Review

Driver Behavior and Active Safety (Overview)

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Abstract

Active safety systems are gradually becoming practical with advances in environmental sensing and vehicle control technologies. Analyses of driver errors leading to road traffic accidents, however, have shown that drivers still make mistakes in their cognition of the external world and in judging between safe/not safe.

Research into drivers' behavior and active safety has advanced with improvements in driver support technologies that help compensate for the cognition, judgment, and actions of drivers. This paper introduces recent trends in research based on the above viewpoints.

Keywords: Driver behavior, Active safety, Driver support system, Human error, Human-machine cooperative system, Cognition, Judgment, Operation, Risk, Workload

1. Introduction

Motor cars are a very commonplace means of transportation, especially when compared to public transport. We can make journeys whenever we like without the constraints of a timetable, going wherever we want without being tied to rail routes, and without having to carry heavy baggage. The number of private cars in Japan continues to increase, having reached 54,471,376 in March 2003 or, in other words, 1 car for every 2.3 people. Detracting from this convenience, road traffic accidents have become a problem. Thus, there is a need for a means of reducing the number of road traffic accidents without compromising the convenience that cars offer us. As a result, much research is currently being done in the field of active safety.

Active safety systems are gradually becoming practical with advances in environmental sensing and vehicle control technologies. On the other hand, analyses of driver mistakes, referred to as "human errors", in road accidents has shown that drivers continue to make mistakes in the cognition of their external world and in judging between safe/not safe. So, research into driver behavior and active safety is being performed to develop driver support technologies that take the characteristics of a driver's cognition, judgment, and actions into account.

This special issue centers on this viewpoint and focuses on research into driver behavior. The Toyota CRDL R&D Review has already published special issues dealing with active safety. Special issue,[1] published in 1998, took the theme "Analysis of Driving Maneuvers for Active Safety." It dealt mainly with the analysis of driver behavior in emergency situations.[2, 3] Special issue,[4] published in 2002, focused on "Millimeter-Wave Radar for Automotive Applications" and explained how performance gains in millimeter-wave radar have allowed it to be applied to the detection of vehicles ahead.[5, 6] The previous special issue[7] (published in 2004) on "Speech-Based Interfaces in Vehicles" dealt with the use of speech-based interfaces to operate in-vehicle information equipment. The central themes of this issue were related to ensuring that safety is not compromised while driving, methods of evaluating the safety of verbal interfaces,[8] and voice information systems that adapt to a driver's mental workload.[9]

In this issue, we will first present statistics on road traffic accidents in Japan and analyze the human errors that lead to those accidents. We will also review recent advances in research into drivers' behavior and driving support systems. (This is mainly taken from recent Toyota CRDL R&D Reviews, the Proceedings of the ITS World Congress, the Proceedings of the International Technical Conference on the Enhanced Safety of Vehicles, and so on.) Finally, we introduce the papers presented in this issue.

2. Human error and road traffic accidents

According to Japanese statistics on the number of road traffic accidents, casualties and fatalities, even though the number of fatalities has fallen steadily since 1992 to reach 7,702 last year, the number of road traffic accidents and casualties has actually increased steadily since the latter half of the 1970s, reaching 947,993 accidents and 1,181,431 casualties last year. If we divide the number of casualties by the population of Japan, we find that the probability of a person being injured is 0.93%. That is, approximately 1 in every 100 people each year. Given the ratio of casualties to fatalities, we can say that one person in every 150 casualties will die each year in a road accident.

First, let's consider the factors that contribute to the occurrence of accidents. Those factors that are directly related to people - the so-called "human errors" - has been examined by considering a car to be a cooperative human-machine system and through the analysis of about 300 road traffic accidents[10] by the Institute for Traffic Accident Research and Data Analysis (ITARDA). When human errors are grouped into three categories, namely, cognitive errors (ex. errors caused by oversights), judgment errors (ex. wrongly judging that the other vehicle will stop) and operation errors (ex. failing to apply the brakes strongly enough in an emergency), they are found to constitute 47%, 40%, and 13% of the total, respectively, meaning that cognitive errors and judgment constitute about 90% of all human errors. When the reasons for cognitive and judgment errors are analyzed, we find that about half of the cognitive mistakes are caused by "carelessness" and "mistaken assumptions", while about half of the judgment mistakes are caused by "mistaken assumptions".

Watanabe et al.[11] investigated the visual checks made by drivers to ensure that it was safe to cross an intersection without traffic signals. It was found that, in the case of about half of the 172 observations, the driver failed to check the conditions adequately or was too late. Such drivers seem to assume that there will be no other vehicles in the intersection, so do not confirm that the conditions are safe.

The development of driver support systems that address the mistakes made by drivers requires that we consider those driver characteristics that require support, including the activation conditions, driver conditions, degree of support and the timing of that support. Furthermore, we know that driver characteristics are not fixed - a driver's skills can be improved by training or, on the other hand, he or she can become dependent on equipment and become careless.[12] All these points must be kept in mind when developing a driver support system.

3. Overview of research into driver behavior and driving support systems

Here, we review the trends in research related to driving support systems for active safety and reducing the driving workload from the viewpoint of human-machine cooperative systems, with an emphasis on the relationship between the driver's behavior and the support systems.

Driving a car involves a kind of human-machine cooperative system like that shown in **Fig. 1**. It seems that the role of the driver is considerable. Roughly speaking, the machine plays the role of the feet of a person, while the driver plays the role of cognizing the frontal situation , determining what is safe, and issuing instructions to move forward, turn, or stop.

Figure 2 is a block diagram of a human-machine cooperative system that was constructed based on Fig. 1 with the addition of driver support systems.

Driver support systems aid some parts of the driver's cognition, determination or actions. The system consists of an environment sensing block that corresponds to the driver's cognition, a block for determining risk (where risk roughly corresponds to

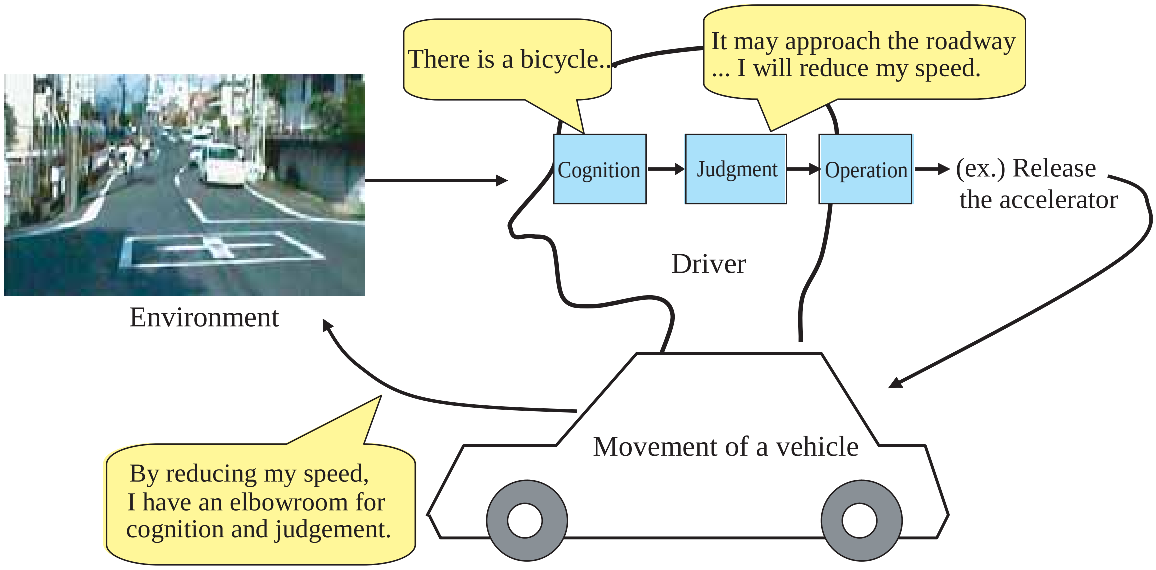

Fig. 1 Block diagram of a vehicle regarded as a human-machine cooperative system.

the possibility of an accident occurring), and so on.

The first block at the far left senses information that is important to safety by using hardware such as radar,[4, 13] cameras, or GPS to sense lane markers,[13, 14] vehicles in front, or pedestrians.[15, 16] Some technologies for augmenting human cognitive abilities are being developed. For example, a nighttime sight augmentation system has recently been developed that irradiates infrared light ahead of the vehicle and uses an infrared camera to detect reflections from pedestrians etc. and presents an image to the driver.[17]

The environmental sensing module roughly corresponds to the cognitive functions of the driver, while the risk-judging module corresponds to the judgment of the driver. Various risk judgment criteria exist according to the application, such as available information, alarms, and intervention. For example, in the pre-crash safety system shown in Ref. 13, the risk judgment criterion attempts to judge the risk of a collision occurring based on the location of an obstacle as detected by the radar sensor and the direction of travel of the car, after which the system judges whether to activate the pre-crash brake assist and/or the pre-crash seat belt.

A driver support system cooperates with the driver as a human-machine cooperative system. That is, if the risk determined from the results of sensing of the frontal environment is great, the final decision to activate (display of information, issue of warning, or takeover of vehicle control) is not reached based on this information alone. It is also assumed that the driver's cognition, judgment, and actions are sufficient to assure safe driving. Should these be insufficient to assure safety, the system acts as described above. There may be cases, however, where the driver will be irritated by the issue of the warning because he/she is aware of the situation.

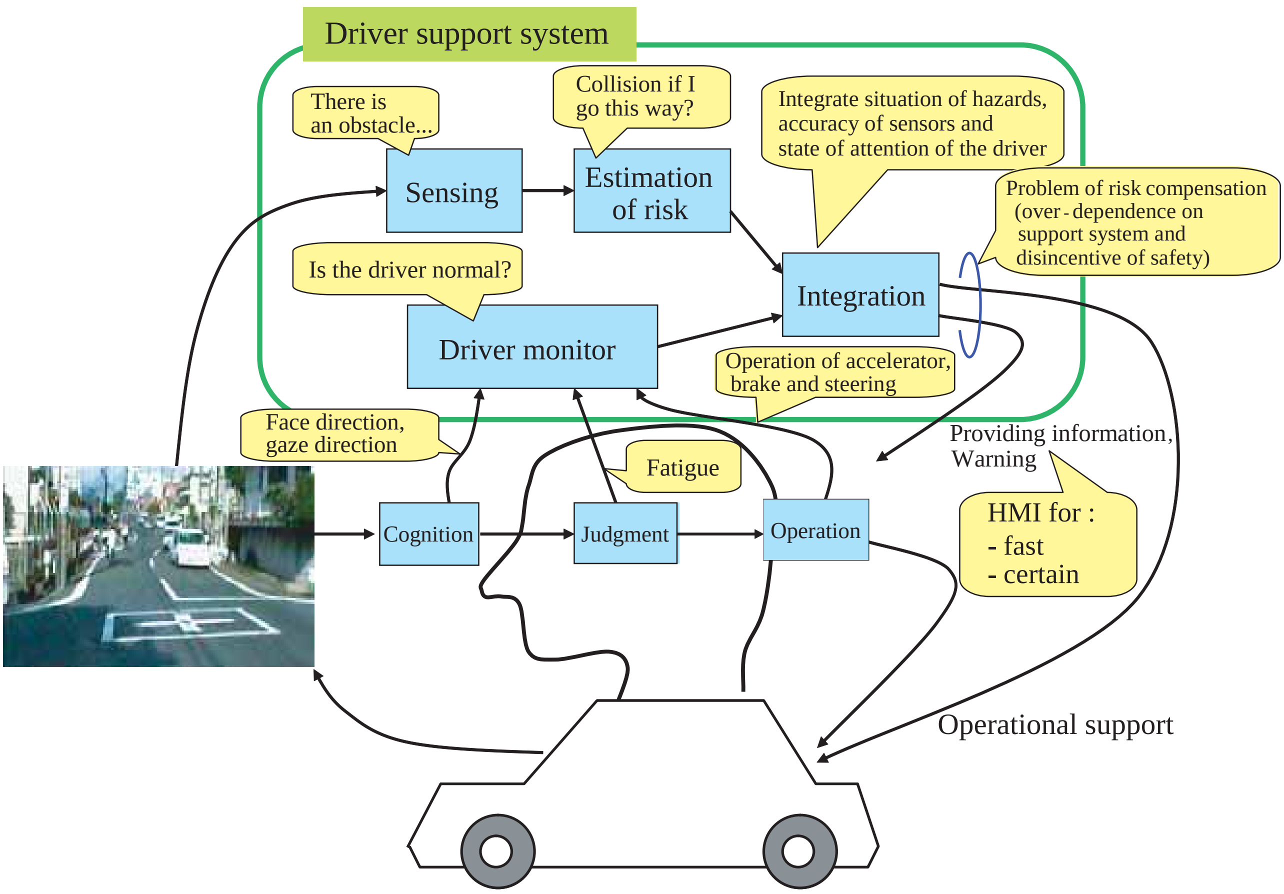

Fig. 2 Block diagram of a human-machine cooperative system including driver support systems.

Several research projects have studied the sensing and estimating method of driver's state to be unified with the risk judgment estimated based on the result of sensing the frontal environment. Tsugawa et al.[18] considered a system that monitors the driver's gaze, judges whether the driver is concentrating on the task in hand, and adjusts the assistance parameters accordingly. The "lane-keeping" support system[15] senses the distance between the car and the lane markings, estimates the driver's intention to change lanes based on the state of the direction indicator and determines whether lane-keeping control is necessary. The collision warning system described in Ref. 19 uses the distance between the car and the vehicle in front as environmental sensing information, estimates the driver's intention to brake, and determines whether it is necessary to sound a collision warning.

According to the aforementioned integrated risks that are given by the risks determined from sensing of the frontal environment and driver state, the output of information, warnings, or operational support are selected as the output of the driver support system. There is a need to select the most appropriate type of output considering the accuracy of the information and the urgency. For example, when a collision is judged to be inevitable within the next few seconds, a pre-crash safety system should be activated. Other research has concentrated on how to provide information and warnings while the driver is at the wheel, with an emphasis on how to provide information intelligibly and precisely in as little time as possible. To provide information on an in-vehicle display, especially, a high level of visibility is needed so that the driver does not have to take his/her eyes off the road to study the display. To improve such displays, a technology is being studied that uses image processing to compress and store the necessary information into the narrow dynamic range of the display.[20] A computer simulation method has been developed that simulates the visibility of such a display based on the eyesight of older people and a display method that compensates for any degradation in the driver's eyesight.[21] A decision method is being studied to determine the character sizes and colors used in an in-vehicle display based on the driver's eyesight.[22] And, regarding warning sounds, the characteristics of auditory qualities relative to system priority are being studied.[23]

As mentioned above, there is a need to consider the support contents including items, activation conditions, driver state, amount of feedback and timing of that feedback based on the typical mistakes made by a given driver. Though the characteristics of drivers are not fixed: they change with the individual driver and his or her experience including habituation of the support system. From this viewpoint, several trials have examined how a system can adapt to a driver to detect unusual (unsafe) driving behavior.[24]

There is a phenomenon that we know as "risk homeostasis". This refers to the fact that, although accidents decrease immediately after the introduction of a given safeguard, the number of accidents inevitably returns to the original level after a while.[12] This phenomenon can be explained by the fact that a driver consumes the safe margin obtained by the safeguard by driving more dangerously. A theoretical study has examined the improvement in safety provided by driver support systems using a risk perception model in which a driver perceives his/her risk and changes his/her driving behavior (ex. increases his/her speed when the risk is low) so that the risk taken rises to a level with which he/she is comfortable.[25] Concerning risk perception by a driver and changes in his/her driving behavior, some studies have examined the over-dependence of drivers on driver support systems. A study of this has evaluated compensation behaviors such as a lack of attention resulting from a reduction in the workload realized by driver support systems.[26] Another research project has examined how the parameters of a support system can be adjusted so that the driver does not enter a state of over-dependence.[27]

The performance of a driver including his/her cognition, judgment, and actions is influenced by the mind-and-body state of the driver. The most extreme case is the driver becoming sleepy so that, to date, several research projects have attempted to develop technologies for detecting a driver's degree of sleepiness.[28, 29] Even if the driver does not actually fall asleep, the driving performance will fall as a result of fatigue brought on by his/her workload. Several research projects have examined methods of measuring and evaluating mental workloads.[30, 31) A joint research project between Japan, the U.S., and Europe has examined a method of measuring a driver's performance in recognizing an important dangerous object by peripheral detection to ensure safe driving.[32)]

4. Contents of this special issue

Figure 3 illustrates the three papers presented in this special issue:

(1) Research into a method of estimating a driver's subjective risk from the driving operation feature

(2) Research about a method estimating risks from hazard information

(3) Research about a method of adapting the timing at which a warning is issued based on a driver's personal characteristics

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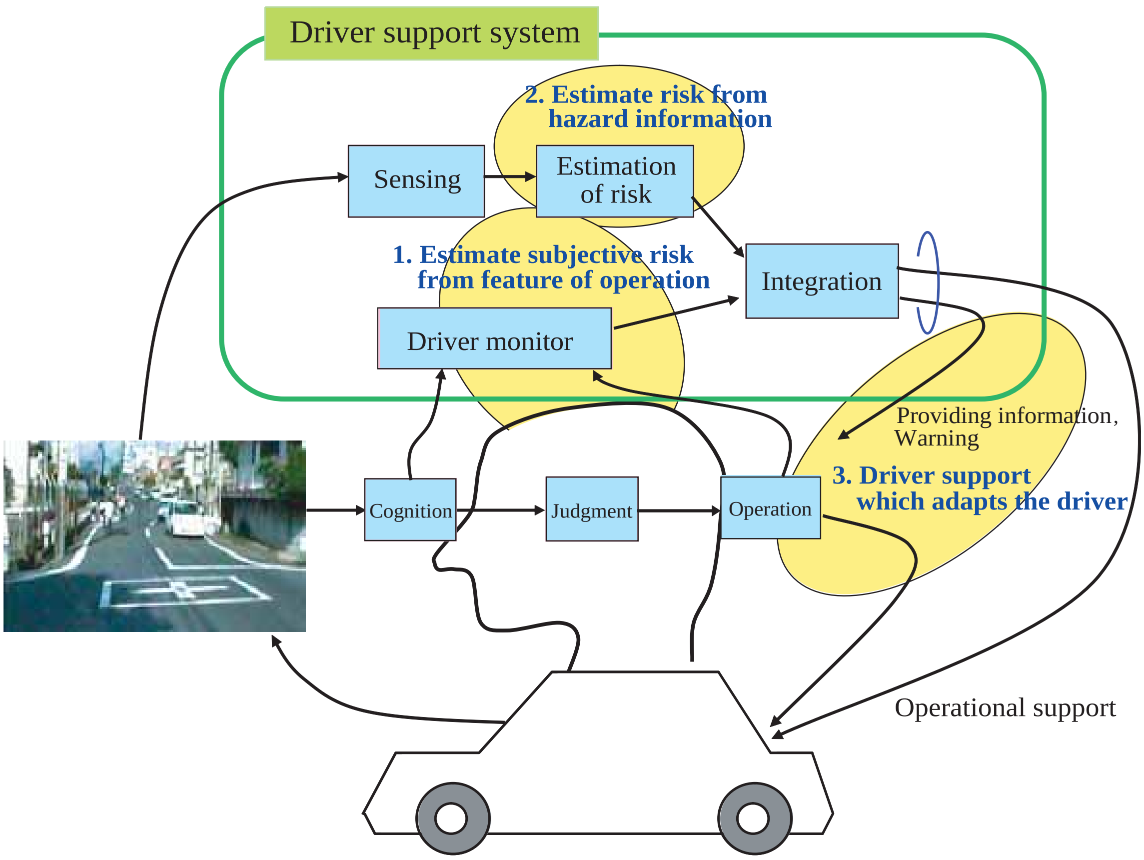

Fig. 3 Contents of this special issue.

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