*Available online www.jsaer.com*

*Journal of Scientific and Engineering Research*, 2024, 11(1):77-81

**Research Article**

**ISSN: 2394-2630**
**CODEN(USA): JSERBR**

# Overview of human-machine co-driving technology

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**Abstract** In recent years, the rapid development of unmanned driving technology has reached the L3 conditional automatic driving stage, but there will be a long window period in the highly automated driving from the L3 level to the L4 level, and human-machine co-driving can effectively fill the gap in this stage. According to the current research results of human-machine co-driving, this paper comprehensively analyzes its concept, classification and research status, and puts forward several prospects for the future development of the current research status.

**Keywords** unmanned; Human-machine co-driving; steering model; Take over the request

## 1. Introduction

Since the concept of driverless cars entered the WTO, the development of the automotive industry in the field of unmanned driving has been changing with each passing day. The L0~L5 classification of driverless cars proposed by the Society of Automotive Engineers (SAE) has not only been highly recognized by the industry, but also has been vigorously developed by major automobile manufacturers, such as traditional car brands such as BMW and Mercedes-Benz, as well as emerging Internet industries such as Baidu and Google. At the same time, countries such as the United States, Japan, and the United Kingdom have also continuously put forward clear layout plans for the development of driverless vehicles.

Although driverless vehicle technology has been fully developed in recent years, most of the driverless vehicles on the market so far are at the L0-L3 level and cannot break through the L3 level for a long period of time due to various factors such as the key technology jam, the need to improve relevant laws and regulations, and the driver's acceptance of driverless driving. As a result, in order to solve this long level gap period, man-machine co-driving technology came into being. The concept of human-robot co-driving was inspired by Flemisch et al. who were watching humans ride horses. The so-called human-machine co-driving is that people and cars both enjoy the control and decision-making power of the car, and realize the driving of the car under the joint cooperation of the two, on the one hand, the unmanned driving system can reduce the workload of the driver to a certain extent, reduce the burden of the driver, on the other hand, the driver can also rely on his own driving experience to make up for the shortcomings of the unmanned driving algorithm, and at the same time deal with the complex road conditions that the current unmanned driving technology can not deal with.

At present, there are many unmanned driving assistance technologies that belong to the category of human-machine co-driving. Such as Lane Keeping Assisted System (LKAS), Adaptive Cruise Control (ACC) and Electronic Parking Brake (EPB). In view of the fact that the advanced unmanned driving technology is still in the dilemma of not being able to achieve a level breakthrough in a short time, human-machine co-driving, a transitional technology to solve the level disconnection of unmanned driving, has received enough attention and research from the industry.

**Table 1:** SAE autonomous driving classification standard

| Level | Control | Monitor | Take over | Conditions |
|---|---|---|---|---|
| L0 | Human | Human | Human | - |
| L1 | Human and System | Human | Human | part |
| L2 | System | Human | Human | part |
| L3 | System | System | Human | part |
| L4 | System | System | System | part |
| L5 | System | System | System | all |

## 2. Definition and classification of human-machine co-driving

### 2.1 Definition of human-machine co-driving

In a broad sense, human-machine co-driving is defined as a technology in which the driving task is completed by the cooperation of the natural driver and the unmanned driving system, and is an assisted driving technology that includes a single L0 assistance system such as ABS and EPS. The narrow concept refers to the intelligent vehicle that the unmanned driving system can realize the independent execution of certain driving tasks, that is, the intelligent car that is completely operated by the system and the driver does not perform any input, the driver and the unmanned driving system can distribute the control of the vehicle, that is, they can independently complete the driving task or jointly complete the driving task on the basis of the technical architecture. From the perspective of SAE intelligent vehicle level standards, human-machine co-driving in the broad sense refers to L0-L3 level vehicles, and L1-13 level vehicles in the narrow sense. Similarly, for the definition of driverless cars, Yan Wei of Jilin University stated in his paper that autonomous vehicles, mainly at the L3 level and below, can independently detect the weather, road conditions, traffic flow and other external environments, and at the same time make correct and safe steering, acceleration, braking and other driving operations on the basis of their own speed, vehicle posture, etc., and send a takeover request to the driver when the unmanned driving system fails or encounters beyond its adaptability and cannot respond, and the driver can take over in time and complete the safety response.

### 2.2 Classification of human-machine co-driving

At present, the classification standards of human-machine co-driving are also uneven, but in general, it is nothing more than a horizontal extension of switching human-machine co-driving and shared human-machine co-driving, that is, it is more refined on the basis of the two.

As the most chosen co-driving mode of traditional smart cars, the switching human-machine co-driving is more simple and mature in comparison because the control of the vehicle is switched between the natural driver and the system, and both control the vehicle independently, without coupling relationship. The determination of the driving right of the vehicle in the switching co-driving system is through the comparison of evaluation indicators, and the party with better control input is selected as the owner of the driving right, and the evaluation index is generally the respective working state and operation mode of the two. In this switching mode, because there is no coupling between the controllers, the control is simpler and clearer, and it is easier for the driver to adapt to it. But on the other hand, because the driver is absent from the ring for a long time, it is difficult to guarantee the driver's mental state and the degree of access to road information. Therefore, the choice of takeover time, which refers to the time it takes from the time the system makes the takeover request to the driver to take action, including the driver's re-acquisition of environmental information and decision-making responses, is crucial. If the takeover time is too long, the increase in the frequency of takeover requests will inevitably lead to an increase in the frequency of takeover requests, and the higher frequency of takeover requests and too high conservatism will eventually lead to a decrease in the driver's trust in the system. However, if the takeover time is too short, the driver who has been away from the ring for a long time will not be able to regain access to environmental information, so that he will not be able to make the right decision, resulting in an accident rate.

At present, switching human-machine co-driving can be divided into the following three categories from the perspective of compulsion and initiator:

(1) A switching request initiated by a person that can be selected from a row, that is, a switching initiated by transferring to the system to drive to reduce the driver's burden under the smooth road condition that both the person and the system have the ability to drive.

(2) A mandatory handover request initiated by a person, that is, a handover initiated when the driver is unable to complete the driving task for some reason, and is urgently transferred to the system, or when the driver finds that the system cannot complete a certain driving task.

(3) The mandatory handover request initiated by the system, that is, when the system encounters some incompetent special road conditions, it sends a takeover request to transfer it to others, or the system detects that the person is in a state of inability to drive normally

Due to the many scenarios involved, the switching type of human-machine co-driving is particularly difficult to choose the switching time point due to the different state capabilities of the drivers who need to complete the takeover. In addition, on the basis of safe switching, how to achieve smooth and comfortable switching is also something that needs to be considered.

Compared with the switching type, the control mode of shared human-machine co-driving is very different, and its control is the superposition of people and systems, and the proportion of all parties will be dynamically adjusted according to factors such as road environment and decision-making of all parties. The possession of control by both parties is determined by the proportion coefficient lambda, and the final amount of control performed by the vehicle is the cumulative value of the product of the control quantity of the person and the system and the specific gravity coefficient. When the lambda is not zero (when lambda is zero, one party has full control of the vehicle, and the vehicle is fully human-driven or completely unmanned.) Both sides of the control are in the loop for a long time, and the final output is the result of the coupling of both sides, so it is more complex than the switching type. In this mode, the driver is in the ring for a long time, which can ensure that the driver obtains road information in real time, and can make correct responses in time when encountering emergencies. However, because the control of the two parties is a coupling relationship, when the decisions are different, the actions made by the two parties will inevitably conflict. Therefore, how to prevent and resolve human-machine conflict is the focus of this model.

Shared control can be divided into direct control through force feedback or indirect control by steer-by-wire. The former is also known as haptic interactive cooperative steering control, and its principle is that the torque output by the intelligent controller is directly superimposed with the torque exerted by the driver on the steering wheel, so this scheme is mostly used in traditional mechanical steering systems. The advantage of direct control is that the driver can directly feel the feedback of torque from the steering wheel, so as to interact with the intelligent controller to achieve torque, so it is more in line with the traditional driving concept and habits, and it is easier to gain the driver's trust. On the one hand, the disadvantage is that the torque feedback generated by the intelligent controller is very likely to cause the driver to confuse it with the road sense fed back to the driver by the tires, thus affecting the driver's judgment. On the other hand, when there is a great conflict between the intelligent controller and the driver's intentions, if the driver insists on performing his own operation, this torque will become an external interference resistance, which will have a huge impact on the driver's experience and safety. Indirect control does not directly apply torque intervention to the steering wheel, but uses an intermediate controller to correct the driver's control signal, and outputs the corrected control signal as the final control signal. In this mode, the control of the system is amplified, and even the right to cancel the driver's input.

## 3. Research status of human-machine co-driving

### 3.1 Human-machine co-driving control method

For the calculation of the final control quantity of the vehicle, there are mainly switching method, moment superposition method, weighted summation method, control theory method, game theory method.

1. Switching method

The switching method is mainly used in switching human-machine co-driving, in which one party of the person or system has full control of the vehicle, so both parties have independent state space equations to solve the control quantity. Its system can be expressed as:

$$\dot{x} = \begin{cases} \boldsymbol{A_1}x + \boldsymbol{B_1}u_h \; t_s = 0 \\ \boldsymbol{A_2}x + \boldsymbol{B_2}u_a \; t_s = 1 \end{cases} \quad (1)$$

2. Moment superposition method

This kind of method is mostly used in direct shared control, which is a kind of output coupling, and the trouble of authority allocation can be avoided by directly superimposing the output torque of people and systems. Its moment superposition can be expressed as

$$T = T_h + T_a \tag{2}$$

Where $T$ is the total torque output by the vehicle, and $T_h$ and $T_a$ represent the torque output by the driver and the system.

3. Weighted summation method

This method is mainly used in indirect shared control, by setting up the weight coefficient lambda, adjusting the lambda according to the risk assessment, driver status and other factors, and multiplying the output of the person and the system by lambda respectively to change the proportion of the control quantity of each party in the final control quantity. The final control volume can be expressed as:

$$u = \lambda u_h + \lambda u_a 0 \leq \lambda \leq 1 \tag{3}$$

Where $u$ is the final control quantity, and the $u_h$ and $u_a$ are the control quantities of the driver and the system.

4. Control theory method

In essence, the driver's input is also brought in as a variable in the system, and the final control quantity is calculated under the premise of considering constraints in system algorithms such as MPC. It not only reduces the difficulty of design, but also amplifies the driver's control authority to a certain extent. Its system can be expressed as:

$$u = f(\boldsymbol{x}, u_h, \boldsymbol{r}_a) \tag{4}$$

Where $x$ is the state variable of the system, $u_h$ is the driver's control quantity, $u$ is the final control quantity, and $r_a$ is the expected trajectory of the system.

5. Game theory

Game theory is suitable for finding the best decision-making scenario when multiple decision-making conflicts, and the NA and COLE of Cambridge University divide game theory into two categories: cooperative and non-cooperative games. Among them, the cooperative game is to make both parties meet the expectations under constraints, and the non-cooperative game is to strive to achieve their best expectations. Its system can be expressed as:

$$\dot{\boldsymbol{x}} = f(t, \boldsymbol{x}, u_h, u_a) \tag{5}$$

The minimized control output of the driver and system can be expressed as:

$$\begin{cases} u_h^* = argmin J_h(t, \boldsymbol{x}, \boldsymbol{r_h}, u_h, u_a^*) \\ u_a^* = argmin J_a(t, \boldsymbol{x}, \boldsymbol{r_a}, u_h, u_a^*) \end{cases} \tag{6}$$

Where $J_h$ and $J_a$ represent the objective functions of the driver and the system, respectively, $\boldsymbol{r_h}$ and $\boldsymbol{r_a}$ represent the desired trajectories of both parties, and $u_h^*$ and $u_a^*$ are the minimized outputs of both sides calculated after the game.

### 3.2 Driver steering model

There are two points in adding the driver's steering model to replace the natural driver's in the shared controller, one is that the driver's model can provide a human-machine dual-in-the-loop simulation environment, and on this basis, the development of the controller can greatly save the resource cost consumed in the real vehicle experiment. Second, an accurate and reasonable driver model can better characterize the operating behavior of natural drivers and be more general, which is crucial for the study of control algorithms.

As early as the 60s of the last century, people began to work on the driver's steering model. The researchers proposed a single-point preview theory by observing the focus of natural drivers during driving, and Gray et al. successfully applied this theory to forward collision avoidance shared control to predict the steering behavior of drivers. Since then, researchers have begun to tend to think that natural drivers are looking at multiple points of the road rather than one point, and then proposed the theory of multi-point preview, and Salvucci et al. were the first to propose the concept of near and far previewers.

After the 80s of the last century, optimal control and model predictive control have gradually become a new trend in the research of driver steering models. At the same time, MacAdam combined optimal control with single-point preview to propose an optimal preview steering model for drivers. Sharp et al., on the other hand, combined a linear quadratic regulator with a multi-point preview to establish a cost function based on the multi-point preview. Ungoren et al. used adaptive predictive control as the theoretical basis to establish a driver's steering model, and found that the driving style can be changed by adjusting the weight parameters of the cost function, which greatly increases the possibility of the driver model.

**4. There are problems and development prospects**

(1) In the switching type of human-machine co-driving, there is still a lack of unified standard switching evaluation indicators, how to grasp the appropriate switching scene and timing is still to be discussed, for the driving level of natural drivers is different, the switching conditions should also be appropriately changed, and how to properly handle the takeover request in an emergency situation that is difficult for both parties to deal with. The focus of this problem is how to ensure the rationality and security of the switchover.

(2) For shared human-machine co-driving, how to solve the human-machine conflict is an unavoidable topic, and the current more recognized solution is to give all the control authority of the vehicle to a certain party when the human-machine conflict occurs. However, the problem with such an approach is that the driver may be influenced by other systems and distrust the autonomous driving system, and on the other hand, what indicators should be used to determine the allocation of driving authority. In addition, how to effectively realize information sharing between man and machine in shared human-machine co-driving, the system can obtain the driver's information through the driver's intention and prediction, and the driver's acquisition of system information is much more difficult.

3) With the help of the driver's steering model, the system can better adapt to the driver's behavior, but this requires high accuracy of the driving model, and because the driving behavior of the natural driver has high randomness, the driving model is forced to fail to completely cover the driver's posture behavior and habits, and it is difficult to cope with complex scenes. Big data using deep learning and reinforcement learning is the future research direction.

(4) In addition to overcoming technical difficulties, it is also essential to improve relevant laws and regulations, and how to determine whether the accident liability can be clarified will greatly affect the development of the industry.

**5. Conclusion**

For a long time in the future, autonomous driving technology will be in the stage of human-machine co-driving, which is not only the transition of L3-L4 level, but also the development of human-machine co-driving technology will greatly affect the L5 level, and many technologies at this stage will be directly applied to L5 vehicles in the future. Although there are still many key points to be broken through at the current human-machine co-driving, it will also effectively solve the gap period at the L3-L4 level.

**References**

[1] Lu Z, Happee R, Cabrall D C, et al. Human factors of transitions in automated driving: A general framework and literature survey [J]. Transportation Research Part F: Psychology and Behaviour, 2016, 43.

[2] Na X, Cole J D. Game-Theoretic Modeling of the Steering Interaction Between a Human Driver and a Vehicle Collision Avoidance Controller [J]. IEEE Trans. Human-Machine Systems, 2015, 45(1).

[3] Plöchl M, Edelmann J. Driver models in automobile dynamics application [J]. Vehicle System Dynamics, 2007, 45(7-8).

[4] Liu C, Zheng J, Pan J. Robust semi-autonomous vehicle control for roadway departure and obstacle avoidance [J]. 제어로봇시스템학회 국제학술대회 논문집, 2013.

[5] Salvucci D D, Gray R. A Two-Point Visual Control Model of Steering [J]. Perception, 2004, 33(10).

[6] C. C M. An Optimal Preview Control for Linear Systems [J]. Journal of Dynamic Systems, Measurement, and Control, 1980, 102(3).

[7] Sharp R, Casanova D, Symonds P. A Mathematical Model for Driver Steering Control, with Design, Tuning and Performance Results [J]. Vehicle System Dynamics, 2010, 33(5).

[8] Ungoren A, Peng H. An adaptive lateral preview driver model [J]. Vehicle System Dynamics, 2005,43(4).