Development and Effectiveness Evaluation of Interactive Voice HMI System

Chiharu KATAOKA†, Member, Osamu KUKIMOTO†, Yuichiro YOSHIIKAWA††, Kohei OGAWA†††, and Hiroshi ISHIGURO†††, Nonmembers

SUMMARY Connected services have been under development in the automotive industry. Meanwhile, the volume of predictive notifications that utilize travel-related data is increasing, and there are concerns that drivers cannot process such an amount of information or do not accept and follow such predictive instructions straightforwardly because the information provided is predicted. In this work, an interactive voice system using two agents is proposed to realize notifications that can easily be accepted by drivers and enhance the reliability of the system by adding contextual information. An experiment was performed using a driving simulator to compare the following three types of notifications: (1) notification without contextual information, (2) notification with contextual information using one agent, and (3) notification with contextual information using two agents. The notification content was limited to probable near-miss incidents. The results of the experiment indicate that the driver may decelerate more with the one- and two-agent notification methods than with the conventional notification method. The degree of deceleration depended on the number of times the notification was provided and whether there were cars parked on the streets.

key words: interactive voice system, multiple agents, VUI

1. Introduction

Connected services have been under development in the automotive industry. Meanwhile, the volume of travel-related information has been increasing. Such information includes recommendations of bypassing routes to avoid traffic jams by linking cars with real-time information, including probe and highway data, or an evacuation route guide in the event of a disaster [1]. The development of connectivity has expanded the information provided, both in terms of time and service content, to include not only the latest safety and security information but also entertainment information about the destination. It is also expected that information on drivers’ preferences can be utilized to provide more individualized services. The purpose of these services includes the improvement of functions to guarantee safety, effective travel management, and usability [2], [3].

Although utilizing data to predict events that may occur in the future makes early provision of information possible, the driver may become unable to absorb such information if there are too many pieces of information or because of the way such information is provided. Therefore, this study focused on notification technology and the acceptability of predictive notifications to drivers.

As a new interface related to notification technology, voice user interface (VUI) has become increasingly common in smartphones and smart home speakers, such as Amazon’s Alexa, Google Assistant, and Apple’s Siri [4]. Looking at the information display to obtain information and operating the touch panel while driving can raise the risk of accidents. Hence, it is expected that the VUIs that enable the driver to obtain information and operate them while looking forward will also be used for in-vehicle devices [5]–[7].

Tanaka et al. [8] showed that driving actions were improved when drivers were supported with voice notification. However, they reported a challenge that the voice notification support can be annoying.

There may also be a concern that predictive information, which is provided early, may not be followed straightforwardly. Other research has found that systems may fail to provide correct information under rapidly changing circumstances and that the reliability of the agent providing the information is a factor that affects the degree of annoyance [9].

Reliable notifications must also provide contextual information. Furthermore, easy-to-understand contextual information must match the current reality. Such contextual information tends to include a long description. Therefore, maintaining the information consistent with reality is not an easy task. It is unknown how much effect the addition of contextual information has on reliability.

Kadowaki et al. [10] showed that messages are more understandable when they are produced by two agents speaking from different standpoints compared with one agent. It was reported that, compared with one-agent systems, two-agent systems tend to maintain a sense of conversation, even when the speech does not match the context [11]–[13]. Karatas et al. [14] showed that a three-agent system can provide information that the driver does not find annoying (the driver can half-listen to it). However, drivers may also neglect significant information.

In this study, the focus was on notifications, including contextual information inconsistent with reality. The need for contextual information to provide reliable notifications...
Table 1  Notification scenarios in an interactive voice human-machine interface system

| No. | Contents of notification                                                                 |
|-----|------------------------------------------------------------------------------------------|
| 1   | A: Please drive carefully on this street.                                                   |
| 2   | B: Why?                                                                                  |
| 3   | A: Accidental contact has frequently occurred because of pedestrians running into the street. |
| 4   | B: Okay, let’s take care.                                                                 |

was validated. An attempt was made to realize notifications that are easy for drivers to accept and understand, and whose importance is easy to judge. Two agents were used, one of which had a role to go along with drivers. An experiment was performed using a driving simulator (DS) to compare the following three notification types: (1) notification with no contextual information, (2) notification with contextual information using one agent, and (3) notification with contextual information using two agents. The effectiveness of the two-agent system was tested.

2. Interactive Voice Human-Machine Interface (HMI) System

In this study, an evaluation system was developed to validate the effectiveness of predictive information.

2.1 Interaction Scenarios

Near-miss incident scenarios were selected as the target of predictive notification. Notifications of such potential incident scenarios are highly demanded by drivers and are suitable for objectively evaluating notifications that result in deceleration actions.

Notifications that lack contextual information are assumed to be difficult for drivers to accept. However, adding contextual information inevitably makes messages longer, imposing recognition stress on drivers. Furthermore, receiving excessive contextual information that drivers already know and do not need to have repeated can make the drivers feel imposed upon. To solve these problems, the following three-step scenario using two agents, A and B, is proposed. 1) Agent A provides a notification. 2) Agent B asks Agent A to add contextual information. 3) Agent A provides it. It is assumed that the scenario enriches the understanding of notifications to make them more acceptable to the drivers.

Agent B speaks for drivers who wish to have contextual information. As a result, drivers are expected to feel empathy with the agents and put more trust in them. To make drivers more convinced, Agent B finally adds words agreeing with the contextual information. Table 1 summarizes the notification scenario in the interactive voice HMI system. Agents A and B speak with different voices to represent their respective roles. Figure 1 shows the relationship between the agents and the driver.

3. Method

An experiment was performed using a DS on the driving course depicted in Fig. 2. The subjects in the experiment used a DS to execute virtual driving tasks while receiving three types of notifications, including those produced by the proposed system.

3.1 Subjects

Forty-two Denso Ten employees (26 men and 16 women, average age of 35.7) who knew the purpose of the experiment or were engaged in the VUI business were selected as the subjects. Each performed the experiment for all three notification methods described in Sect. 3.2. The order of the methods presented to the subjects was randomized.

3.2 Apparatus

To compare the effect of notifications, the experiment comprised the methods of notifications listed in Table 2 and the condition of parked car presence shown in Fig. 2. Note that a constant notice sound was played one second before each notification was provided. The notification included information on a coming near-miss incident point.

We adopted sentences for each notification method so that the one- and two-agent notifications involved additional information to support the message conveyed by the conventional notification. While the one- and two-agent notifications did not have different content, the form of presentation was different: a monologue for one-agent notification and dialogue for two-agent notification. For the conventional
Table 2 Notification methods

| Method          | Notification                                      |
|-----------------|--------------------------------------------------|
| Conventional    | Please drive carefully on this street.            |
| One agent       | Please drive carefully on this street. Accidental contact has frequently occurred because of pedestrians running into the street. |
| Two agents      | A: Please drive carefully on this street.  
                    B: Oh, why?  
                    A: Accidental contact has frequently occurred because of pedestrians running into the street.  
                    Hmm, okay. |

Table 3 Added contextual information (one-agent and two-agent methods)

| Context          | Notification                                      |
|------------------|--------------------------------------------------|
| A                | Accidental contact has frequently occurred because of pedestrians running into the street. |
| B                | Accidental contact has occurred because of children running into the street. An elementary school is located nearby. |
| C                | Accidental contact has frequently occurred because of two-wheel vehicles passing by. |

notification, we used a warning sentence to notify the subject of the necessity to pay attention. The notification was similar to that used in commercial in-vehicle navigation systems. For the one-agent notification, we added a sentence to explain the reason for the above warning sentence. For the two-agent notification, we made up a series of sentences to be alternately produced by two agents to sound like a conversation about the same contents as the one-agent notification. Namely, the sentence of the conventional notification was followed by a “why” statement requesting the reason for it. Then, an explanation of the reason followed by a simple acknowledgement was provided.

(1) Notification method

Conventional notification An agent provides a notification with a synthesized voice.

One-agent notification Contextual information (details of the probable near-miss incident point) is added to the conventional notification provided by an agent with a synthesized voice.

Two-agent notification Contextual information (details of the probable near-miss incident point) is added to the conventional notification provided by two agents with respective synthesized voices in a conversation.

Notifications are issued six times in one trip, as shown in Fig. 2. If only a single pattern of contextual information is provided, drivers may become bored and not trust the information. To avoid such repetition, the three patterns of contextual information listed in Table 3 were set.

(2) Street-parked car conditions

A notification is provided at each of the six points where probable near-miss incidents are set on the driving course. Parked cars are placed at every other point. The points with parked cars represent places where drivers feel that the information is invalid.

Near-miss points 1, 3, and 5 No parked car
Near-miss points 2, 4, and 6 Parked cars present

The experiment was performed in a test room at Denso Ten. A DS and two speakers playing driving sounds and voice notification were placed in the test room. Two PCs, one to control the DS and the other to output notifications, were placed behind the DS (Fig. 3).

3.3 Procedure

The test subjects were initially told that their task was to drive the course created in the DS at a constant speed, which was set as the reference state for the evaluation of the voice notification provided while driving. They were then told that they were allowed to decrease the speed freely according to driving situations and their own state of mind. After preparing for driving (adjusting the seat position), the subjects test-drove on the DS to become familiar with virtual driving. The course of the test drive was the same as the actual course for the experiment. To keep the subjects’ sense of tension close to that of driving a real car, the course had one point where a pedestrian ran into the street. The subjects repeated driving three times, once for each respective notification methods. After each drive, they completed a set of questionnaires.

3.4 Metrics

This experiment included the following three types of measurements.

(A) Subjects’ background: The test subjects completed a questionnaire to grasp their driving actions. The items were taken from the driving-style check sheet designed by Research Institute of Human Engineering for Quality Life [15].

(B) Objective metrics The amount of deceleration and the effect of deceleration continuation were measured as metrics representing the effect of notifications. Figure 4 shows a schematic diagram corresponding to the calculation. The amount of deceleration (in km/h) is a speed difference calculated by subtracting the speed (2) measured when the car passes by the near-miss
point from the speed (1) measured just before the corresponding notification was provided.

(C) **Subjective evaluation** The test subjects completed a questionnaire on acceptability of the notification information to subjectively evaluate its validity and their degree of annoyance. Because we were unable to find an appropriate, established index to subjectively evaluate the conversation with the navigation system while driving a car from related studies. The questionnaire asking about the notification validity included three questions: (Q1) Were the instructions provided in the notifications accurate? (Q2) Was the reason for the instructions clear? (Q3) Did you understand what to do? The questionnaire asking about the degree of annoyance also included three questions: (Q4) Did you feel that the instructions were annoying? (Q5) Did you feel that the instructions were noisy? (Q6) Did you feel that the instructions were difficult to execute? A question was added to ask about the change in the test subject’s evaluation of the degree of annoyance during the trip. (Q7) Did your degree of annoyance increase as you repeatedly received notifications? A seven-point Likert scale (from “1: Strongly disagree” to “7: Strongly agree”) was applied to each question.

3.5 Hypotheses

For objective and subjective viewpoints, the following four hypotheses were validated.

**Hypothesis 1** The two-agent notification method exhibits a greater deceleration effect than the conventional and one-agent methods and is not dependent on the presence of parked cars.

**Hypothesis 2** The deceleration effect of the two-agent notification method is maintained over repeated notifications.

**Hypothesis 3** The notification of the two-agent method is felt more accurate than that of the conventional method.

**Hypothesis 4** Test subjects evaluate the notification of the two-agent method as less annoying than that of the conventional and one-agent methods.

4. Results

None of the 42 subjects refused to perform the virtual driving experiment using the DS. All subjects recognized the front driving picture and notification voices, which caused no trouble when going through the course created in the DS. Objective and subjective evaluations were performed for the measurement items. The Bonferroni method was used for multiple comparisons. When Mauchly’s test revealed a violation of the assumption of sphericity, the Greenhouse–Geisser correction was adopted in ANOVA.

4.1 Objective Evaluation

For the amount of deceleration, a three-way repeated measures ANOVA was performed on the following three within factors: 1) notification method (three levels: conventional, one-agent, and two-agent), 2) parked car presence (two levels: with/without), and 3) points (three levels: 1, 2, and 3). Since we adopted a random block factor design with three factors (i.e., RBFpq design), we first confirmed the second-order interaction and simple interaction, and then tested simple-simple main effects [16]. We adopted the individual error term for the error term in the post-hoc test [17]. Note that we adopted Bonferroni correction for comparisons among more than two levels. The analysis revealed a significant second-order interaction [F(4, 164) = 2.64, p = .036].

The simple interaction on each level of the parked car presence factor was significant for the without-car level [F(4, 164) = 2.66, p = .035] as well as for the with-car level [F(4, 164) = 2.64, p = .036].

Figure 5 shows the average deceleration as well as the results of multiple comparisons for the factor combinations concerning the parked car presence and points, which indicates significant and marginally significant simple–simple main effects. The simple–simple main effect for the case with no parked cars at Point 2 was significant [F(2, 82) = 4.79, p = .011], whereas the multiple comparisons did not reveal any significant differences. The simple–simple main effect concerning the notification method for the case with no parked cars at Point 3 was marginally significant [F(2, 82) = 3.00, p = .055], whereas the multiple comparisons did not reveal any significant differences. The simple–simple main effect for the case with parked cars at Point 2 was significant [F(2, 82) = 9.79, p = .000]. The multiple comparisons revealed a marginal significant difference [F(1, 41) = 6.02, p = .057], indicating that the amount of deceleration of the two-agent notification method is greater than that of the conventional method. The simple–simple main effect for the case with parked cars at Point 3 was significant [F(2, 82) = 3.78, p = .027]. The multiple comparisons revealed that the amount of deceleration of the one-agent notification method was greater than that of both the conventional method [F(1, 41) = 15.55, p < .01] and two-agent method [F(1, 41) = 7.54, p = .027] and two-agent method was marginally significant [F(2,
The multiple comparisons revealed a marginally significant result \( F(1, 41) = 6.02, p = .057 \), indicating that the amount of deceleration in the two-agent condition at Point 3 with no parked cars was greater than that at Point 1. The simple–simple main effect concerning the point for the case with parked cars and the one-agent notification method was significant \( F(2, 82) = 3.50, p = .035 \). The multiple comparisons revealed that the amount of deceleration in the one-agent condition at Point 2 with parked cars was greater than that at Point 1 \( F(1, 41) = 6.56, p = .045 \). The simple–simple main effect concerning the point for the case with parked cars and the two-agent notification method was significant \( F(2, 82) = 6.72, p = .002 \). The multiple comparisons revealed that the amount of deceleration in the two-agent condition at Point 2 with parked cars was greater than that at Point 1 \( F(1, 41) = 7.55, p = .027 \) and Point 3 \( F(1, 41) = 15.55, p < .01 \).

### 5.2 Subjective Evaluation

The results of the questionnaire concerning the degree of acceptability of the notifications were analyzed. For each question about validity and the degree of annoyance, a one-way repeated measures ANOVA and post-hoc multi comparisons with paired t-test were performed concerning the factor of the notification method (three levels: conventional, one-agent, and two-agent). Figure 7 shows the average scores and the significant differences for each questionnaire item. Concerning the validity, a significant main effect was revealed for Q1 “Were the instructions provided in the notifications accurate?” \( F(1.3, 54.4) = 33.46, p < .01 \). The multiple comparisons revealed that both notification methods, the one-agent \( t(41)=6.18, p < .01 \) and two-agent \( t(41)=6.00, p < .01 \), were evaluated as more accurate than the conventional method. A significant main effect was also revealed for Q2 “Was the reason for the instructions clear?” \( F(1.2, 50.0) = 159.34, p < .01 \). The multiple comparisons revealed that notification methods with one agent \( t(41)=12.8, p < .01 \) and two agents \( t(41)=13.4, p < .01 \) were evaluated as providing clearer reasons for instructions than the conventional method. A significant main effect was also revealed for Q3 “Did you understand what to do?” \( F(1.4, 55.4) = 74.50, p < .01 \). The multiple comparison revealed that the participants saw more clearly what to do with notification methods with one agent \( t(41)=10.0, p < .01 \) and two agents \( t(41)=8.66, p < .01 \) than with the conventional method.

Regarding annoyance, a significant main effect was revealed for Q4 “Did you feel the instructions were annoying?” \( F(2, 82) = 7.44, p < .01 \). The multiple comparisons revealed that the notification methods with one agent \( t(41)=3.53, p < .01 \) and two agents \( t(41)=3.27, p < .01 \) were evaluated as more annoying than the conventional method. A marginally significant main effect was also revealed for Q5 “Did you feel the instructions were noisy?” \( F(2, 82) = 2.40, p = .097 \), whereas multiple comparisons did not reveal any significant differences. A significant main effect was also revealed for Q7 “Did your degree of annoyance increase as you repeatedly received notifications?” \( F(2, 82) = 3.20, p < .01 \). The multiple comparisons revealed a marginally significant difference, indicating that the notifications by one agent were increasingly felt as more annoying than the conventional method \( t(41)=2.45, p = .056 \).

### 5. Discussion

#### 5.1 Objective Evaluation

Adding contextual information was supposed to increase the amount of deceleration in both the one-agent and two-agent notification methods. Hypothesis 1, referring to the difference between the two methods, was not judged to be valid. The unexpectedly small effect in the two-agent method might have resulted from drivers who were unfamiliar with or felt strange about the presence of two agents in navigation. A future challenge is to perform a proof test in circumstances in which the drivers can naturally accept the two-agent notification environment.

For the case with parked cars, Hypothesis 2 was invalid because the amount of deceleration successfully increased with the second notification but decreased with the third notification. For the case with no parked cars, Hypothesis 2 was partially valid because the amount of deceleration in-

![Fig. 5](image-url) Amount of deceleration at each point

![Fig. 6](image-url) Amount of deceleration with each notification method

![Fig. 7](image-url) Results of subjective evaluation
creased as notifications were repeated, showing a nearly significant trend. In the case of parked cars, the decrease in the amount of deceleration measured when the third notification was provided may have resulted from the test subjects becoming familiar with driving and optimizing the amount of deceleration with reference to visible parked cars. In the case with no parked cars, in contrast, the subjects might have continuously decelerated because they could refer only to the notification information to judge the amount of deceleration.

As seen in Fig. 6, the amount of deceleration was higher with parked vehicles than without at all locations. This is thought to indicate that drivers perceived parked cars as obstacles that could cause a collision, and as a result they were more likely to perceive the need to decelerate, and, as a result, they were more likely to decelerate. At Point 2, with parked cars, the amount of deceleration for one- and two-agent notifications is high, which is thought to indicate that the effectiveness of the alert effect is enhanced by getting used to the alert information and its presentation in a dialogue format at the first notification. At Point 3, there are two possible interpretations for the different tendency in the amount of deceleration between one- and two-agents. First, the large deceleration in one-agent notification method may imply dependency of the preferred notification type on the category of information to be conveyed: simple form may be preferred for in-vehicle hazard notification and therefore effective. On the other hand, the deceleration in the two-agent notification method with parked cars at Point 3 was larger than Point 1, and it was smaller without parked cars. This may reflect that the user learned from two-agent notifications that the situation would not be so dangerous in the case without parked cars and, as a result, adapted the deceleration to a modest degree. On the contrary, the maintained deceleration in one-agent notification case may indicate that this notification was so intrusive as to prevent such an adaptation of the user. In other words, the two-agent condition could be a way to promote users’ understanding of information tailored to the actual situation, by being able to alert them with non-intrusive reminders.

5.2 Subjective Evaluation

Hypothesis 3 was judged to be valid. The two-agent method included the same contextual information as the one-agent method, which was judged to be more accurate than the conventional method. The addition of contextual information is thought to have raised the accuracy of the notification.

Unlike the annoyance with the two-agent method, the degree of annoyance with the one-agent method was marginally significantly higher than with the conventional method. However, Hypothesis 4 is not fully supported. Particularly, the answer option “I felt the instructions were annoying” of Question Q4 applies to both the two-agent and one-agent notification methods more than to the conventional method. The annoyance produced by the added contextual information might cancel out the effect of the conversational style of the two-agent method. The conversation style may be improved if notifications are limited to only uncertain cases; that is, notifications are not provided when an obvious risk exists. An average score of 4.38 for the one-agent method was obtained for Question Q4, and the two-agent method had the same score. In the seven-point scale applied to the questionnaire, the middle point 4 represents a neutral state, which is thought to indicate that the annoyance level was acceptable to the drivers.

As a limitation, this study was not able to adequately validate the index concerning its validity because we were unable to find a suitable subjective index for our study. It is expected that validating communication with cars will be an important research issue. Therefore, the creation of the index itself.

6. Conclusion

In this study, the aim was to establish a notification method acceptable to drivers. An interactive voice system was proposed using two agents, considering the general problems with providing predictive notifications while driving. The effect of the system was evaluated in a DS environment in which the notifications were limited to information on probable near-miss incidents.

The effect of the two-agent notification method shows a different pattern from the one-agent and conventional notification methods. The results indicate its potential for repeatedly notifying the driver about the necessity to decelerate at near-miss points with detailed risk information, especially when the driver does not visually recognize the risk. Two challenges remain for future work. One is to prevent drivers from feeling that the notifications provided by the two agents are strange, which possibly weakens the notification effect. The other challenge is to lower the annoyance that the drivers feel when more information is provided than in the conventional notification method.

In the present study, various factors were eliminated and evaluated by DS in order to make a basic assessment of the multiple-agent effect focusing on information conveyance. Therefore, we could not deeply consider and precisely evaluate the effect of possible distracters on driver attention and fatigue that would be prone to appear in real driving situations. Such distracters would include not only outside ones (e.g., traffic lights, store signage, and passenger interaction) but also inside ones (e.g., music and talk show on the radio which might be similar with the situation under two-agents condition). Actual vehicle testing with consideration of the driver’s attention should be performed in the future to overcome this limitation. In addition, to reduce the potential variance of the results, we adopted only one pattern of sentences for notifications to be tested. Although we suppose the effects would be maintained if the sentences were changed by following the process to extend the conventional message to the forms of one- and two-agent notifications, such scalability should be examined in the future. Actual vehicle testing should also be conducted for this purpose.
The fact that there was no difference between one and two agents in the subjective evaluation (Fig. 7) and the fact that there was a partial dominance of the one-agent method for Point 3 in the quantitative evaluation (Figs. 5 and 6) may be seen, as contrary to the results of previous studies [10–13]. However, it is possible that the difference in the situation between the previous studies and the present study explains this discrepancy: the previous study investigated a non-driving situation where the user could focus only on the interaction. Therefore, the effect of the notification may depend not only on the category of information but also on the situation. To clarify these issues, further experiments dealing with notifications containing information of varying degrees of complexity as well as with near-miss situations with varying degrees of actual risk are a future challenge.

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Chiharu Kataoka received the M. degrees in System Engineering from the Waseda University, Japan in 2008. And She majored in an Ergonomics. From 2008, She has been an associate in the Denso Ten Limited. She engages in a development of in-vehicle HMI.

Osamu Kukimoto received the B. degrees in Mechanical Engineering from the Setsunan University, Japan in 1996. And he graduated from the OSAKA DESIGNERS’ COLLEGE in 1999. After working for an advertising production company, he joined Denso Ten Limited in 2003. He engages in a development of in-vehicle HMI.

Yuichiro Yoshikawa received the Ph.D. degree in engineering from Osaka University, Japan, in 2005. From 2005, he was a Researcher at Intelligent Robotics and Communication Laboratories, Advanced Telecommunications Research Institute International. From 2006, he has been a Researcher at Asada Synergistic Intelligence Project, ERATO, Japan Science and Technology Agency. From 2010, He has been an Associate Professor in the Graduate School of Engineering Science, Osaka University.
Kohei Ogawa received the Ph.D. degree in system information science from Future University Hakodate, Japan, in 2010. From 2008, he was a Researcher at Intelligent Robotics and Communication Laboratories, Advanced Telecommunications Research Institute International. From 2012, he has been an Assistant Professor in the Graduate School of Engineering Science, Osaka University. From 2016, he has been a Special Appointed Associate Professor of JST ERATO, Ishiguro Symbiotic Human-Robot Interaction Project.

Hiroshi Ishiguro received a D. Eng. in systems engineering from the Osaka University, Japan in 1991. He is currently Professor of Department of Systems Innovation in the Graduate School of Engineering Science at Osaka University (2009–) and Distinguished Professor of Osaka University (2017–). He is also visiting Director (2014–) (group leader: 2002–2013) of Hiroshi Ishiguro Laboratories at the Advanced Telecommunications Research Institute and an ATR fellow. His research interests include sensor networks, interactive robotics, and android science.