Research Report

Voice Information System that Adapts to Driver's Mental Workload

Yuji Uchiyama, Shinichi Kojima, Takero Hongo,
Ryuta Terashima, Toshihiro Wakita

Abstract

With in-vehicle information systems, there is a danger of voice messages causing the user to be distracted while driving. To reduce this danger, the ideal would be for the system to adapt to the driver's mental workload. Such an adaptive system would deliver voice messages only when the driver's mental workload was low, and suppress messages whenever his or her workload is high. Therefore, such a system would have to be able to estimate the current driver workload from the outputs of the car's sensors such as the speed, steering wheel angle, and accelerator pedal position. To establish a relationship between the driver's mental workload and the data that is output by the car's sensors, a dual-task experiment was conducted on a public road. In this experiment, participants performed a memory-task while driving a test car. At the same time, the data from the car's sensors was recorded. The correlation coefficients linking the performance of the memory-task to the data received from the car's sensors showed that the driver's releasing the accelerator pedal was the most significant indicator of workload. Based on these results, a workload estimation model was developed, which was then applied to a voice information prototype system in a test car. The driving situations in which the system postpones the delivery of voice messages were then confirmed.

Keywords: Driver distraction, Mental workload, Dual-task method, Secondary task, Adaptive interface, Voice information system, In-car information system

1. Introduction

In recent years, the development of information technology has led to the rapid spread of sophisticated in-vehicle information systems such as car navigation devices. In Japan, the estimated penetration rate for car navigation systems was about 20% in 2002.[1)] Most modern systems use voice outputs to safely guide the driver to his or her destination. Some systems receive traffic information using FM multiplex broadcasting, while others are connected to the mobile phone network to allow the driver to retrieve a large variety of useful information.

There is a risk that, in a demanding situation, a driver may be too absorbed to "catch" the voice messages output by the in-vehicle information systems. Previous research using a dual-task method while driving suggested that the performance of secondary verbal tasks depends on the driving situation.[2-6)]

To be effective, the voice messages output by an in-vehicle information system must be clear and precise. Otherwise, the driver would have to resort to pushing buttons or watching a screen to determine the information that the system was trying to convey. Doing so is very likely to distract the driver's attention.

So, there is a definite need for in-vehicle voice information systems to be able to adapt to changes in the driver's mental workload.[7-9)] Whenever the driver is busy, the system would postpone the output of a voice message.

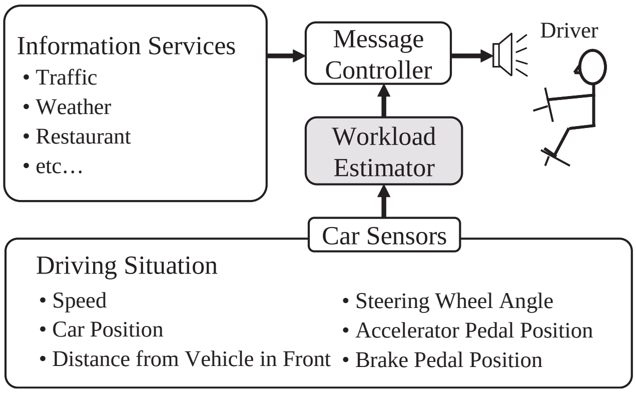

Fig. 1 Diagram of voice information system that adapted to driver's mental workload.

Figure 1 is a schematic of such a system. The system's main purpose is to deliver voice messages from information services. A workload estimator indirectly judges whether the driver's workload is high or low based on the data being received from the car's sensors. While the estimated driver's workload remains high, the message controller postpones the delivery of the voice messages. Once the estimated driver's workload falls, the message controller conveys the voice messages to the driver.

In this system, the workload estimator is the key component. The estimator must not use physiological sensors that are attached to the driver, but can use the car's sensors such as those for speed, steering wheel angle, and accelerator pedal position. The estimator must be able to estimate the driver's workload in real time at least, and be capable of prediction, if possible.

Development of such a workload estimator demands that we first clarify the relationship between the driver's mental workload and the driving situation. Some previous studies have investigated and found a correlation.[2-6)] Unfortunately, these studies tended to concentrate on the relationship between mental workload and the state of the road. Furthermore, merely knowing the correlation between the mental workload and the car sensor outputs is insufficient.

The purpose of this study was to establish a correlation between the level of the driver's mental workload and the output of the car's sensors by using a dual-task method on public roads (**Fig. 2**), and to investigate the behavior of the prototype adaptive system in a test car based on the determined relationship.

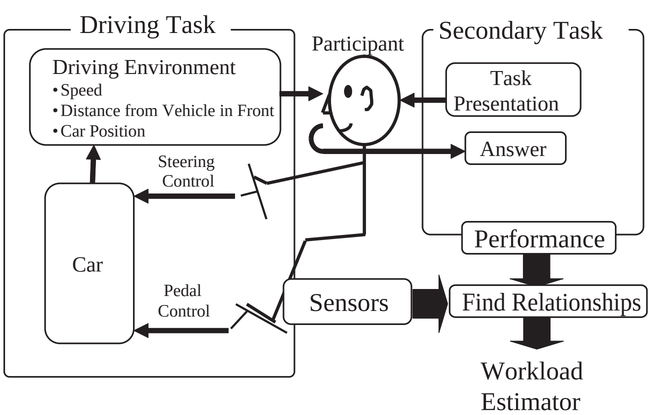

Fig. 2 Process for development of the workload estimator.

2. Method

2. 1 Measurement of mental workload

This experiment required a method for determining temporal changes in a driver's mental workload while he or she was driving on a public road. Secondary task measurements and physiological measurements could both be used to achieve this. We chose to use secondary task measurement, however, for the following two reasons.

- The secondary task can correspond to the task of understanding voice messages.
- Previous studies used secondary task measurement and identified a correlation between the driving situation and secondary task performance.[2-6]

2. 2 Secondary task

We used a memory-task as the secondary task. The task involved memorizing and then recalling five nouns. This was chosen for the following two reasons.

- The secondary task must have a short duration. Generally, a listening span test[10] is used to measure how well the listener understands a message. We chose not to use this test, however, because it would have incurred a long trial duration.
- The secondary task must be similar to the actual understanding of voice messages.

Figure 3 shows the timing of the memory-task. Five Japanese nouns were presented by a synthesized voice. The interval between the nouns was 1 s. The participants attempted to memorize these presented nouns. After the nouns had been presented, five beeps were sounded. The interval between the beeps was 2 s. The participants were instructed to recall and utter a noun after each beep. If a participant had forgotten any particular noun, he was asked not to say anything after the beep. Each trial took about 18 s. The trials were repeated consecutively while the subject was driving. The 336 presented nouns were selected from the EDR corpus (Japan Electronic Dictionary Research Institute, Ltd.) based on their frequency of everyday use. The number of nouns that the participants could recall correctly was recorded as their memory-task performance.

2. 3 Driving task

The participants drove the test car on public roads. The route was selected based on the assumption that the driver would most likely use the in-vehicle information system while driving along a main road. The route involved a round-trip on Aichi prefectural road No. 6, for a distance of 7.1 km and a duration of about 20 minutes. The road was almost straight, four lanes wide, and featured crossings with traffic lights. The posted speed was 60 km/h.

On the outbound leg, the participants were instructed to drive in the slow lane, whenever possible. On the return leg, they were asked to drive in the fast lane. The participants memorized the route and practiced driving it before the actual experiments.

2. 4 Procedure

Each experimental session consisted of a memory-task condition and a dual-task condition. The participants all underwent five sessions, at a rate of one a day.

For the memory-task condition, the participants performed ten memory-task trials while the test car was stationary in a parking area. For the dual-task condition, the participants performed the memory-task while driving. Three of the participants performed an additional driving task, namely, driving the route without any memory-tasks.

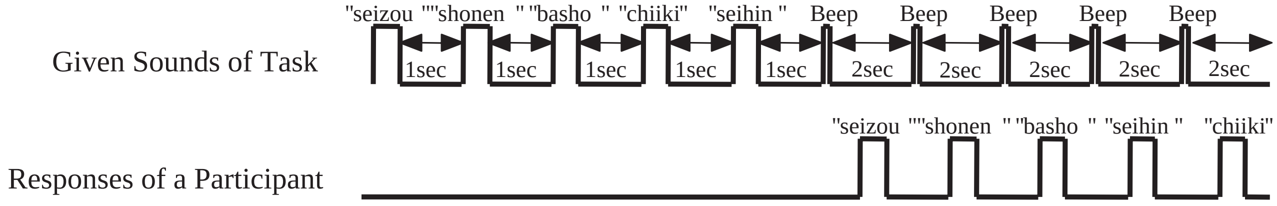

Fig. 3 Time chart of memory task .

2. 5 Apparatus

Figure 4 shows the apparatus installed in the test car. This apparatus provided the memory-task to the driver, using a synthesized voice. A VCR recorded the road ahead of the car as well as the driver's voice. The data acquisition system simultaneously recorded the speed, accelerator pedal position, brake pedal position, steering wheel angle, distance from the vehicle in front (as measured by laser radar), the car's position (GPS), time-code from the VCR, and the memory-task timing. The data acquisition interval for speed, accelerator pedal position, brake pedal position and the steering wheel angle was 10 ms. That for the laser radar was 100 ms and that for the GPS was 1 s.

2. 6 Participants

The participants were nine adult males, aged 33 to 59. Four were in their thirties, another four were in their forties, and one was in his fifties. Before the actual experiment, they each independently practiced the memory-task and the dual-task on a road inside our research institute. The participants were instructed to drive as safely as they normally do and to give priority to the driving task.

3. Results

3. 1 Analysis of the relationship between the driver's mental workload and the data from the car sensors

Under the single task condition, 450 memory-task trials were performed, while under the dual-task condition, 2268 trials were performed. The average number of recalled nouns was 4.04 under the memory-task condition, and 3.81 under the dual-task condition.

The correlation coefficients between the memory-task performance (number of correctly recalled nouns) and the measurement parameters are shown in **Fig. 5**. The duration of the memory-task trials (about 18 s) was much longer than the data acquisition intervals of the car sensors. Therefore, speeds, accelerator pedal positions, brake pedal positions, steering wheel angles, and distances from the vehicle in front were averaged for each individual memory-task trial. "Pedal release" refers to the number of pedal releases during the memory-task trial. In those cases where a car in front was detected radar for only part of the trial, the average distance from the vehicle in front, for that period, was used for the entire trial. The correlation coefficients were averaged for each participant because individual differences in the memory-task performance were large. The memory-task trials performed on the main road were selected using the GPS data. Only those memory-task trials that were done when the car's speed was greater than 1 km/h were used.

The absolute correlation coefficient between the number of recalls and the number of times the driver released the accelerator pedal proved to be the highest of all the measurement parameters. The averaged correlation coefficient was negative and those for all eight participants were negative. This implies that, whenever the driver released the accelerator pedal, the memory-task performance was

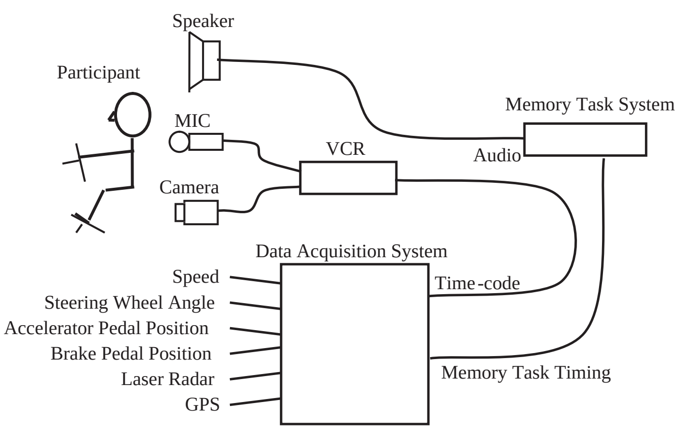

Fig. 4 Apparatus on test car.

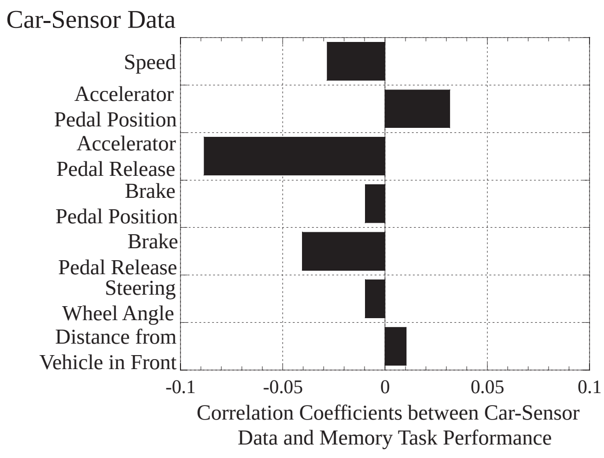

Fig. 5 Correlation coefficients between data from car sensors and memory task performance.

low. Thus, we came to regard the release of the accelerator pedal as being the most decisive factor in this investigation.

4. Development of a workload estimator

An estimation method was then developed based on the release of the accelerator pedal. From the results of the experiment, it is not clear whether the mental workload before or after the release of the accelerator pedal was high. It was presumed that the driver's mental workload before releasing the accelerator pedal was higher than that after releasing the pedal. If the driving situation before releasing the accelerator pedal increases the driver's mental workload, a means of predicting the release of the pedal is needed. Such prediction is currently impossible, however. Therefore, in our estimation method, the high mental workload is assumed to start from the instant when the driver's foot is removed from the accelerator pedal.

The duration of the high mental workload is not clear. To examine the test system while driving, a continuous series of 2- to 3-s road information voice messages were played during the test drives. The duration of the driver's high mental workload was assumed to be 5 s for the workload estimation.

Figure 6 illustrates the estimation method. The threshold of the accelerator pedal position was 8% (where 100% corresponds to the pedal being pushed to the floor). When the driver releases the accelerator pedal, the estimated mental workload is high. After 5 s, the estimated mental workload is low.

This estimation method was evaluated by applying it to the data obtained from the dual-task experiment. **Figure 7** is a histogram of the memory-task trials. The memory-task trials are divided into two groups as identified by the workload estimation method, namely, low mental workload and high mental workload. The memory-task trials were the same as those used to calculate the correlation coefficients. Those trials for which any part is regarded as incurring a high mental workload by the estimation method were placed in the high mental workload group. The shapes of both histograms correspond to the normal distribution. For both histograms, the peak is at 4. The drivers' ability to "catch" voice messages was assumed to be low when he was performing a trial for which the number of recalls was less than three. In this low-ability region, most of the trials fall into the high workload group.

Based on the results shown in Fig. 7, the percentages of the low and high workload groups for each number of recalls were calculated. The result

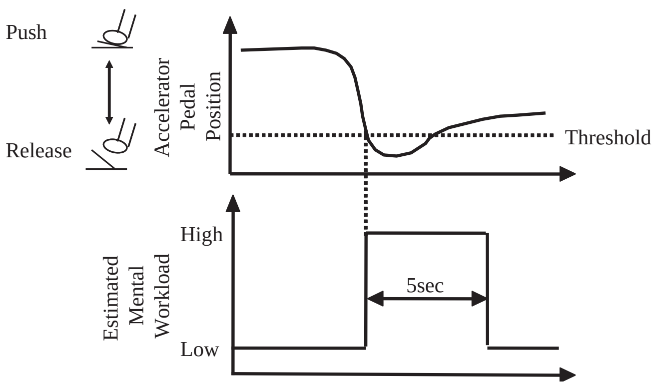

Fig. 6 Estimation method .

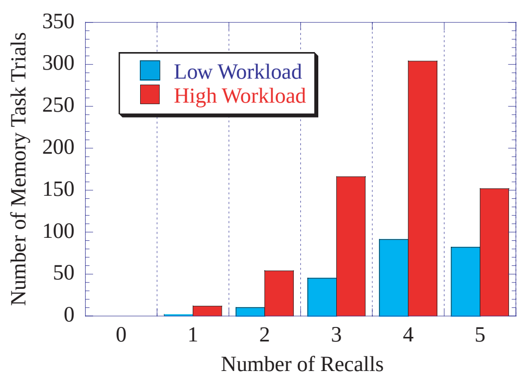

Fig. 7 Histogram of memory task trials divided into two levels of mental workload by the workload estimation method.

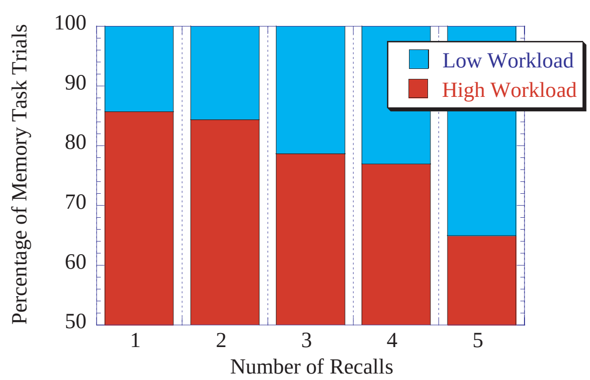

Fig. 8 Effect of the workload estimation method.

is shown in **Fig. 8**. No trial produced zero recalls.

As the number of recalls increases, the percentage of the trials that were judged to indicate a high mental workload decreases monotonously. If the estimation method is random, the percentage would be constant relative to the number of recalls. As the estimation method indicates that there was a greater percentage of high mental workload/low number recall trials than high mental workload/high number recall trials, it appears to operate correctly.

Assuming that, when the participants are performing trials for which their recall number is less than three, there is a high mental workload, the correct estimation percentage is about 85%. On the other hand, assuming that, when the participants perform trials for which the number of recalls is more than two, is a low mental workload, the correct estimation percentage is about 26 %. With a low workload, the estimation accuracy with this estimation method is low. With a high mental workload, however, the estimation accuracy is high. For driving safety, of course, high estimation accuracy with a high mental workload is more important than with a low mental workload. The high mental workload is expected to be more dangerous for a driver with a low mental workload. This suggests, therefore, that the probability of a driver being distracted by voice messages can be reduced by applying this estimation method.

5. Behavior of the prototype system

A test system that used this new estimation method was installed in the test car. The system continuously presented road and traffic voice messages except when the estimation method judged the driver's mental workload to be high. The duration of the messages was 2 to 3 s. For the test, the car was driven on an urban road and the behavior of the system was examined. Output of the voice messages was postponed in the following situations.

- Obstacles or stopped cars ahead
- Car in front slowing down
- Upon approaching a left or right turn
- Upon approaching a curve

Two drivers drove the car and the system postponed the output of the voice messages in almost the same situations.

6. Discussion

The correlation coefficient for the accelerator pedal release was found to be higher than the other measurement parameters. As a result of the experiment, it was observed that, when a quick decision and planning was required in a complex traffic situation, the memory-task performance was low. A typical example would be when the driver has to change lanes to avoid a stopped truck on the road ahead. To increase the amount of time available for decision-making and planning, the drivers tended to release the accelerator pedal. Therefore, the memory-task performance was closely related to the driver removing his foot from the accelerator pedal.

The conditions of this experiment were limited. The participants only drove straight along the test road and were not required to make frequent left or right turns during the experiment. With the test system, the postponement of voice message output before left or right turns was observed. This behavior of the system was not deduced from the results, however. More experiments that take diverse conditions into account are needed.

The difference between memory-task performance with and without the driving task was not significant. One of the reasons might be the modification of the driving task by the secondary task. This is indicated by the headway time with the secondary task being longer than that without it. This tendency might be caused by differences in the traffic conditions. This experiment was conducted on a public road on which the traffic conditions vary continuously. However, this tendency was observed for all those participants for whom comparisons are available. Therefore, it would seem that the driving task is modified by the secondary task. In light of this problem, physiological measurement may prove more effective than dual-task measurement if physiological measurement can provide a means of measuring mental workload.

7. Conclusion

A dual-task experiment was conducted to establish the relationship between a driver's mental workload and the data gathered from a car's sensors. The correlation coefficients between memory-task performance and the data obtained from the car sensors showed that the release of the accelerator pedal is the most pertinent factor in this investigation. Based on this result, a prototype adaptive information system that delivers short voice traffic messages was developed. The driving situations in which the system postpones the delivery of these voice messages were confirmed.

References

1) Council for Science and Technology Policy, Cabinet Office of Government of Japan : "Car Navigation Systems *no Genjo*", (online), available from <http://www8. cao. go. jp/cstp/tyousakai/cosmo/ haihu12/siryo12-4-1.pdf>, (accessed 2003-12-12)
2) Harms, L. : "Drivers' Attentional Responses to Environmental Variations: A Dual-Task Real Traffic Study", Vision in Vehicles, (1986), 131-138
3) Harms, L. : "Variation in Drivers' Cognitive Load. Effects of Driving through Village Areas and Rural Junctions", Ergonomics, **34**-2(1991), 151-160
4) Verwey, W., B. : "Adaptive Interfaces based on Driver Resource Demands", Designing for everyone, (1993), 1541-1543, Taylor & Francis
5) Zeitlin, L. : "Estimates of Driver Mental Workload: A Long-Term Field Trial of Two Subsidiary Tasks", Human Factors, **37**-3(1995), 611-621
6) Verwey, W. B. : "On-Line Driver Workload Estimation. Effects of Road Situation and Age on Secondary Task Measures", Ergonomics, **43**-2(2000), 187-209
7) Brookhuis, K. A. and Brown, I. D. : "Ergonomics and Road Safety", Impact of Sci. on Soc., **165**(1992), 35-40
8) Michon, J. A. (ed.) : Generic Intelligent Driver Support, A Comprehensive Report on GIDS., (1993), Taylor & Francis.
9) Aragane, Y., Maeda, F., Tsuji, Y. and Yoshikai, N. : "Development and Evaluation of Communication Navigator for Driving Environments", 2000 IEEE Intell. Trans. Syst. Conf. Proc., (2000), 210-215
10) Daneman, M. and Carpenter, P. A. : "Individual Differences in Working Memory and Reading", J. of Verbal Learn. and Verbal Behav., **19**(1972), 450-466

(Report received on Dec. 19, 2003)

Yuji Uchiyama
Year of birth : 1966
Division : Human Factors Lab.
Research fields : Functional brain imaging and human factors of driving
Academic society : Org. for Human Brain Mapping, Soc. Automot. Eng. Jpn., Vision Soc. of Jpn.
Awards : NICOGRAPH Best Paper Award, 1996
R&D 100 Award, 2002

Shinichi Kojima
Year of birth : 1964
Division : Sensing System Lab.
Research fields : Driver behavior analysis, Driver modeling
Academic society : Soc. Autom. Eng. Jpn.

Takero Hongo
Year of birth : 1956
Division : Human Error Prevention Lab.
Research fields : Human factors of driving and driver modeling
Academic society : Soc. Instrum. Control Eng., Soc. Autom. Eng. Jpn., Human Interface Soc.

Ryuta Terashima
Year of birth : 1968
Division : ITS Lab. II
Research fields : Spoken dialogue system, speech recognition
Academic society : Inf. Process. Soc. Jpn., Acoust. Soc. Jpn.

Toshihiro Wakita
Year of birth : 1960
Division : ITS Lab. II
Research fields : Human interface in vehicles
Academic society : Acoust. Soc. Jpn.