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An Intelligent Cooperative System Using Fuzzy Instruction for an Operator Training System

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Abstract: In human-machine cooperative control system, it is important to design a flexible impedance controller or model to execute the cooperation task. In this paper, the authors propose a new impedance controller and construct an intelligent cooperative system based on fuzzy instruction that is a fuzzy set of control instruction candidates and composed of satisfaction rating with the candidates. The intelligent cooperative system can adapt to the surrounding variation environment flexibly, and is applied to an operator training system to help beginner learn driving a vehicle safely and quickly. The overall intelligent human-vehicle cooperative control system is constructed and evaluated by experiments that run on narrow/wide road using driving simulator.

Keywords: Human-machine system, intelligent cooperative system, impedance controller, fuzzy instruction, operator training system.

1. INTRODUCTION

In the last few years there has been a lot of interest in the area of human-machine cooperation, especially in the field of human-robotic 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. force extender/supplement, health care for the elderly, domestic robot, entertainment, agriculture, etc. Therefore it is necessary to establish a control system to cooperate with human[1].

Many methods have been developed for design and controlling a human-machine system constructed with an impedance-controlled machine. Such systems using an impedance model can be grouped roughly into two types: one is a power-assist system which executes a task by the amplified human force; the other is a human-machine cooperation system in which machine supplement the human with an assistive force[2][3]. Also, those studies can be classified into two types according to whether the machine impedance property is constant or varible[3][4]. In our study, a new varible machine impedance model is proposed.

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 flexibly. 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 goal to make decision like human to adapt to the surrounding situation. 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 (1991) has shown that in the predictive fuzzy controller[5][6], 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[7].

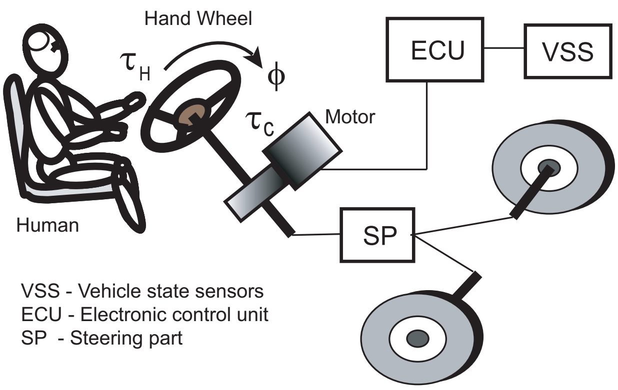

Fig. 1 Human-vehicle cooperation

Prior study places emphasis upon the support to human from the system, and the vehicle can not automatically drive[8]. 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 automatically drive perform a task together. As an operator training system, trainee is allowed to change the control instruction which the system outputs according to the surrounding environment. The main purpose of this study is to examine how the path tracking alterability of the human-vehicle system change according to the surrounding situation. In this paper, two kinds of experiment course is designed and tested by using developed human-vehicle cooperative system. Experimental results demostrate that computer attempts to maintain the predictive optimal path, and human can change it with the vary of the impedance with the change of the surrounding situation.

2. INTELLIGENT COOPERATIVE CONTROLLER USING FUZZY INSTRUCTION

2.1 Definition of Fuzzy Instruction

Fuzzy instruction is fuzzy set which are composed of the membership value of the control instruction candidates u_i. The membership value $\mu(u_i)$ of each discrete control instruction candidate u_i represent the satisfaction rating of the control purpose. As shown in Fig.2, control instruction candidates have 5 numbers, and we suppose that the control instruction candidates u3 is the optimal value to the control purpose, and $\mu(u_3)$=1.0, the satisfaction rating of the control purpose is 100%. Then $\mu(u_2)$=0.8, and the satisfaction rating of the control purpose is 80%. $\mu(u_1)$ =0.4, the satisfaction rating of the control purpose is 40%, and so on. Fuzzy instruction Φ_n in the current state is defined by the following expressions now when the total set of the control instruction is assumed to be U.

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

Here, $\mu(u_i)$ are the membership function of control instruction candidate u_i.

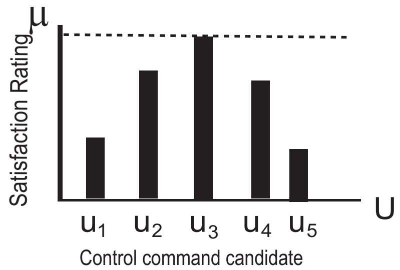

Fig. 2 Fuzzy Instruction

2.2 Generator of Fuzzy Instruction

In this study, fuzzy instruction is generated by a method of predictive fuzzy control. As shown in Fig.3, vehicle will go from current state to target, and operation candidates are assumed such as 'Turn right.' , 'Turn left.', 'Go straight', etc. The vehicle predicts the future state of each operation candidate during t sencond which 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, and the state of vehicle can be gotten by sensors to be as the parameters for predict model. Then, fuzzy inference engine based on the knowledge of human's operation is to evaluate the satisfaction rating $\mu(u_i)$ through calculating the distance to the environment constraints and target as shown in Fig.4. Fuzzy instruction is a set of control instruction candidates and the membership value shows the satisfaction rating of the candidates.

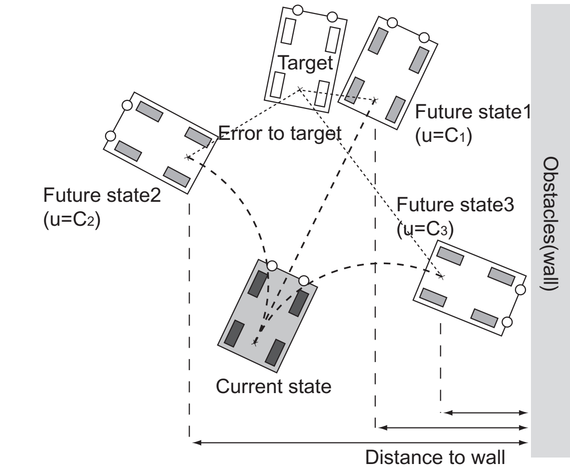

Fig. 3 Operation candidates with prediction

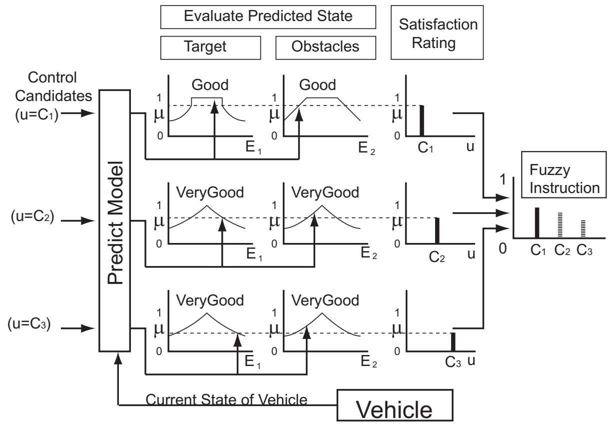

Fig. 4 Process of predictive fuzzy inference

2.3 Design of Impedance Controller

Impedance controller is related to the human's operation and the surrounding situation, and the controller adds reactive torque τ_c that shows strength of the will of the computer to the human's operation to the hand wheel. In this study, 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.(2). And the power τ_c can be expressed as Eq.(3).

$$k_{IC} = k_\phi \Delta\phi = k_\phi(\phi_c^* - \phi). \tag{2}$$

$$\tau_c = k_1\, k_{IC} = k_1\, k_\phi(\phi_c^* - \phi). \tag{3}$$

Here, k_ϕ is satisfaction rating error between present 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 $\mu(\phi)$ of the present operator's steering angle ϕ and computer command satisfaction rating $\mu(\phi^*)$ of steering angle ϕ^*. 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.5.

$$k_\phi = \mu(\phi^*) - \mu(\phi). \quad (4)$$

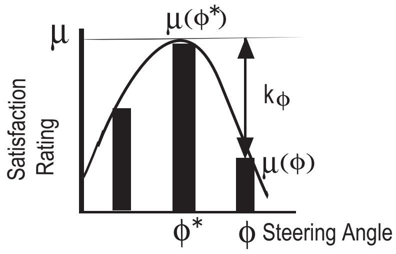

Fig. 5 Decision of satisfaction rating error k_ϕ

2.4 Human-Vehicle Cooperative System

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. According to the state of vehicle (x, y, θ), obstacles information and final target, the fuzzy instruction is generated using a method of predictive fuzzy controller. Intelligent cooperative controller is composed as shown in Fig.6, and when operator tries to operate the hand wheel by power τ_h from the arm, the intelligent cooperative controller will output the proper reactive torque τ_c to cooperate with human according to the surrounding situation. As we expounded in 2.3, the reactive torque is related to the human's operation and the surrounding situation, and in the same surrounding situation, if the difference of human's operation changes bigger and bigger, the reactive torque will be stronger and stronger. Thus the support power to human's operation is explicit and variable.

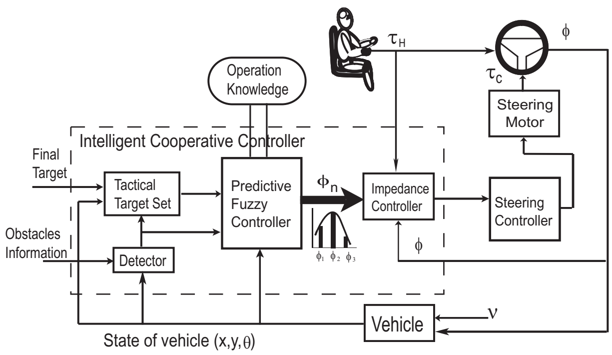

Fig. 6 System configuration

3. APPLICATION TO AN OPERATOR TRAINING SYSTEM

In this chapter, the intelligent control system that uses fuzzy instruction is applied to the operator training system. The operator training system as a cooperation task by a vehicle and human as shown in Fig.7. An expert can drive a vehicle safely in the unknown situation, and if a beginner drives a vehicle with an expert together, the beginner can cooperate with the expert and learn driving quickly and safely as shown in Fig.7 (1.human-human cooperation). The beginner decides his/her action by his/her own characteristic such as sense, knowledge, the experiences, etc. The beginner's characteristic can be expressed by a fuzzy set $FS1$. The X-axis shows control instruction candidates and Y-axis shows the membership value of the candidates. Similarly, the expert's characteristic is a different fuzzy set $FS2$. But, in this study the auto-driving vehicle works instead of the expert to cooperate with beginner. The intelligent vehicle will imitate human's thinking to send out a finite number of control instruction candidates, and the beginner's characteristic is a set of continuous control instruction candidates as shown in Fig.7 (2.human-computer cooperation).

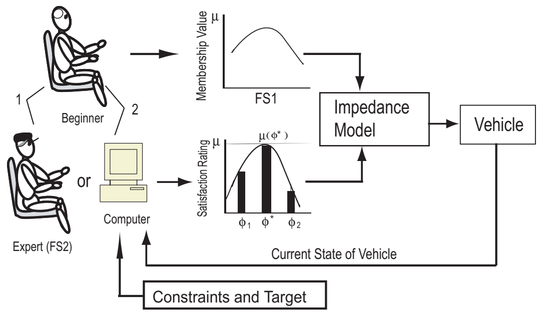

Fig. 7 Operator training system

The authors have considered a cooperative task in which a human learns driving a vehicle which can drive automatically in the experimental course as shown in Fig.1. The equation of the motion in this system is

$$J\ddot{\phi} = \tau_c + \tau_H \quad (5)$$

where J, θ, τ_c and τ_H are the moment, the angle of steering wheel, torque generated by steering wheel and human's arm, respectively. Here for simplicity, the torque of friction is not considered.

4. EXPERIMENT

4.1 Experiment Setup

The experimental set-up for the human-vehicle cooperation experiment was as shown in Fig.8. It consists of computer auto-driving simulation system and driving simulator with steering wheel (WingMan FORMULA GP, Logicool Corp.). The steering wheel is actuated by a motor, and the steering angle is sensed by a potentiometer. The power τ_H 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.9 (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, π/2) to goal point (10m, 20m, π/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.

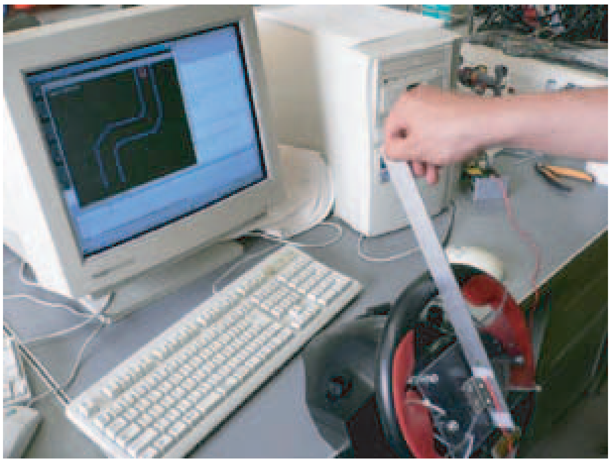

Fig. 8 Experimental setup for cooperation experiment. Photograph shows the computer auto-driving simulation system, driving simulator, the reinforcing girder, and a strain gage pasted on the reinforcing girder.

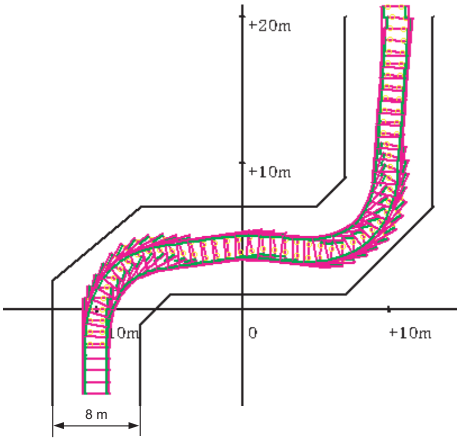

Fig. 9 Experiment course (an example of auto-driving trajectory on wide road, width=8m)

4.2 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.10. 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 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.11.

Fig.11 shows the varying of the k_ϕ and the strain gage value P when the angle ϕ of steering wheel is changed by the reinforcing girder. we want to explain the different support on narrow/wide road through a example point ϕ_1.

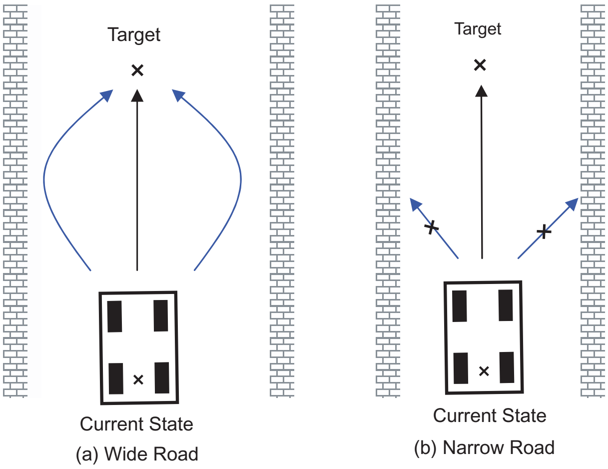

Fig. 10 The support of human's operation in different situations

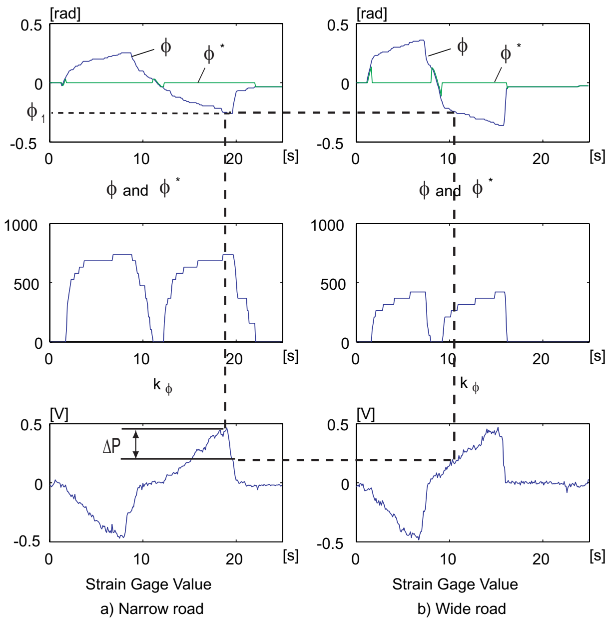

Fig. 11 Relation of τ_c and $\Delta\phi$

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.

4.3 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.9 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, π/2, 0.0]. Through setting the tactical target, the vehicle moves keeping away from the obstacles from initial state to final target. In Fig.9, polylines are shown as the obstacles (e.g. wall). The result is shown in Fig.12 and Fig.13.

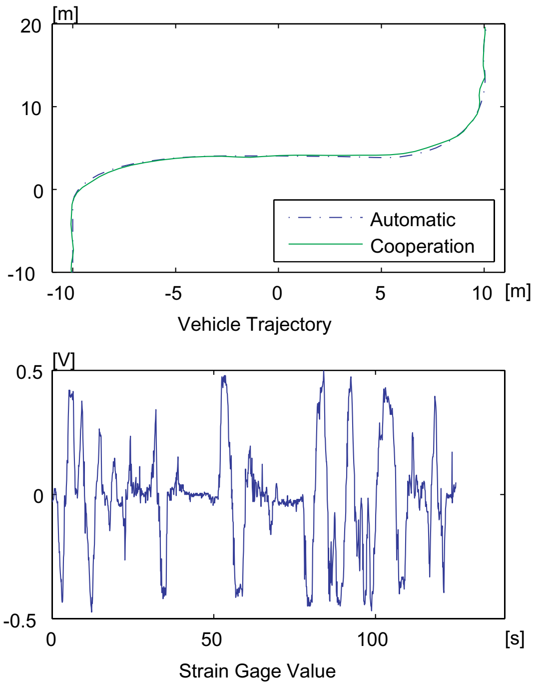

Fig. 12 The support on narrow road (width = 4m)

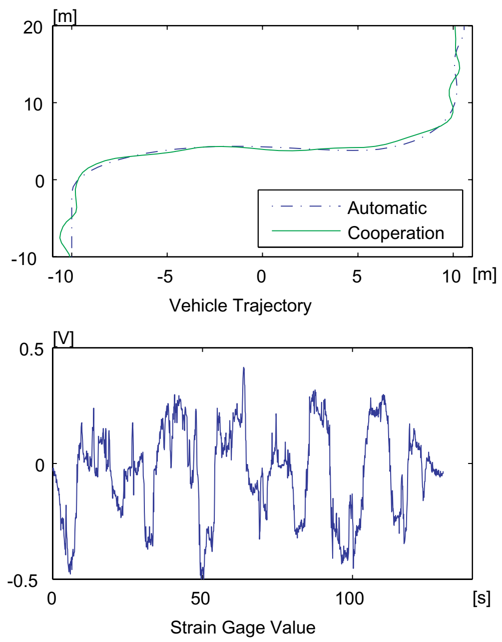

Fig. 13 The support on wide road (width = 8m)

Fig.12 and Fig.13 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 weak, and human could change the route observably.

5. CONCLUSION

In this paper, an intelligent human-vehicle cooperative system is constructed based on fuzzy instruction. Fuzzy instruction as a fuzzy set which includes control instruction candidates is generated utilizing predictive fuzzy reference, and decided by the state of vehicle, surrounding situation(constraints) and target. As a part of intelligent cooperative system, an impedance controller is designed which the impedance is variable according to the surrounding situation. This paper has analyzed the alterability of path tracking of a human-vehicle cooperative system according to the sourrounding situation. As an operator training system, experimental results indicate that on the different width road the developed system can flexibly support the trainee's operation. The computer attempts to maintain the predictive optimal path, and human can change it with the variable impedance according to the surrounding situation. Experiment with driving simulator has been done on narrow/wide road and the effectiveness of the cooperative methodology is confirmed.

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