Scientific and Social Research, 2024, Volume 6, Issue 2
https://ojs.bbwpublisher.com/index.php/SSR

Conceptual Design of Transparent Machine Behavior to Facilitate Human-Machine Driving

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Abstract: To facilitate human-machine driving, the functions of the intelligent system need to be displayed clearly to the driver. In this way, the driver will be able to understand the goals, plans, and decisions of the intelligent system. In addition to internal states, the transparency of external states such as the level of control during automated driving is also important. However, the current autonomous driving systems do not allow visibility of the tangible state of the intelligent system. Therefore, we designed a Human Machine Interface (HMI) concept that makes the machine's behavior visible through virtual changes on the steering wheel, foot pedals, and turn signals. In this way, the lack of awareness of the driver due to the loss of tactile feedback from the vehicle can be compensated, and the driver will be able to observe and predict the behavior of the system, resulting in a better human-machine driving experience.

Keywords: Transparency; Autonomous vehicle; HMI; Human computer-interaction; Human-machine driving

Online publication: February 27, 2024

1. Introduction

According to the Society of Automobile Engineers (SAE) International's autonomous driving classification, Level 3 is conditional autonomous driving, where a human has full control over the driving of a machine [1]. In this form of autonomous driving, the human cooperates with the machine, and the facilitation of this relationship will be the focus of the HMI design.

Human-machine driving should involve three forms of vehicle control: strategic, tactical, and operational [2]. Strategic control means long-term planning, including route navigation and traffic conditions; tactical control refers to short-term planning, such as steering, lane changing, and overtaking; operation control is the driver's control of the vehicle via the steering wheel and foot pedal [3]. The interface is designed with the concept of transparency (understanding, decision-making, planning) and external (behavior) states, which facilitates the driver in understanding the actions of the system and predicting short-term actions [4]. In addition, transparent interfaces can also improve the driver's trust in the machine and its performance [5]. The current information displayed by the central control only includes strategic and tactical controls. For example, the main purpose of Tesla's autopilot display is to show the user the system's situational awareness, path planning, and lane change planning. However, not much consideration has been given to the transparency of the operation control. Many studies have been done on overtaking and unexpected situations in autonomous driving involving steering and speed manipulation (e.g. sudden acceleration or deceleration) [6]. Therefore, we believe that all three levels of control need to be communicated to humans through a transparent interface (**Figure 1**).

One way of Operational level transparency is the figuration of machine behavior, where communication that expresses intent through behavioral visibility helps develop shared situation awareness and trust [7]. Parasuraman and Miller [8] found that people often struggle to trust the vehicle when they do not understand its actions fully. Zihsler *et al.* [9] proposed to flesh out the machine's behavior into an anthropomorphic robot so that the machine's driving behavior can be better perceived. For example, the maneuvering of the steering by the machine can be displayed as the robot moving left and right.

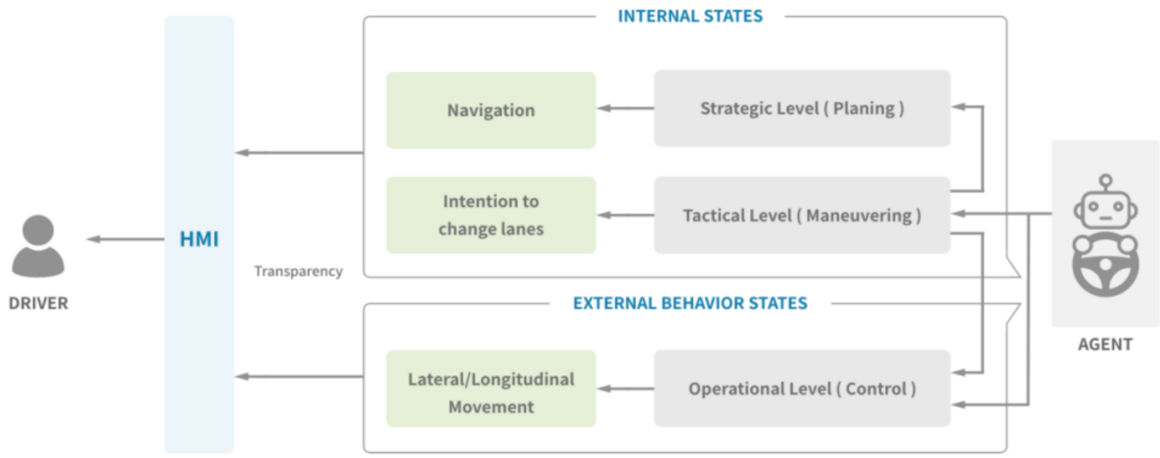

Figure 1. Transparency at three levels of vehicle control

The objective of this research is to allow drivers to predict the actions of the system through transparency in operational control. The machine's behavior is presented through a virtual steering wheel, throttle, brake, and turn signals. By doing so, the driver can better predict the machine's behavior and the loss of tactile control over the vehicle can be compensated.

2. Concept

The goal of our design is to visualize the machine's operational behavior to facilitate human-machine driving and ensure that the driver has access to situational awareness. Below are the important points of our design.

(1) Cooperation interface

Walch *et al.* [10] suggest that interfaces for human-machine collaboration should fulfill the requirements of mutual predictability, directability, shared situational awareness, and calibrated trust. They emphasize that predictability plays a crucial role in this context. Hoc [11] suggests the entities involved need internal models or representations to enable them to predict future states of themselves, other entities, and tasks.

(2) Using vision to compensate for the loss of situational awareness of the driver

Situation awareness is the human perception, understanding, and prediction of the changing environment around them [12]. Guy *et al.* [13] analyzed how situational awareness is acquired while driving and showed that tactile feedback is largely rivaled by visual feedback in basic vehicle control.

However, in autonomous driving, humans lack tactile feedback from the steering wheel and pedals. They can only observe the vehicle's driving behavior to assess the machine's actions. More importantly, the lack of control over the vehicle pedals may result in an inability to anticipate vehicle acceleration and deceleration behaviors in advance.

(3) Head-up display (HUD)

To avoid taking the driver's eyes off the road, we chose the HUD as the host interface for the HMI. We first developed an abstraction hierarchy that facilitates human-machine driving using the Cognitive Work Analysis (CWA) approach (**Figure 2**). Instead of choosing a humanoid robot as the representation, we chose the physical controllers. Control variations are expressed by rendering elements like the steering wheel, accelerator, brake, and left and right turning as virtual elements. Furthermore, the HMI information is laid out on the HUD (**Figure 3** and **Figure 4**).

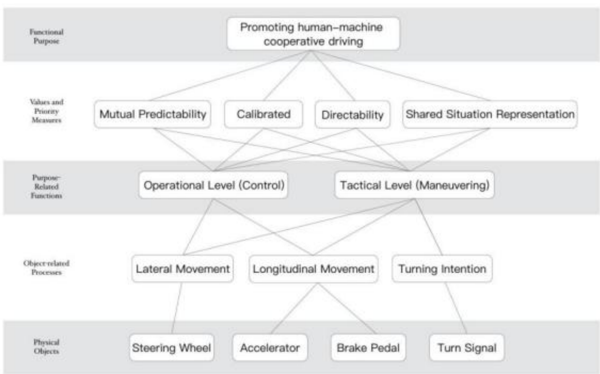

Figure 2. A flowchart of how this project facilitates human-machine driving

Figure 3. HMI prototype

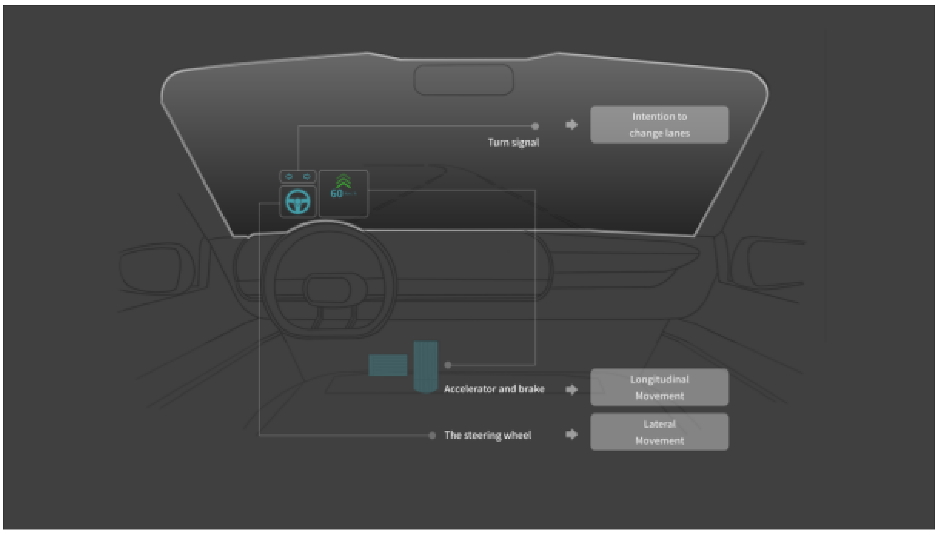

Figure 4. Conceptual design of transparent machine behavior

3. Virtual steering wheel

In autonomous driving, the steering wheel is turned according to the desired direction, which gives the driver information on the behavior of the machine. However, since the steering wheel is not within the driver's primary field of view, and switching focus from the forward environment to the steering wheel can blur the surroundings, it may affect the perception of the situation. To keep the driver focused on the environment while monitoring the steering wheel's movements and the real scene simultaneously, we designed a virtual steering wheel on the HUD to represent the vehicle's lateral control (**Figure 5**).

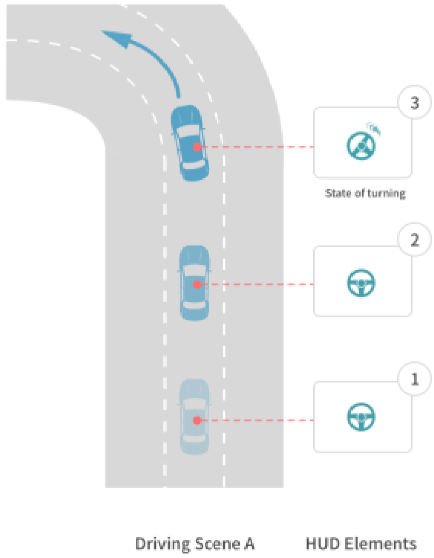

Figure 5: Horizontal control information

4. Acceleration and deceleration

Acceleration and deceleration are not different than driving at a constant speed. When people are not driving the car themselves, their feet are not on the pedals, so they cannot tactically transmit information about vehicle acceleration and deceleration control. Instead, they can only analyze the results of changes in vehicle speed afterward. To compensate for this loss of tactile feedback, we aim to utilize visual design. We have designed visual dynamic elements. Acceleration and deceleration during machine driving can be presented to the driver through graphical changes (**Figure 6**).

Figure 6: Acceleration and deceleration information

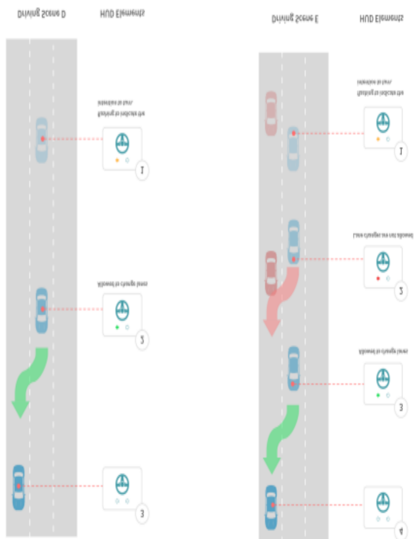

Figure 7: Intent to change lanes

5. Changing lanes

The intention to change lanes is an example of an activity at the tactical level, but it is also closely linked to the operational level. Current autonomous driving offers a lane change function that allows the machine to determine the timing of the lane change when the driver decides to change lanes. Turn signals are essential while changing lanes. Therefore, the element of turn signals is added to express the intention of the machine, and the mode of operation of the turn signals is explained below.

(1) When a machine initiates a turn (e.g. right turn), the right turn indicator will light up.

(2) If the machine decides that it is now possible to turn, the light turns green and the turn is then made.

(3) If the machine decides that it cannot turn at the moment, it turns red. The machine will observe the traffic through its sensors and once the time has come to change lanes, the turn signal turns green.

6. Conclusion

We designed the machine's autonomous driving behavior to be transparent so that in the case of autonomous driving, humans can observe the machine's actions at the operational level, allowing them to assess the machine's behavior and intentions, including directional control, acceleration, deceleration, and turning intentions.

In the future, we plan to conduct an empirical study through simulation to determine the feasibility of our conceptual design. These include testing the user's reaction time, situational awareness, and trust in the machine. Reaction time may be an important piece of evidence, as we will record the time it takes for the user to feel the lateral movement, acceleration, and deceleration of the vehicle. We will then compare the user's reaction time with the actual lateral and acceleration/deceleration times of the vehicle to verify the validity of the design. The design will also be further refined based on the data of the experiment.

As autonomous driving technology advances, according to the latest SAE automation classification (J3016, APR2021), future intelligent cabins of L4 and above may likely not have physical steering wheels, throttles, or brakes [14]. Therefore, making machine behavior transparent may become increasingly important for building human trust, enhancing human situational awareness, and improving user experience. Enriching machine behavior through HMI may be a good way to achieve this goal.

Disclosure statement

The authors declare no conflict of interest.

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