An Intelligent Cooperative System Using Fuzzy Instruction for Car-Like Driving

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Abstract: An impedance controller using fuzzy instruction to support human’s operation in human-vehicle interaction is studied in this paper. Fuzzy instruction is a fuzzy set of control instruction candidates and is composed of satisfaction rating as membership value with the candidates. In order to examine the support performance of impedance controller, an effective car-like driving training system is established, and an intelligent cooperative system using fuzzy instruction is constructed. The intelligent cooperative system is applied to the training system to help trainee learn driving a vehicle safely, available and quickly. The experimental results demonstrate that the intelligent cooperative system cooperates with trainee’s operation according to the surrounding variation situation, and does adaptive support flexibly on a wide/narrow road through the car-like driving training system.

Key Words: impedance controller, fuzzy instruction, human-vehicle interaction, intelligent cooperative system, car-like driving training system.

1. Introduction

In the last few years there has been a lot of interest in the field of human-machine interaction. This is partly due to the fact that the computer equipments have been closer with human, and human-machine interaction has been anticipated for tasks such as hydraulic extender, rehabilitation therapy, domestic robot, entertainment, agriculture, training system, and so on [1],[2],[6]. In such applications, a human often takes the initiative motion and machines are required to amplify/assist the human’s operation. To achieve a conformable human-machine cooperation, it is necessary to establish a control system to cooperate with human [5].

Impedance controller has become well established in the field of human-machine interaction, and many methods have been developed for designing 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 according to whether the machine impedance property is constant or variable [2]–[4]. The human control property depends considerably on the machine impedance [6], and human-machine interaction requires the performance of machine safety rather than precision. Another performance requirements include flexibility, mechanical compliance, gentleness, adaptability toward the user, ease of use, communicative skills, and even humanoid behavior [2].

In pervious studies, generally mechanical impedance as a second-order mass-viscosity-stiffness model is utilized to support to the human’s operation [2],[4]–[6]. The insufficiency of mechanical impedance model is that the parameter of model is fixed when online running, and mechanical impedance model as a mechanical entity must be mounted in a vehicle and cannot interrelate with surrounding environment. However, in human-vehicle interaction machine impedance shall adapt to not only human’s operation but also surrounding environment and can provide the performance of safety, flexibility, adaptability and so on.

In order to examine how to support a human’s operation according to the surrounding variant situation, in this paper a car-like driving training system is supplied. The car-like driving training system is a drive-training system to help beginner to learn driving a vehicle safely, available and quickly. When driving a vehicle, generally beginner cannot make a good decision, e.g. turn a right angle when going around a turn. On a wide road beginner maybe drive a vehicle arbitrarily, and on a narrow road beginner almost cannot make a vehicle venture a step farther because of feeling that there is a collision danger ahead. An expert can always drive a vehicle along the safest route 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. In car-like driving training system, a computer imitates expert’s decision to support the beginner’s operation instead of expert. With the support of human-machine cooperative system, beginner will adjust his/her own impedance properties to make a good decision to drive a vehicle. Therefore, an effective car-like driving training system needs to be established.

This paper is organized as follows. Section 2 describes a new method to design an impedance controller based on fuzzy instruction. Section 3 make an exposition of the reason of beginning’s skill up after being trained, and explains a car-like driving training system and structure of human-vehicle cooperative system that is applied to the training system. Section 4 investigates and discusses that the impedance-controlled vehicle is how to support the human’s operation according to the surrounding variant situation on the basis of the experimental findings.
2. Strategy of Impedance Controller

This section describes a new method to design an impedance controller based on fuzzy instruction. Firstly the section introduces an opinion of fuzzy instruction. Fuzzy instruction is a fuzzy set of control candidates, and membership value of each candidate is the satisfaction rating of control purpose through constraint and target evaluation. Then explains how to generate fuzzy instruction by utilizing predictive fuzzy control. A new impedance controller is proposed on basis of fuzzy instruction. The new impedance controller differs from previous mechanical impedance that is mounted in a vehicle as a mechanical entity, and can adapt to the surrounding variant situation to support human’s operation.

2.1 Definition of Fuzzy Instruction

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 the highest satisfaction rating from those candidates. At this point, human can flexibly correspond to the change of the surrounding situations. If control system can also provide some control instruction candidates, then system will make decision like human to adapt to the different situation. 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 [7]. The output of controller is singleton 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 [8],[9], 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 [10],[11].

Fuzzy instruction is fuzzy set which are composed of the membership value of the control instruction candidates \( u \). The membership value \( \mu(u) \) of each discrete control instruction candidate \( u \) represent the satisfaction rating of the control purpose. As shown in Fig. 1, control instruction candidates have 5 numbers, and we suppose that the control instruction candidates \( u_3 \) 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 \( \Phi_n \) in the current state is defined by the following expressions now when the total set of the control instruction is assumed to be \( U \).

\[
\Phi_n = \int \mu(u) / u \quad (1)
\]

Here, \( \mu(u) \) is the membership function of control instruction candidate \( u \).

2.2 Generator of Fuzzy Instruction

In this study, fuzzy instruction is generated by a method of predictive fuzzy control. As shown in Fig. 2, vehicle will go from current state to target, and operation candidates are assumed such as ‘Turn right(\( u = C_3 \))’, ‘Turn left(\( u = C_2 \))’, ‘Go straight(\( u = C_1 \))’, etc. The vehicle predicts the future state of each operation candidate during 1 second that 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 \( \mu(u) \) through calculating the distance to the environment constraints and target as shown in Fig. 3. Fuzzy instruction is a set of control instruction candidates and the membership value shows the satisfaction rating of the candidates.

2.3 Impedance Controller Based on Fuzzy Instruction

Impedance controller is related to the human’s operation and the surrounding situation, and the controller adds reactive torque \( \tau_r \) that shows strength of the will of the computer to human’s operation through hand wheel. In this study, impedance
$k_{IC}$ is decided by satisfaction rating error $k_{φ}$, the angle error of the optimal operation instructions $φ^*$ 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).

$$k_{IC} = k_2Δφ = k_3(φ^* − φ).$$  \hspace{1cm} (2)

$$τ_c = k_1 k_{IC} = k_1 k_3(φ^* − φ).$$  \hspace{1cm} (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 $Φ_φ$. The controller evaluated satisfaction rating $μ(φ)$ of the present operator’s steering angle $φ$ and computer command satisfaction rating $μ(φ^*)$ 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. 4.

$$k_φ = μ(φ^*) − μ(φ).$$  \hspace{1cm} (4)

3. Application to a Car-like Driving Training System

Car-like driving training system can make operator driving-skilled up, especially for novice. While operator drives a vehicle in the training environment, the human-vehicle cooperative system will support human’s operation and operator’s arm will feel variable force with the change of vehicle trajectory. The data of force and trajectory will be recorded and analyzed to improve the human’s operation. If human can drive a vehicle along the best route and almost feel no support force after being trained, this indicates that the operator can drive a vehicle like a skillful driver.

3.1 Car-like Driving Training System

The car-like driving training system as a cooperation task by a vehicle and human as shown in Fig. 5. An expert can drive a vehicle along the safest route in the unknown environment, 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. 5 (1. Beginner-expert cooperation). The beginner decides his/her action by his/her own characteristic such as sense, knowledge, the experiences, etc. Driving candidates of beginner’s decision can be expressed by a fuzzy set $FS_1$. The X-axis shows instruction candidates and Y-axis shows the membership value of the candidates. Similarly, driving candidates of expert’s decision is a fuzzy set $FS_2$ which differs from $FS_1$ in that $FS_2$ is flatter than $FS_1$ seemingly. But, in this study a computer works instead of the expert to cooperate with beginner. The computer will imitate human’s thinking to send out a finite number of control instruction candidates, and the beginner’s decision is a set of continuous control instruction candidates as shown in Fig. 5 (2. Beginner-computer cooperation).

In this training system, two different width roads are set primarily. One is a wide road, and road width is 8 m. The other is a narrow road, and width is 4 m. On different road there will do flexible support to human’s operation.

3.2 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 hand 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 cooperation controller is composed as shown in Fig. 6, and when operator tries to operate the hand wheel by power $τ_H$ from the human’s arm, the intelligent cooperation controller will output the proper reactive torque $τ_c$ to cooperate with human according to the surrounding situation. As we expounded in section 2, the reactive torque is related to the human’s operation and the surrounding situation. 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.

4. Experiments

4.1 Experiment Procedure

An overview of experimental system for the human-vehicle cooperation experiment was shown in Fig. 7. It consists of computer auto-driving simulation system and driving simulator.
with hand wheel (WingMan FORMULA GP, Logicool Corp.). The hand wheel is actuated by a motor, and the steering angle is recorded 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 will be promptly detected. Fig. 8 shows the experiment set-up. Experiment course was shown in Fig. 9 (width is 8 m). Two different width roads were assumed. Wide road width is 8 m, and narrow road width is 4 m. Road was from start point (-10 m, -10 m, π/2) to goal point (10 m, 20 m, π/2). The characteristics of the vehicle are 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. 7 Overview of experimental system.

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 is 8 m).

In this study, the main purpose is to examine how the developed intelligent cooperative system supports a beginner’s operation according to the variant situation. First of all, the variant situation is grouped into two types, outside road environment change and vehicle posture change. For outside road environment change, as shown in Fig. 9 experiment course is divided into five sections A, B, C, D, E. Among them section A, C, E are the unchanging environment areas, and section B, D are the variant environment areas. Vehicle posture change is about the coordinate(x, y, θ) and speed v of vehicle.

Two experiments were designed in this paper. One was Fuzzy Prediction Performance Experiment (FPPE) in order to investigate the support performance on unchanging situation including unchanging environment and stationary vehicle posture through fuzzy prediction function. The other experiment was driving experiment when vehicle was running on the experiment course. The purpose of the second experiment was to investigate assisting support to human’s operation when both outside road environment and vehicle posture changed.

4.2 FPPE Experiment

In this experiment, two conditions were assumed that vehicle was in neutral gear (speed is 0) and at the center of section A. Section A is an unchanging environment area, and run direction of vehicle was roadway. In this experiment only angle φ of hand wheel had been changed. Simultaneously front wheel and sensors of detecting state of vehicle had been turned with the change of angle φ. The change of steering angel φ predicted the change of vehicle posture by prediction model. Through moving the reinforcing girder the relation of assisting signal P and angle error Δφ 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 higher, so the satisfaction rating error is lower, and the human could move the reinforcing girder from -0.46 rad to +0.46 rad. The assisting signal both is between -0.5 V and +0.5 V. The result is shown in Fig. 10.

Fig. 10 Different support on wide/narrow road by fuzzy prediction function.

Fig. 10 shows the varying of the kφ and the assisting signal P when the angle φ of steering wheel is changed by the reinforcing girder. We want to explain the adaptive support on narrow/wide road through an example point φ1. Angle φ1 = -0.28 rad, on narrow road the satisfaction rating error kφ = 755, assisting signal Pn = 0.492. However, on wide road the satisfaction rating error kφ = 397, assisting signal Pn = 0.254. The difference of assisting signal ΔP = 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. The experimental result demonstrated that although the surrounding situation did not change, through fuzzy prediction function the developed system could support the human’s operation flexibly and the support power has been adapted for the different width road.

4.3 Driving Experiment

In driving experiment, vehicle has run on the experiment course cooperating with human from initial point to final target, and the trajectory was compared with an automation-mode trajectory. Fig. 9 showed an example of automation-mode trajectory, and the road width is 8 m. The initial point of experimental course is $q_i = [x, y, \theta, \phi] = [-12.0, -10.0, \pi/2, 0.0]$, and final target is $q_f = [x_f, y_f, \theta_f, \phi_f] = [10.0, 20.0, \pi/2, 0.0]$. 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, and here is wall. The result is shown in Fig. 11 and Fig. 12.

Fig. 11 Support on a wide road (width is 8 m).

Fig. 12 Support on a narrow road (width is 4 m).

5. Conclusion

This paper has analyzed change of support power of a human-vehicle system to human’s operation according to the surrounding situation. A new method to design impedance controller is proposed based on fuzzy instruction. Fuzzy instruction as a fuzzy set that includes control instruction candidates is generated by utilizing predictive fuzzy reference, and decided by the state of vehicle, surrounding situation(constraints) and target. In order to examine how to support a human’s operation according to the surrounding variant situation, an effective car-like driving training system is designed and established. And an intelligent human-vehicle cooperative system is constructed based on fuzzy instruction and applied to the car-like driving training system. The intelligent cooperative system can cooperate with the trainee according to the surrounding situation, and the support power to human’s operation can make adjustment to the wide/narrow road. Experimental results demonstrate that the developed intelligent cooperative system has fuzzy prediction performance and can give an adaptive support to a beginner to learn driving safely and availably through the car-like driving training system.

References


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