

An Intelligent Cooperative Control System Based on Predictive Fuzzy Control

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Abstract: In this paper, we propose an intelligent control system which cooperates with human. This system gives power to reflect the will of the computer to human's operation. This system consists of "predictive fuzzy controller" and "cooperation controller". The effectiveness of this system is confirmed by experiments that human operates a virtual vehicle.

Keywords: Intelligent control, Fuzzy control, Impedance control, Cooperation with Human

1. Introduction

Recently, the application of the robot equipment is expected of various scenes that need the direct interaction with human. For example, such a scene is nursing and the helps of the sick person and the senior citizen.

Various researches have been done so far. The research is a system that has the interaction of man and the machine. The research is a design and a control method of the robot that works cooperatively with man etc. In this manner, it is important to establish the control algorithm of the cooperative type with human 1)2)3).

Human has decided the action from an own sense, knowledge, and the experience, etc. consciously or unconsciously. In that case, information that human use is fuzzy. It is because polysemy, indistinctness, and human's subjectivities etc. are contained. Therefore, it is difficult for the computer to correspond to the human's intention flexibly.

In this paper, we propose an intelligent control system which cooperates with human. This system calculates the fuzzy control instruction by using the predictive fuzzy control and gives power to reflect the will of the computer to human's operation. This system is evaluated by experiments that human operates a virtual vehicle.

2. Cooperation method of human and computer

The cooperating method of the computer and the human is described here. The computer evaluates and judges the human's operation. And, the computer tells the human the judgment result. As a result, the cooperation of the computer and the human is intended. The predictive fuzzy control is used to evaluate and to judge the human's operation. The impedance control is used to tell the human the judgment result.

2.1 Predictive fuzzy control

The predictive fuzzy control is one of the methods of an intelligent control based on human's control strategy 4)5). This control predicts the future state of some operation candidates, and it evaluates the predictive result by various purposes. It uses the fuzzy inference for the evaluation. This fuzzy inference uses knowledge and the experience of the expert described with fuzzy rules. As a result, it is similar to the predictive control based on the expert's experience.

2.2 Impedance control

The impedance control is one of the methods of controlling power using sense of force information 6)7). This control can freely adjust inertia, the viscosity, and the rigidity of the controlled object. As a result, power to act between the controlled object and the environment can be appropriately selected. This control generates power τ like the following expression by using factor of inertia M , viscous coefficient D , and rigidity coefficient K .

$$\tau = M\ddot{x} + D\dot{x} + Kx \quad (1)$$

2.3 Cooperation method

The predictive fuzzy control predicts the future state of some operation candidates and evaluates the results. The operation candidate whose evaluation value is the highest in the evaluation result was an operation instruction up to now. But, here, this control uses other evaluation results also. As a result, this control can express the will of the computer at that time. We call sets of the evaluation values of the operation candidate the fuzzy control instruction.

Power is decided by using the fuzzy control instruction. The power shows strength of the will of the computer. This power is output by the impedance control. As a result, we tell human the will of the computer.

Human can do the control that cooperates with the intention of the computer by these fuzzy control instruction and impedance control.

3. System configuration

Intelligent cooperative control system that built in the cooperation method of the computer and the human was constructed. The system was applied to driving the vehicle. Human who is riding the vehicle tries to turn the steering wheel. The power output from intelligent cooperative control system is added to there. The system configuration is shown in figure1.

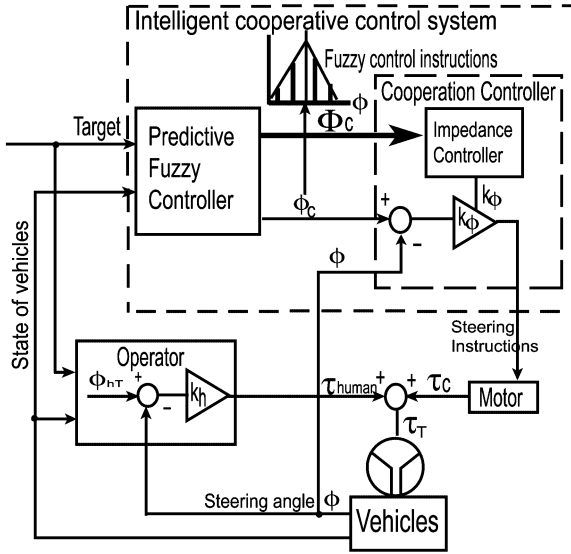


Figure 1: System configuration

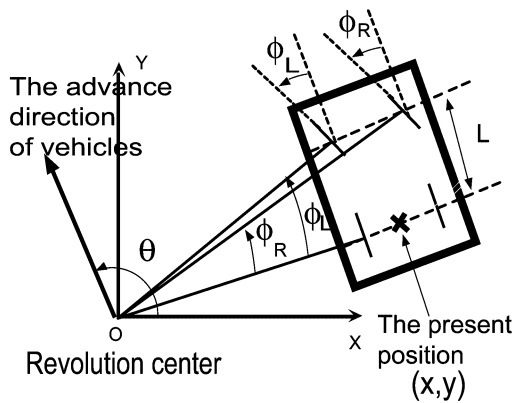


Figure 2: Dynamic characteristic of vehicle

3.1 Dynamic characteristic of vehicle

The vehicle with nonholonomic characteristic has the shown geometrical relation in figure2.

Slipping of the tire and the generation of the centrifugal force can be disregarded in the four-wheeled vehicle of the front wheel steer when the speed is very slow. 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 average of the steering angle of a right and left front wheel is (ϕ) , the distance of the front wheel and the rear wheel is L , the average speed of the front wheel is v , and the rotational speed of the front wheel is ω . At this time, the motion equation of Ackerman-Jeantaud is

$$\frac{dx}{dt} = v \cos(\phi) \cos(\theta), \quad (2)$$

$$\frac{dy}{dt} = v \cos(\phi) \sin(\theta), \quad (3)$$

$$\frac{d\theta}{dt} = \frac{v}{L} \sin(\phi), \quad (4)$$

$$\frac{d\phi}{dt} = \omega. \quad (5)$$

Therefore, when steering angle ϕ and speed 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

$$x_t = \frac{L}{\tan(\phi)} \cos(kt) + x_0, \quad (6)$$

$$y_t = \frac{L}{\tan(\phi)} \sin(kt) + y_0, \quad (7)$$

$$\theta_t = kt + \theta_0. \quad (8)$$

In this case, k is

$$k \equiv \frac{v \cos(\phi) \tan(\phi)}{L}. \quad (9)$$

3.2 Intelligent Cooperative Control System

Intelligent cooperative control system decides power to show strength of the will of the computer. This power works at the direction of the optimal instructions to an operator's power. In addition, the control system gives motor the instruction that generates this power. This intelligent cooperative control system consists of two "Predictive fuzzy controller" and "Cooperation controller".

Predictive fuzzy controller The predictive fuzzy controller decides the fuzzy control instruction by using the predictive fuzzy control. First, the controller prepares some operation candidates. The operation candidate is "The steering wheel is turned to the right." and "The steering wheel is turned to the left." etc. The controller is assumed to have executed each operation candidate during t second. The t is attainment expectation time to the target. And, the controller predicts

the state of each operation candidate's future. Each purpose is evaluated by using the fuzzy inference for each operation candidate's prospect result. The purpose is target deflection (distance and angle), and the distances (back and front, right side, and left side) with the wall. As a result, the evaluation value is requested. The controller decides the fuzzy control instruction $\tilde{\Phi}_c$ from the evaluation value. The fuzzy control instruction $\tilde{\Phi}_c$ is sets of the evaluation values to each operation candidate. Moreover, the optimal operation instruction whose evaluation value is the highest in the fuzzy control instruction is ϕ_c . The process is shown in figure3.

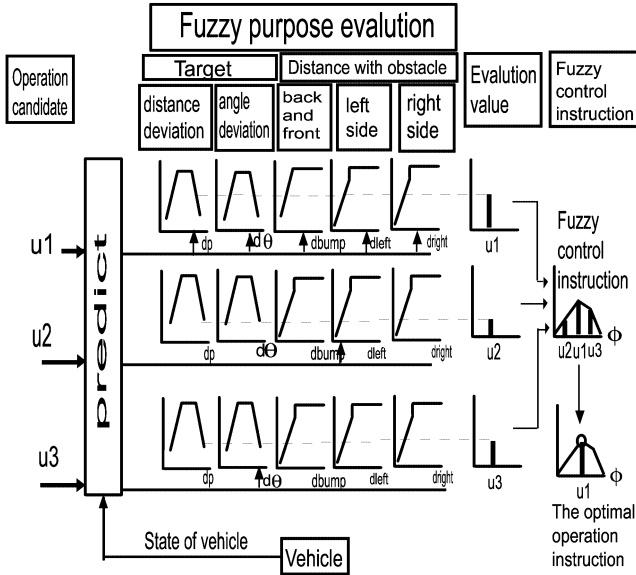


Figure 3: Decision of fuzzy control instruction

Cooperation controller Cooperation controller decides impedance k_ϕ used to cooperate. This is decided from fuzzy control instruction $\tilde{\Phi}_c$. The controller asks for evaluation value ω_ϕ of the present operator's steering angle ϕ . The evaluation value is requested from present steering angle ϕ and fuzzy control instruction $\tilde{\Phi}_c$. Moreover, the controller requests evaluation value ω_{ϕ_c} . The evaluation value is requested from the optimal operation instructions and fuzzy control instructions. The controller decides impedance k_ϕ from the next expression by using each evaluation value. The appearance of the decision of impedance is shown in figure4.

$$k_\phi = \omega_{\phi_c} - \omega_\phi \quad (10)$$

Cooperation controller decides power τ_c that shows strength of the will of the computer. The power is decided from impedance k_ϕ , the steering angle ϕ which the operator is operating and the optimal operation instructions ϕ_c . The expression is shown as follows. And, the power instruction is given to the motor.

$$\tau_c = k_\phi * (\phi_c - \phi) \quad (11)$$

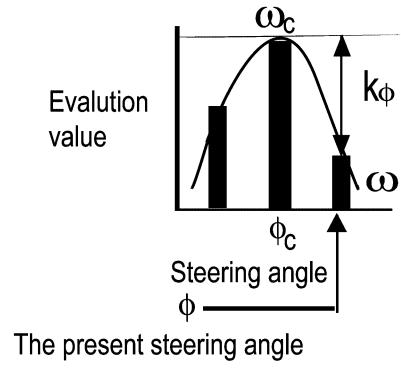


Figure 4: Decision of impedance

3.3 Operator

The operator is always observing of the state of the vehicle and the contact with obstacle. Moreover, the operator is observing whether the vehicle has reached the target. If the vehicle has not reached the target, the operator decides target steering angle ϕ_{hT} . The steering angle is an appropriate steering angle in which it is getatable to the target well. The steering angle is decided by predicting the future state of the vehicle from a present position. The operator turns the steering wheel by power τ_{human} of the arm. As a result, present steering angle ϕ is brought close to target steering angle ϕ_{hT} .

3.4 Steering wheel operation

The operator tries to turn the steering wheel by power τ_{human} of the arm. The controller adds power τ_c that shows strength of the will of the computer to the human's operation on there. The power was decided in intelligent cooperative control system. As a result, the steering wheel moves finally by necessary torque τ_T and the operator will operate the vehicle in steering angle ϕ .

4. Experiment

We did the running experiment of a virtual vehicle by using the intelligent cooperative control system previously described. The vehicle and the road are prepared as a simulation. Human operates the vehicle by turning the steering wheel while seeing the screen. The appearance is shown in figure5.

4.1 Experiment conditions

The specification of the vehicle used to experiment is shown in table1. Human drives the vehicle from start $(-6m, 0, 0)$ to goal $(0, 4m, \frac{\pi}{2})$. The steering wheel used WingMan FORMULA GP (made by the Logicool company). The steering wheel has the force feedback func-



Figure 5: Experiment scenery

Table 1: Specification of vehicle used to experiment

Wheelbase	0.8m
Width of vehicle	0.55m
Minimum outside turning radius	0.95m
Advance	0.4m/s
Back	-0.4m/s
Stop	0.0m/s

tion. After the vehicle starts, the running tracks of the vehicle of 65 seconds are shown in figure6.

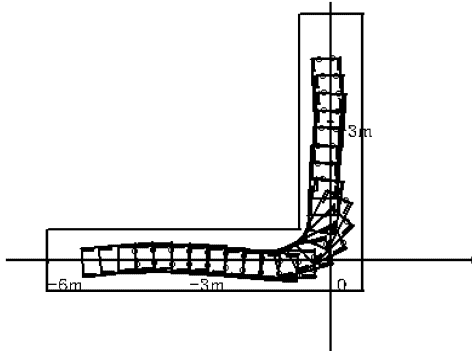


Figure 6: Tracks of cooperated driving of human and computer

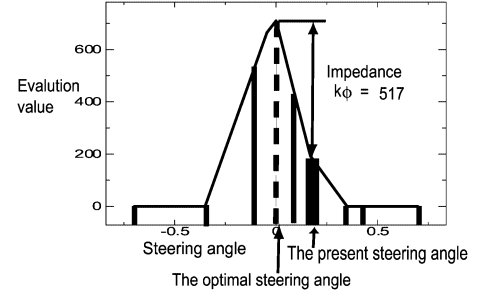
4.2 Experiment result

At the time of 15 seconds after the vehicle starts, the fuzzy control instruction is shown in figure7(a). The optimal operation instruction of that time is $\phi_c = 0.0$, and a present steering angle is $\phi = 0.168$. Impedance is $k_\phi = 517$. The difference of the steering angle is small, but the operator is feeling that the steering wheel is not turned easily because impedance is large.

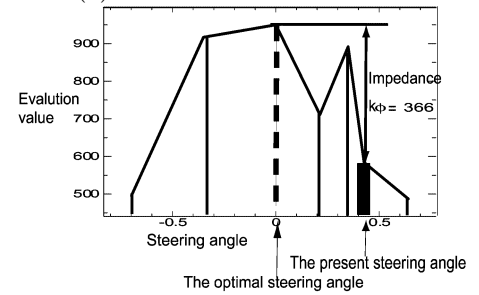
At the time of 30 seconds after the vehicle starts, the fuzzy control instruction is shown in figure7(b). At that time, $\phi_c = 0.0$, $\phi = 0.427$ and $k_\phi = 366$. The difference of the steering angle is great but impedance is smaller than that at the time of 15 seconds.

At the time of 40 seconds after the vehicle starts, the fuzzy control instruction is shown in figure7(c). At that time, $\phi_c = \phi = 0.699$. ϕ_c and ϕ are corresponding. Therefore, impedance is $k_\phi = 0$, and power is not generated. Therefore, the operator can freely move the steering wheel.

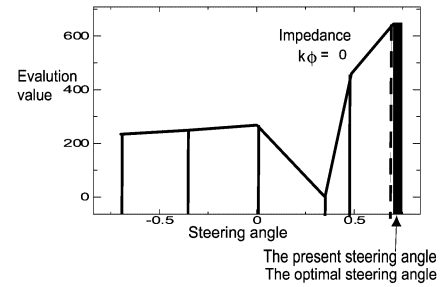
At the time of 55 seconds after the vehicle starts, the fuzzy control instruction is shown in figure7(d). At that time, $\phi_c = 0.0$, $\phi = -0.097$ and $k_\phi = 343$. The difference of the steering angle is small and impedance is not so large either. Therefore, the operator doesn't feel that the steering wheel is not so turned easily.



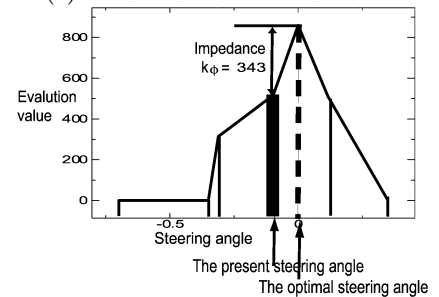
(a) At the time of 15 seconds



(b) At the time of 30 seconds



(c) At the time of 40 seconds



(d) At the time of 55 seconds

Figure 7: Fuzzy control instructional and Impedance used to cooperate

4.3 Discussion

The fuzzy control instruction changes by the situation of that time. As a result, if the fuzzy control instruction is different, impedance is different also in the same steering angle. The operativeness of the steering wheel changes by the impedance's changing. Human can drive while understanding the will of the computer naturally from the operativeness of the steering wheel. As a result, human can drive while flexibly corresponding to surrounding circumstances.

5. Conclusion

In this paper, we proposed the intelligent control system which cooperated with human. This system calculates the fuzzy control instruction by using the predictive fuzzy control, and reflects the will of the computer to human's operation by using the impedance control. The cooperation of the will of the computer and human could be intended by this system. Moreover, the effectiveness of the proposed system was confirmed by experiments that human operates a virtual vehicle.

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