = [-10.0 -2.0 $\pi/2$, 0.0; 5.0, 4.0, 0.0, 0.0; 10.0, 20.0, $\pi/2$, 0.0]. The result is shown in Fig.13 and Fig.14.

4. Discussion

Fig.12 shows the varying of the k_ϕ and the strain gage value P when the angle *phi* of steering wheel is changed by the reinforcing girder. we want to explain the different support on narrow/wide road through a example point phi_1. Angle $phi_1 = 0.28rad$, on narrow road the satisfaction rating error $k_\phi = 755$, strain gage value $P_n = 0.492$. However, on wide road the satisfaction rating error $k_\phi = 397$, strain gage value $P_n = 0.254$. The difference of strain gage value $\Delta P = 0.238$. As stated above we can know that on narrow road the support to human is stronger than that on wide road, and to turn the same angle on wide road the force of human's application is only about 52 % of the force on narrow road. In this cooperative system based on fuzzy instruction it is possible to support human's operation flexibly.

Fig.13 and Fig.14 shows the different support to human corresponding to the change of the environment. Narrow road width is 4 m, and wide road width is 8 m. On the narrow road, vehicle cooperated with human to move from initial point to final target, and though the strain gage value changed from minimum value to maximun value the trajectory was almost superposition with the automatic drive trajectory. On the narrow road, the support power to human was strong, and it was difficult for human to changes the route which computer command planed. However, on the wide road, vehicle cooperated with human to move from initial point to final target, the trajectory was different with the automatic drive trajectory. On the wide road, the support power to human was soft, and human could change the route observably.

5. Conclusion

In this paper, fuzzy instruction as a fuzzy set which includes control instruction candidates is calculated. Control instruction candidateswhich are evluated by satisfaction rating to control constraints. Based on fuzzy instruction auto-driving method is implemented, and then cooperative auto-driving system was proposed to flexibly support the human's operation in different situations. As a automatic driving vehicle, when human holds the steeering wheel to intervene the motion of the vehicle, the cooperative system can response quickly and support flexibly according to the current situation, and when human releases the steering wheel, the cooperative system will return to the state of automatic drive. Experiment with driving simulator has been done on narrow/wide road to confirm the effectiveness of the cooperative methodology.

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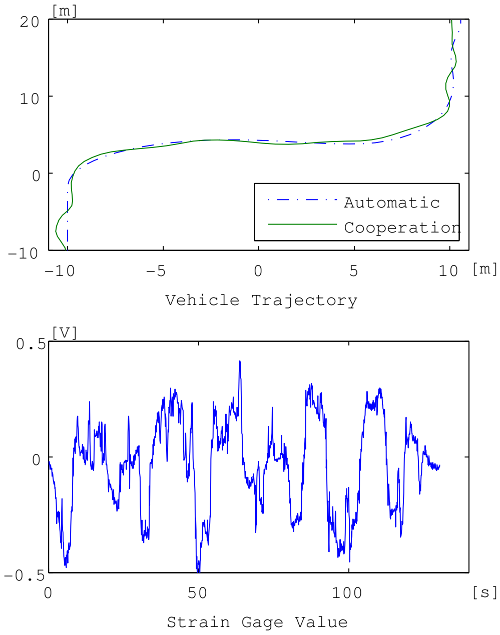

Figure 14: The support on wide road (width $= 8m$)

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