Multimodal Interface for Driving-Workload Optimization

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Abstract. Today, driving convenience has increased greatly owing to the availability of various telematics devices developed recently. However, this convenience often comes at the cost of driving safety. With the aim of achieving a balance between them, we propose a multi-modal interface for optimizing driving workload and describe an efficient design for the interface. To demonstrate the effectiveness of the interface, we use it in a simulator environment resembling real driving situations, designed to allow the interface to detect and analyze states of both the driver and the vehicle in real time. The proposed interface transfers information by optimizing the driving workload such that it within a range appropriate in view of driver safety. In the future, we intend to demonstrate the feasibility of the proposed interface through multiple experiments.

Keywords: Driving-Workload Optimization, Multi-Modal Interface, Telematics Devices, Vehicle Simulator, Human-Computer Interaction (HCI).

1 Introduction

Today, numerous telematics technologies, i.e., technologies developed by integrating telecommunications with information processing, are applied in vehicles. One such developmental application of this technology to vehicles is to increase the safety or convenience of drivers by providing them with necessary information such as warnings and information on emergencies and traffic situations. However, under certain conditions, there is a high probability of traffic accidents if the driving workload is high [1-2]. Thus, it is necessary to reduce the driving workload through the effective design of interactions between the telematics device and the driver. Among all the information transmitted to a driver driving a vehicle, some information is more important than the other is. Therefore, it is important to prioritize the information transferred to the driver in the case of two or more types of information; then, it would be beneficial to have a tool that would achieve this. One such tool is an adaptive multimodal interface, which facilitates information transfer using an appropriate modality determined on the basis of the driver state. The performance of this tool in prioritizing

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information and determining modality is affected by various factors such as conditions in the surroundings of the driver, examples of which include movement of vehicles and road situation. In this paper, this movement of vehicles is referred to as the driving task (DT) and the road situation is referred to as the environment task (ET). Using these definitions and concept, we develop a multimodal interface for optimization of the driving workload. The developed interface decides the priority of each type of information transferred to the driver from telematics devices such as mobile phones and navigation systems. Next, it selects one transfer modality from among the visual, auditory, and tactile modalities, and it thereafter classifies and controls that modality's level and transfer time, respectively.

In this study, we validate the effectiveness of the proposed interface by developing an effective design for it. As future work, we intend to verify our results experimentally. As a part of the proposed design, we first create an experimental scenario for each module and build an experimental environment for the scenario. To test the effectiveness of the method that decides the priority of each type of transferred information, the interface first creates a scenario for four driving situations of high importance in real life. Subsequently, we design and construct the interface according to the created scenario. Next, to verify the method that selects modality and its level, the interface transfers the same information to a driver using different modalities. Thereafter, it monitors the driver's feedback and checks her/his driving workload. To this end, the interface simulator is equipped with camera-based eye-tracking equipment and a biological signal measurement device. These devices measure, compare, and analyze the driving workload.

An interface simulator is designed to emulate the actual driving environment. In addition, it sends information to drivers in an actual vehicle at an appropriate time and modality level. Therefore, the proposed interface not only reduces the driving workload but also provides effective information. Furthermore, we expect that the proposed interface will enhance the driver safety. To verify the proposed interface design, we intend to experimentally test it on multiple subjects in the future.

2 Proposed Interface

The proposed multimodal interface consists of four modules: the message input module (MIM), priority decision module (PDM), interaction-managing module (IMM), and message output module (MOM). First, the interface provides more than one type of information as input to the MIM, after which it determines the order of the transferred information using the classified information priority in the PDM. For this, the interface first classifies information with their attribution; subsequently, the information is ordered by weighting importance using a two-task-based classification method. Next, the IMM of the interface selects the most efficient modality for the driver among the visual, auditory, and tactile modalities, and it then controls the modality's level. In this paper, we define the modality level as the transfer strength of modality. Finally, the interface adds any other modality in the absence of feedback from the driver. The proposed interface limits the increase in the driving workload by transferring information using the minimum of a number of modality and its level.

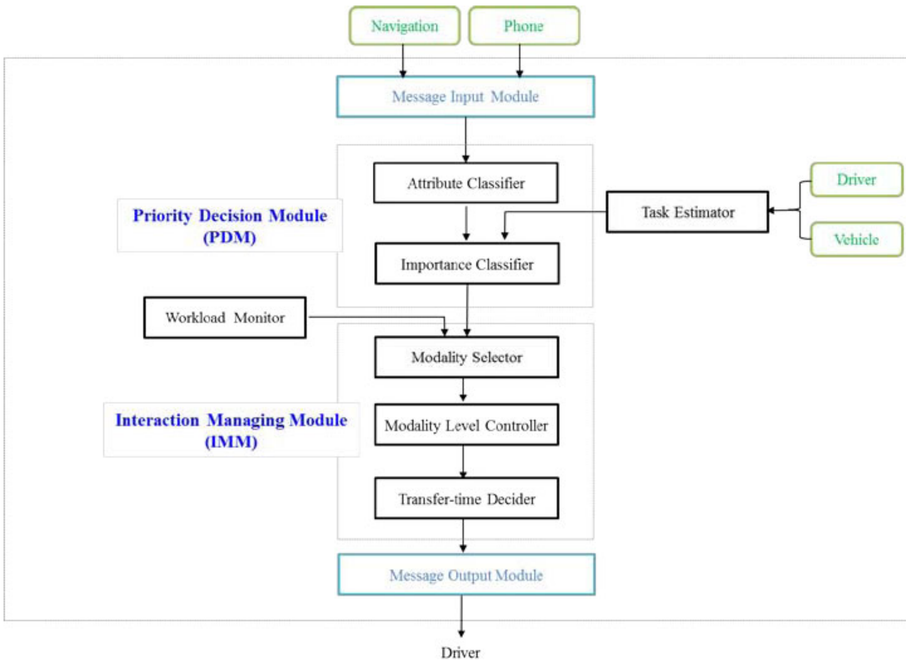

Fig. 1. Proposed interface

The proposed interface, shown in Fig. 1, first provides the PDM with information from a navigation system or phone as input and then orders each type of input information using the corresponding classified attributes and priority weights. Finally, the interface selects an appropriate modality and controls its level with the minimum driving workload.

2.1 Priority Decision Module (PDM)

A vehicle driver may be able to drive more safely and effectively if s/he receives a large amount of information. However, information overload, improper timing of transfer, and unsuitable transferring devices not only increase the driving workload but also interfere with safe driving. Thus, it is essential to first identify the numerous properties of the information given to the driver. Among these properties, the interface classifies the transferred information in terms of its properties of constancy, urgency, and timeliness. Constancy refers to the property that the information is always provided to the driver, whereas urgency is the property that the information provided is of immediate importance to the driver. Timeliness refers to the property that the information should be provided at an appropriate time according to the driving situation. These properties are hereafter referred to as attributes. The proposed interface selects one of these three attributes whenever an input is entered. The interface then classifies both the information transferred from a navigation system or phone and the measured state of the vehicle or driver from sensors into one of the above three attributes (Table 1).

Table 1. Classification results of information transferred from telematics devices to driver and measured state of vehicle or driver into attributes

Class 1	Class 2	Transferred Information	Attribute
Driver State	Safe	Physiological state problem Alarm	Urgency
	Safe	Drowsiness Alarm	Urgency
	Safe	Distraction caused by dialogue in vehicle Alarm	Timeliness
Vehicle State	Safe	CO_2 problem in vehicle Alarm	Urgency
	Safe	Obstacle Alarm	Timeliness
Navigation	Driving	Speed limit Alarm	Timeliness
	Driving	Road rise against over-speed Alarm	Timeliness
	Driving	Rapid turn Alarm	Timeliness
	Driving	Overload vehicle enforcement Alarm	Timeliness
	Driving	Bus zone enforcement Alarm	Timeliness
	Driving	Major accident Alarm	Timeliness
	Driving	Wild animal zone Alarm	Timeliness
	Driving	School zone Alarm	Timeliness
	Driving	Driving Alarm (turn left/go straight…)	Timeliness
	Driving	Driving direction Alarm	Timeliness
	Driving	Entrance Alarm	Timeliness
	Driving	Crossroads Alarm	Timeliness
	Driving	Underground Alarm	Timeliness
	Driving	Highroad Alarm	Timeliness
	Driving	Bifurcation Alarm	Timeliness
	Driving	U-turn Alarm	Timeliness
	Driving	P-turn Alarm	Timeliness
	Driving	Highway Alarm	Timeliness
	Driving	Tunnel entrance Alarm	Timeliness
Phone	Etc.	Receiving a call Alarm	Urgency
		Receiving an SMS Alarm	Timeliness

In the PDM of the proposed interface, the information entered as input is classified into one of the above three attributes as indicated in Table 1. The PDM classifies the obstacles access notification into urgency, whereas it classifies other types of information into timeliness because information entered as input from a navigation system while driving is mostly related to the speed limit or certain special areas such as school zones. Next, in the case of information received through phones, the interface can either activate the SMS service or identify calls that should be made after stopping the vehicle, because the interface prioritizes safe driving. This is explained as follows. If the sender's name is stored in the phone's address book, then the interface identifies that this call is important and subsequently classifies it as an emergency. When the interface determines that the driver cannot take the call immediately, it activates the SMS service and automatically replies to the sender with a message such as "Driving now, will call later."

The proposed interface estimates the ET (environment task) based the current driving situation with driver and vehicle states, which are observed by cameras or other devices, after classifying the information attributes according to Table 1. It can be different to the weighting importance and order of information despite providing the same information. The ETs consist of the vehicle state, driver state, and information transferred from the navigation system and phone; it is affected by surrounding roads, obstacles, and the cost of failing to acquire information about them. DTs (driving tasks) include seven driving actions—left turn, right turn, acceleration, deceleration, U-turn, change from left lane to right lane, and change from right lane to left lane. In reality, actual driving situations are very diverse. Therefore, because it is difficult to estimate each such situation, we select the most typical driving situation that would be encountered while driving and estimate them experimentally in this study. The experimental results are then input to the information classification module. The selected driving situations and the subsequent information provided to the driver are listed in Table 2.

Table 2. Driving situations based on ET and subsequently transferred information

Included Scenarios / Case No.	Driving Situations	Transferred Information
Case 1	Highway, Speeding, Speed camera, Bifurcation, Rear obstacle, Major accident zone	- Bifurcation Alarm - Major accident Alarm - Speed limit Alarm - Obstacle Alarm - Camera speed enforcement Alarm
Case 2	Alley, U-turn, Appearance of a pedestrian, Speed limit region, School zone	- U-turn Alarm - Speed limit Alarm - Driving road Alarm - Obstacle Alarm - School zone Alarm
Case 3	Highway, Drowsiness, Tunnel entrance, Wild animal zone, Lane change	- Drowsiness Alarm - Tunnel entrance Alarm - Lane change Alarm - Wild animal zone Alarm - Obstacle Alarm
Case 4	City road, Hyperventilation, Cold sweats, Work zone, Vehicle blocking, Appearance of a motorcycle, Receiving a call	- Physiological state problem Alarm - Work zone Alarm - Vehicle blocking Alarm - Obstacle Alarm - Receiving a call Alarm

The PDM processes all input information according to the priority determination process shown in Fig. 2. Then, it considers the information attributes and information importance.

As shown in Fig. 2, the PDM first checks whether more than two types of information have been input; if yes, then that information is entered as input, and the priority of each type of information is determined by classifying its attributes and importance. At this point, the database for the weighting importance based on the two tasks (i.e., ET and DT) is used in the method in [3]. Transferred information for each priority is provided to the driver with the most appropriate modality and at a moderate level, in the way described in Section 2.2.

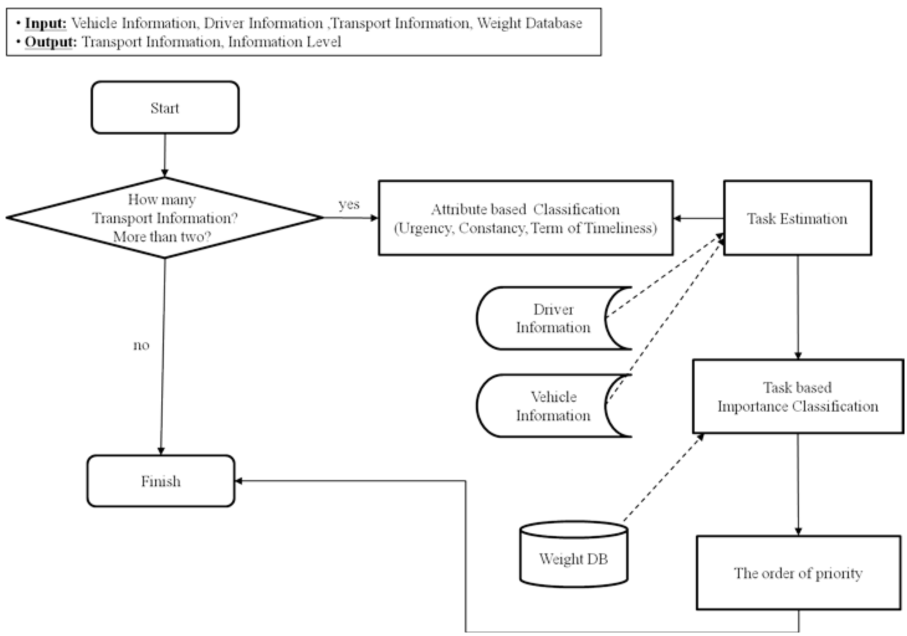

Fig. 2. I/O processing sequence in priority decision module (PDM)

2.2 Interaction-Managing Module (IMM)

This module not only reduces the driving workload but also effectively provides transferred information by determining the means of transferring "what, how, and when," after the priority of the information entered as input is determined. The proposed interface transfers information to the driver using one out of the following three modalities: visual, auditory, and tactile. By default, navigation information is provided through the visual and auditory modalities because these modalities are most efficient. However, in certain circumstances, these two modalities divide. Drivers get nearly 90% of their information about the driving situation through the visual modality [4]. Nevertheless, when driving, drivers still get the feeling of a high driving workload because they must maintain a frontward gaze. Consequently, it is very important to select the appropriate modality to ensure efficient transfer and driving safety. For this purpose, the IMM first selects a modality by comparing the visual and auditory modalities. Subsequently, it supplements the selected modality with additional modalities or changes the level of the modality by checking the driver's cognitive ability. To this end, our interface efficiently provides information such that drivers get the feeling of minimal driving workload. Fig. 3 describes the I/O processing sequence in the IMM.

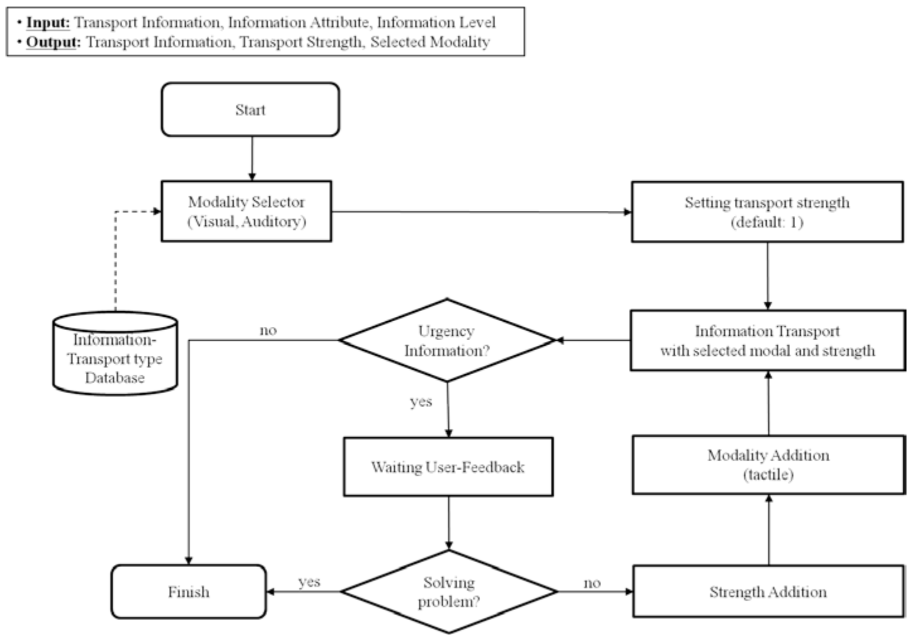

Fig. 3. I/O processing sequence in interaction managing module (IMM)

First, the IMM selects the modality on the basis of each measured driving workload from among the visual, auditory, tactile, and cognitive modalities when the information is input. As stated previously, the IMM compares the visual and auditory modalities and then selects the modality with a lower workload. The selected modality is kept at the minimum level by default, after which the IMM changes the level according to the importance of the transfer and the results of the observed driver feedback. Thus, the level of the selected modality may gradually increase; alternatively, other modalities may be added. To achieve this, the IMM detects the states of the driver and vehicle in real time and monitors the driver's feedback with changes in these two states. For example, when the system detects drowsiness, it sounds an alarm until the driver recognizes it and wakes up. At this point, the system detects the driver's state using a camera-based device via three measures related to the driver's eyes. The first measure is variations in pupil size (i.e., pupil opening); this measurement is an effective approach for detecting the workload [5,6]. The second measure is eyelid movement, whose measurement is useful in determining driver fatigue [7,8]. For this measurement, the IMM uses a measure very similar to the percentage of eye closure (PERCLOS). To calculate this measure, the IMM determines the period for which the driver does not blink. In this study, we determine the driver's drowsiness using PERCLOS. The third measure is the gaze trail (trajectory), which is used to determine the extent of the driver's distraction. In our simulator, we use faceLab-5 as the gaze estimation device. To detect the driver's eye, the threshold of 0.75 is set for the device, based on experimental results. Generally, if the driver's gaze departs from a predetermined area, then the IMM determines that s/he is distracted while driving.

On the other hand, we also detect and measure the state of the vehicle using the methods established in [9].

3 Experimental Environment and Design

To verify the effectiveness of the proposed interface, a real simulator environment as shown in Fig. 4 is set up. The left side of the figure shows the actual simulator environment. A detailed explanation of this experimental environment is given below.

Fig. 4. Experimental environment of the proposed interface

3.1 Driving Simulator

The simulator was developed in a laboratory at Kookmin University[1]. The proposed interface was operated in this simulator environment. The simulator has a pc-based full-scale environment with three front channels and one rear channel. Therefore, it can generate realistic and highly graphic images and simulate vehicle movements resembling those in real driving with roll and pitch. In addition, it is equipped with a monitoring system, a device for measuring physiological signals, and an eye-tracking device. We describe them in detail below.

a) Physiological signal measurement device
For measuring the physiological signals, we use the MP100 data acquisition system (BIOPAC, USA), which can detect and analyze various physiological signals using up to 16 channels. The system consists of MP100A-CE and UIM 100c, which are the data acquisition unit and universal interface module, respectively. The system has various cables and USB adapters. We use Acqknowledge-3.7 as the analysis program.

[1] This work was partly supported by the Vehicle Control Laboratory in the Graduate School of Automotive Engineering at Kookmin University in Korea.

b) Eye tracking device

For eye tracking, we use the faceLab-5 system developed by Seeing Machines, Australia. The system extracts gaze direction and estimates eye and head movements. In addition, it detects the pupil size, eye opening, and PERCLOS. The system consists of two digital cameras and one infrared illumination. We operated an additional camera as the scene camera. Data were acquired and analyzed through data synchronization with connections to two note-PCs using IEEE 1394 and USB interfaces.

4 Conclusions and Future Directions

Owing to the availability of a multitude of electronic automotive devices developed in recent times, it is now possible to obtain more information for ensuring convenience and decreasing monotony for drivers. However, these opportunities may at times pose a threat to driver safety, because increase in information received causes an increase in the driving workload. The proposed multimodal interface optimizes the driving workload and controls the information transferred to the driver by considering the driver's state using various measurement devices. The proposed interface is designed with a real driving simulator, and it analyzes and detects the states of the driver and vehicle using the setting devices. Subsequently, the interface estimates the workload and the driving tasks. In addition, it determines the modality, level, and timing of transferred information using the estimated workload. In a future study, we intend to experimentally test the effectiveness of the interface in various other driving situations and involving a large number of drivers. Then, if the interface proves to be effective, we can aim to equip cars with it so as to make them driver-oriented futuristic intelligent cars.

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References

1. Koo, T.-Y., Park, K.-J., Kim, B.-Y., Kim, H.-J., Suh, M.-W.: A Study on Driver's Workload of Telematics using Driving Simulator - A Comparison among Information Modalities. International Journal of Precision Engineering and Manufacturing 10(3), 59–63 (2009)
2. Road Traffic Safety Authority (South Korea): Statistical Analysis of Traffic Accident: RTSA Annual Report, pp. 61–70 (2005)
3. Kwon, H.-J., Kim, D.-J., Park, H.-S., Kim, K.-H., Hong, K.-S.: A Method for Evaluation of in-vehicle Information Level for Driving Workload Optimization. In: Proc. of the Summer Conference of Korea Institute of Signal Processing and Systems, vol. 11(1), pp. 178–181 (2010)
4. Cohen, A.S.: Feed Forward Programming of Car Driver's Eye Movement Behavior - A System Theoretical Approach: Final report volume one (1980)

5. Tyeruna, L., Gleckler, M., Stoltzfus, D., Johnson, S., Goodman, M., Wierville, W.: A Preliminary Assessment of Algorithms for Drowsy and Inattentive Driver Detection on the Road: Tech. Rep. DOT HS 808 (1999)
6. Ahlstrom, C., Kircher, K., Kircher, A.: Considerations when Calculating Percent Road Centre from Eye Movement Data in Driver Distraction Monitoring. In: 5th International Driving Symposium on Human Factors in Driver Assessment, Big Sky, MT, US, pp. 132–139 (2009)
7. Palinko, O., Kun, A.L., Shyrokov, A., Heeman, P.: Estimating Cognitive Load using Remote Eye Tracking in a Driving Simulator. In: Proc. of the 2010 Symposium on Eye-Tracking Research & Applications, ETRA 2010. ACM, New York (2010)
8. Hanowski, R.J., Bowman, D., Alden, A., Wierwille, W.W., Carroll, R.: PERCLOS+: Moving Beyond Single-metric Drowsiness Monitors: SAE Technical Paper Series, Commercial Vehicle Engineering Congress & Exhibition (2008)
9. Yoon, D., Choi, J., Kim, K., Kim, H., Narayanan, H.: Attention Based Driving Event Simulator for Telematics Environment. In: Proc. of the International Conference on Advanced Communication Technology, vol. 1, pp. 757–759 (2009)