

PAPER

Study on Driver Agent Based on Analysis of Driving Instruction Data — Driver Agent for Encouraging Safe Driving Behavior (1) —

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SUMMARY In recent years, the number of traffic accidents caused by elderly drivers has increased in Japan. However, cars are an important mode of transportation for the elderly. Therefore, to ensure safe driving, a system that can assist elderly drivers is required. We propose a driver-agent system that provides support to elderly drivers during and after driving and encourages them to improve their driving. This paper describes the prototype system and the analysis conducted of the teaching records of a human instructor, the impression caused by the instructions on a subject during driving, and subjective evaluation of the driver-agent system.

key words: driving support, agent, elderly drivers, HCI

1. Introduction

Recently, there has been a gradual decrease in the number of fatalities due to traffic accidents of Japan annually. On the other hand, the decrease in number of traffic accidents caused by elderly drivers has been small, then the accident ratio caused by elderly driver has become to be more [14]. It has been reported in previous studies [12] that the accident ratio of the age group between 65 and 74 years is over two times that of other age groups, and the ratio of the aforementioned age group in several situations such as an intersection with a stop sign is over three times that of other age groups. In this paper, we define people older than 65 years old as elderly too. Extant studies indicate that one of the reasons behind the increase in the number of accidents caused by elderly drivers is the impact of aging on cognitive, visual, and physical functions. Previous studies reported that elderly individuals are unable to focus on appropriate targets or retrieve necessary information owing to changes in the above-mentioned functions [11]. Conversely, automobiles are an important mode of transportation for the elderly, and a lack of this transportation mode decreases their quality of life. Moreover, a high-level disparity exists between individual changes in biological functions according to age. Thus, determining driving capability based on age is insufficient, and investigating an appropriate method for evaluating driving capability and support methods in line with individual features is necessary.

Related works focused on the use of information display devices (such as small displays, car navigators, and

HUD) and presentation methods based on sounds, voice, and vibration [9]. Extant studies have also attempted to improve driver behavior [6] to deal with the negative adaptation [5] or false recognition of sensors. However, these studies indicate that the behavioral transformation toward safe driving caused by advice only while driving is temporary. In addition, communication robots for cars have also been developed [2], [16], with agents and robots accompanying drivers [10], [13].

A research project is being conducted with the theme “Innovation hub for a mobility society, leads to an active and joyful life for elderly” under the Nagoya University Center of Innovation Program (COI) by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) in Japan. In particular, this research project focuses on revealing changes in cognitive, visual, and physical functions that affect driving and aims to construct a data repository for human life-driving anatomy, termed Dahlia, as part of an aging survey research on human and driving features in elderly drivers [1], [22], [23]. This involves performing various cognitive function tests, driving aptitude tests, visual function tests, and driving feature surveys aimed at 300 elderly drivers annually, collecting driving experiment data using actual road-driving data from driving recorders attached to private automobiles and a driving simulator (DS). This enables combined analysis of biological functions, driving records, and driving behavior. To analyze the relationship between the collision rate of the elderly and biofunction, we collected the driving-behavior data of drivers passing through an intersection with a stop sign using a DS [21]. The result of the analysis could indicate whether loss of the visual information processing functions owing to aging was connected to accidents at intersections. However, the result also suggested that encouraging self-awareness of an individual’s own driving behavior and driving ability holds the potential for creating changes in driving behavior such that it is less susceptible to the influence of reduction in biological functions.

The goal of our research is for reducing the traffic accident caused by elderly drivers. Moreover, from our previous researches, the encouraging a self-awareness has a potential to reduce the accidents. In our research, we proposes a driver agent with the aim of encouraging safe driving behavior by allowing drivers to recognize their own behavior. The agent mainly has two functions, driving support and reflection support. To develop the driving support function, we

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collected and analyzed the instruction data from driving instructors in Japanese driving school in Sect. 2. In Sect. 3, we proposed our driver agent system based on those analysis. Moreover, in Sect. 4, we conducted an impression evaluation using a prototype system in a public event and discussed the possibility of driving support by a robot. In Sect. 5, we explained the conclusions and future works in next step of our research.

2. Analysis of Elderly Driver Instruction Records

Recently, driving evaluations and instructions aimed at the elderly are being provided by driving instructors through lectures to the elderly when they renew their driving licenses in Japan. We collected the instruction records provided by the driving instructors of a driving school to elderly drivers, investigated these instructions, and analyzed the impression they had on elderly drivers.

2.1 Collection of Instruction Records by Driving Instructors Experiment

We conducted an experiment that involved collecting the instruction records provided by driving instructors who were seated in the passenger seat, including navigation and auxiliary braking, to elderly drivers while driving on residential roads on the periphery of Nagoya University (Fig. 1). The subjects were 16 elderly drivers (average age: 77 years) comprising nine males and seven females registered with Dahlia. Four instructors participated in this experiment, with each responsible for providing instructions to four subjects. A commercially available drive recorder was used during the experiment to record videos both in front of and within a vehicle.

After driving, the instructors evaluated each subject's driving (5 levels) using a driving diagnosis sheet that is typically used in Japanese driving schools. In addition, the instructors completed a driving evaluation sheet (Table 1) with respect to driving skills, such as driving behavior, acceleration, and deceleration/steering, in traffic scenarios with a high accident rate for the elderly. Furthermore, the subjects



Fig. 1 Scene of collection of instruction records experiment.

completed a questionnaire that was used to evaluate their impression of the instructions, and the number of times and content for which the instructions were received. This experiment was performed after obtaining the approval of the Nagoya University Ethics Committee.

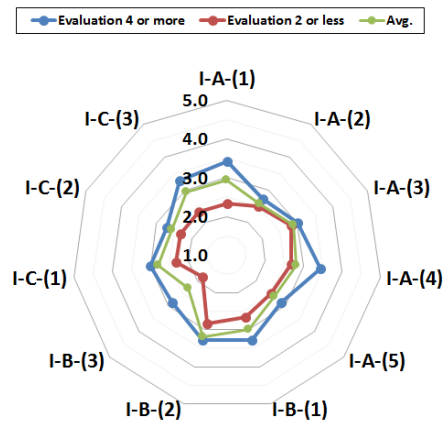
2.2 Analysis Results

2.2.1 Evaluation of Driving of Elderly Drivers by Instructors

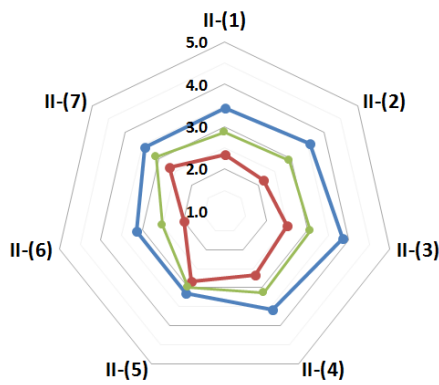
The breakdown of the results obtained from the five-level evaluation of the 16 subjects based on the driving diagnosis sheet was as follows. Evaluation 1: 2 people, evaluation 2: 5 people, evaluation 3: 3 people, evaluation 4: 6 people, and evaluation 5: 0 people. Thus, low evaluations of two or below were obtained for seven individuals and high evaluations of four or above were obtained for six individuals. The subjects were subsequently divided into low evaluation (low group) and high evaluation (high group) groups based on the driving diagnosis results; the results are shown in Fig. 2. The results of a two-way factorial ANOVA for each item in the group based on the diagnosis sheet and driving evaluation sheet indicated that the high group obtained a significantly higher evaluation on the driving evaluation sheet than the low group ($F(1, 198) = 44.1, p < 0.01$). Therefore, the assessment of driving behavior that focused on traffic scenarios is considered to appropriately reflect the driving diagnosis by instructors. The results of the driving evaluation sheet

Table 1 Driving evaluation sheet.

I. Evaluation of Safety Driving Behaviors (1 – 5)	A. At intersection with a stop sign	
	(1)	Speed reduction and driving at slow speed
	(2)	Definite stop at stop line
	(3)	Stop position at stop line
	(4)	Safety confirmation
	(5)	Steering
	B. At intersection without a stop sign	
	(1)	Speed reduction and driving at slow speed
	(2)	Safety confirmation
	(3)	Steering
	C. Avoiding a pedestrian, parked car	
	(1)	Speed reduction and driving at slow speed
	(2)	Safety confirmation
	(3)	Steering
II. Evaluation of Driving Skills (1 – 5)	(1)	Timing of speed reduction
	(2)	Strength of braking
	(3)	Smoothness of braking
	(4)	Smoothness of acceleration
	(5)	Smoothness of steering
	(6)	Appropriateness of driving speed
	(7)	Response capability to instructions



(a) Evaluation results for safety driving behaviors



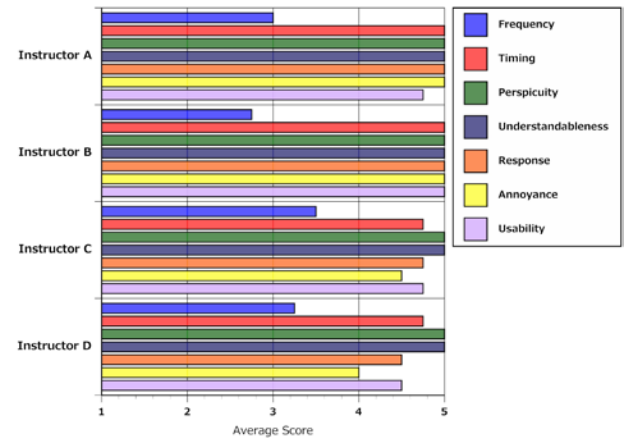
(b) Evaluation results for driving skills

Fig. 2 Driving evaluation sheet results for high evaluation and low evaluation groups.

for the high group and the low group revealed a significantly high difference between the two groups in terms of driving behavior in the following situations: deceleration, slow driving, and safety confirmation at an intersection with a stop sign; deceleration and turning at an intersection without a stop sign; and deceleration, slow driving, and safety confirmation to avoid pedestrians or parked cars. Conversely, no difference was observed between the two groups at stopping and stop locations at intersections with a stop sign, and it was estimated that the existence of an instructor in the passenger seat influenced this evaluation. Furthermore, regarding driving skill evaluation, a significant difference was observed in the acceleration and deceleration timing, strength, and smoothness. This result reveals that the driving behavior of the low group did not reflect appropriate acceleration and deceleration. Therefore, instructions on deceleration timing, degree of deceleration, and appropriate safety confirmation are required to reduce the accident rate of elderly drivers.

2.2.2 Evaluation of Impression with Respect to Driving Instruction

Figure 3 shows the impressions the driving instructions had on the subjects. The evaluation covered the appropriateness of instruction frequency and timing, ease of understanding,

**Fig. 3** Evaluation impression with respect to driving instruction.

ease of understanding intentions, ease of reflecting in driving, annoyance, and whether it is necessary to reflect the same in future driving. Evaluation 3 corresponds to “Neither good nor bad,” with one indicating “worst” and five indicating “best.” While evaluating the appropriateness of instruction frequency, three corresponds to “just right,” one signifies “too little,” and five signifies “too much.” The results of the experiment revealed that the evaluations of instructors C and D, for which the evaluation of instruction frequency exceeded three, were judged to be lower than those for instructors A and B in terms of timing, reflection in driving, and inconvenience. The correlation analysis of these evaluations showed a negative correlation between the frequency and the timing ($R = -0.29$). Moreover, the result also revealed a strong positive correlation between the timing and annoyance ($R = 0.77$). This result suggests the possibility that the evaluation of instructor frequency could influence the impression of annoyance.

Figure 4 shows the number of times the subjects answered how many times they received instructions from an instructor while driving. The number of subjects who answered less than 10 instructions was ten, whereas four subjects answered 20 times or less and two subjects answered 20 times or more. In general, an increase in the number of problems associated with driving increases the number of instructions received from the instructor. Therefore, for individuals who answered less than 10 instructions, most of the subjects indicated an evaluation of four. In addition, two subjects with an evaluation of one and two answered 20 times or more, which is considered reasonable. Conversely, the subjects who answered less than 10 or less than 20 instructions were four individuals with low driving evaluations of one or two. We consider that these subjects had already forgotten the content of the instruction while filling out the post-instruction questionnaire. This result suggests that changes in driving behavior caused by instruction/support during driving are temporary.

The questionnaire results with respect to whether subjects “can accept instructions from driving instructors, spouse, children, grandchildren, friends, car, robot, and nei-

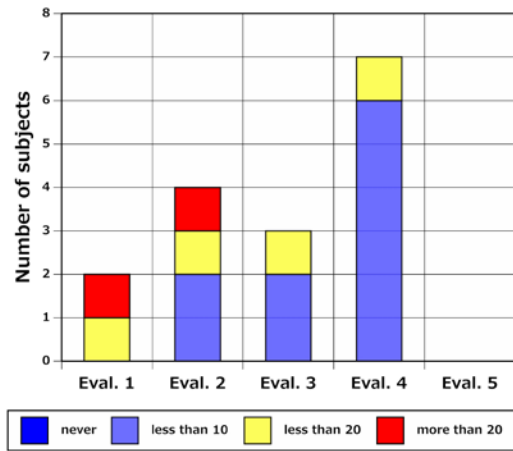


Fig. 4 Number of times instructions were acknowledged.

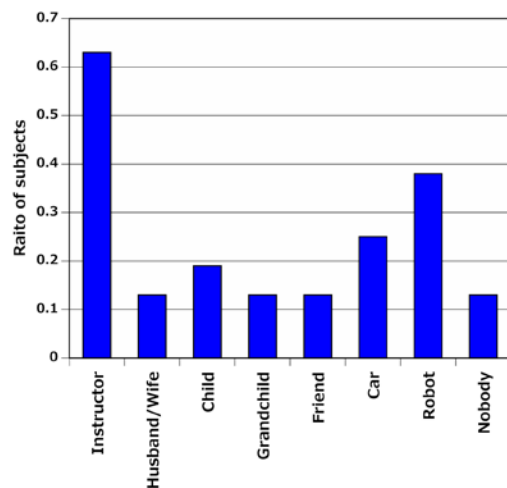


Fig. 5 Targets selected to receive support.

ther” are shown in Fig. 5. The subjects received no explanation regarding the purpose of this study or agents/robots. The results of the questionnaire indicate that the highest proportion was attributed to the instructor at 63%, followed by robots at 38%, and cars at 25%. The result of a chi-square test confirmed a significant difference in the acceptability of options ($\chi^2 = 19.3$, $p < 0.01$). In particular, 56% of all subjects selected a car or a robot, which was equivalent to the same level as the instructor. Introspective reports suggest that the subjects who selected robots or cars imagined a more developed form of car navigation systems. This result suggests the possibility that support from an artifact such as a car or a robot is more acceptable for the elderly than the support from familiar human without trained driving skills.

3. The Proposed Driver Agent

3.1 Encouraging Safe Driving Behavior through Self-recognition

A previous study investigated the instruction records pro-

vided to elderly drivers, interviewed instructors, and developed an instruction model for instructors [20]. As indicated above, the effect of instruction is temporary. Parker et al. [17] suggested that driving behavior is determined based on the driving situation and the driving model acquired from the experiences of the drivers themselves, and thus, drivers will revert to the same driving behavior if the driver model does not change. The training methods based on the Coaching theory to change the driver model to a safer one [4] involve repeating the process in which drivers are made aware of their own driving behavior (self-recognition), analyze their driving behavior (self-analysis), and improve their driving behavior (self-improvement). Furthermore, Japanese driving schools provide lectures for beginner drivers and professional driver training wherein videos of drivers driving are shown and safe driving behavior is discussed based on the video. A study reported that the use of an individual’s own driving record is effective in improving the acceptance of instruction from others [7]. However, a set of big and expensive devices is required for recording and reflecting driving behavior; therefore, these types of courses and the number of users are limited. In this study, with the aim of reducing the accident rates of elderly drivers, we proposed a driver-agent system that provides driving support and a reflection method to encourage changes in driving behavior through self-recognition.

3.2 System Overview

The proposed driver agent has two main functions: (1) driving support function that provides a method of attracting attention and suggestions for revising driving during driving operation in a very acceptable manner; and (2) reflection support function that evaluates a person’s driving behaviors and provides feedback on good/bad driving scenes by giving advice comments and a short movie from recorded data based on the evaluation. Through these support systems, the driver agent makes the elderly aware of their own driving behavior and encourages them to improve their driving behavior.

The system configuration of the prototype driver agent is shown in Fig. 6. The system acquires the driving operational data from the Controller Area Network (CAN) and the facial direction by applying a facial recognition program (faceAPI, SeeingMachines). Further, the agent acquires the distance between the car and objects such as a stop line and pedestrians through onboard sensors and GPS/map information. The control module determines the support content based on the instruction model of instructors. The function and the instruction model are explained in detail in the next section.

The support content determined in the control module is presented to the driver via the presentation module. The method of presentation in this study involved using a small robot [8] located in the dashboard or in the vicinity of the driving seat. Because, from the result of the questionnaire - “can accept instructions from who?,” the acceptability of

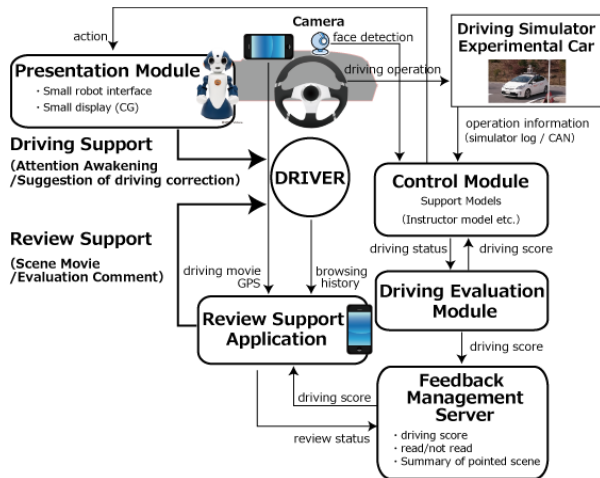


Fig. 6 Structure of the prototype driver agent system.

robot was higher than familiar human without trained driving skills. Moreover, the use of anthropomorphic robots promotes an intuitive understanding of the support content and enables natural control of the presentation strength through the concurrent use of voice and movement. In particular, this study used a personalized small-scale conversation robot that is being actively developed by several companies in recent years. The use of such robots in daily life and cars is expected to improve the acceptability for support and encourage feelings of affection and trust toward the robot. Furthermore, to attract attention, we selected a clear expression combining the use of voice and movement. In contrast, the instruction to change driving operation corresponded to an ambient expression based solely on movement (suggesting driving revision). We also aim to design a detailed method of expression considering the acceptability of the elderly as future work.

It is expected that reflecting driving behavior using an individual's own driving records will improve driving behavior. Further, previous studies have reported that acceptability is higher after driving than during driving because it is possible to view the record more objectively and the effect of instruction using the record after driving remains longer than the instruction during driving only [19]. The time at which the driver can safely confirm the record corresponds to after the occurrence of driving (for example, at home). To develop a low-cost reflection, it is necessary to determine a means of recording driving easily and viewing the recorded data at any location. We are developing a smartphone application to support a replay function after driving; this application is explained in detail in the next section.

3.2.1 Control Module and Instruction Model

The control module of the application determines the support content based on the instruction model of instructors (Fig. 7) developed from the aforementioned data [20]. The instruction content comprises the following five main categories: 1. Route navigation, 2. Review, 3. Attention awak-

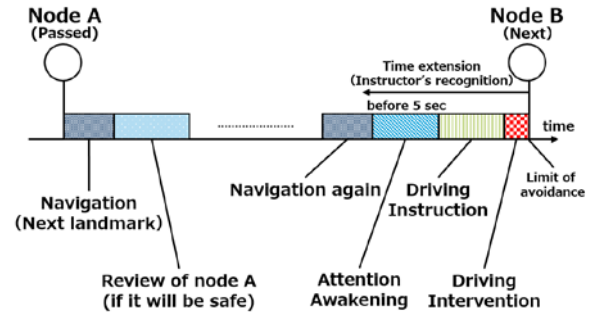


Fig. 7 Model of driving instructor.

ening, 4. Driving instruction, and 5. Driving intervention. The first category involves a car navigation system; the second category is performed when the traffic situation is determined as acceptable by an instructor. Categories 3–5 are based on the grace period until a situation deemed as dangerous by the instructor is reached. Furthermore, they are performed in order while observing the reaction of the driver. The instruction timing is based on a time to collision (TTC), which was calculated by the speed of the vehicle and the distance between the vehicle and the object. From the hearing survey with six driving instructors, the timing of the attention awakening was decided to be 5 s in advance. From the analysis of the impression of instructions, attention attracting affords the impression of being “gentle and kind.” However, the results also indicate that this impression worsened with high instruction frequency and direct instructions to change driving operations. Hence, we selected the traffic scenes in which the agent supports based on the report of accidents by elderly drivers [12]. Moreover, the instructors attempted different methods of expression such as simply performing a movement without voicing any instruction content (demonstrating the action of confirmation in advance).

From the above discussion, considering the support frequency, the following target traffic scenarios were selected: intersections with a stop sign, parked car/pedestrian avoidance, and traffic confluence. Furthermore, the agent provides two types of driving support: attention attracting and revising suggestion of driving operation. For attention awakening, a clear expression combining the use of voice and gesture was selected. Conversely, for revising suggestion of driving operation corresponded to an ambient expression based solely on a gesture (suggesting driving correction). We chose the ambient expression as a revising suggestion because the instruction is a strong expression and has the possibility of decreasing the acceptability of the support from the agent, which has social status lower than that of human instructors. The example of driving supports by the agent at an intersection with a stop sign was shown in Table 2. The timing of supports was based on the hearing survey with driving instructors and the adjustment of the timing is also a future work. The influence of age highly depends on the individual; thus, individual application of support is required. We aim to apply this in an individual manner in future work by adding support required by the in-

Table 2 Example of driving supports by the agent at an intersection with a stop sign.

Kind of driving support	Support Content
Attention Awakening	Timing: TTC to a stop line is 5 s.
	Voice: "There is an intersection with a stop sign."
	Motion: Pointing ahead by the left arm while slightly turning around toward the driver
Speed reduction	Timing: TTC to a stop line is between 2 s to 5 s
	Voice text: none
	Motion: Moving the right arm up and down twice
Revising suggestion of driving operation	Timing: Within 2 m from a stop line
	Voice: none
	Motion: Turning the robot toward the specified direction

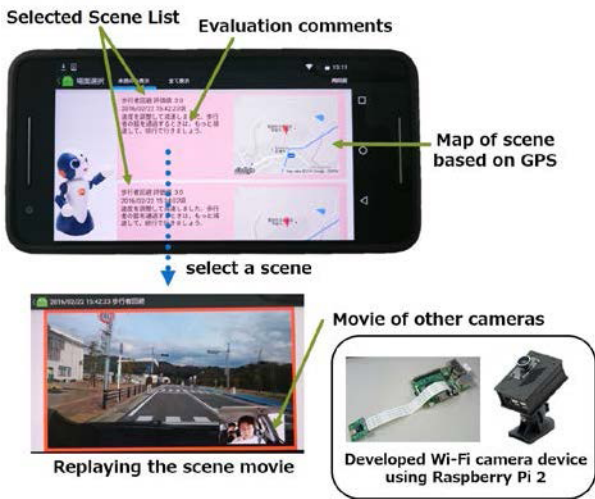


Fig. 8 Developed smartphone application for review support.

dividual (such as confirming the target of attention) based on several kinds of models.

3.2.2 Review Support and Smartphone Application

In this study, a smartphone application was developed to provide a replay function after driving. An example of the developed application is shown in Fig. 8. This application simultaneously records the front view and driver's face while driving using the cameras of a smartphone or developed Wi-Fi image distribution camera device using Raspberry Pi Zero. In addition to these images, it is possible to simultaneously record GPS, pedals, CAN, and the pulse of driver. Furthermore, we are implementing the application to connect other commercially available devices such as a driver recorder or a smart watch.

After driving, the application picks up good/bad scenes

from the record to feedback to the driver based on the driving evaluation by the agent. The feedback scene consists of evaluation value, comments, and a map based on GPS. When the user selects one of the scenes, a movie that begins several seconds before and ends after the period in which the evaluation occurred is played, and the agent reads the comment with gestures to the driver watching the movie. This study also investigated the application of a framework for providing incentives, such as insurance discount, based on the information stored on the server in the future.

4. Prototype System Impression Evaluation

At JST Fair 2016 (held August 25–26 in Japan), sponsored by the Japan Science and Technology Agency, there was a demo exhibition of a prototype driver agent as part of the research results of the Nagoya University COI project.

4.1 Content of Driver-Agent Demo

In the demo exhibition, participants drove over a course in which a residential route was simulated using a DS with a 5-screen monitor and received driving support from an agent during that time. The course was a straight course in a one-lane residential route. While driving, the driver encountered an intersection with a stop sign, pedestrian avoidance, and parked car avoidance scenarios. Each scenario was experienced thrice in the demo.

The demo system connected to DS software. Therefore, the situation recognition functions were not implemented in demo system, and the agent received input about situation recognition from the simulator, such as a distance to a stop line, pedestrian and parked car and car speed. Furthermore, while driving, the agent faced the same direction of Yaw angle as the driver based on the face recognition engine (faceAPI, SeeingMachine). The Yaw angle rotation of the robot was realized by placing the robot on a revolving platform and controlling the angle of the rotating platform on the PC side. In addition, while driving, a smartphone application under development was used to record data in addition to obtaining the driving evaluation and confirming the video for each scenario after driving. We defined the driving support received from the agents in the demo: attention awakening. The attention awakening support involved approach notifications regarding the intersection with a stop sign, pedestrian, and parked car. The agent provided the attention awakening as shown in Table 2. Figure 9 shows an image of the demo.

4.2 Demo Participants and Questionnaire

The participants were 51 individuals (40 males and 11 females, with average age: 42.2 years) with driving licenses; participants were 6, 12, 11, 13, 6, and 3 subjects in their 18–24y, 25–34y, 35–44y, 45–54y, 55–64y, and 65–74y, respectively. They mainly belonged to university research institutions and the development departments of companies, in-

cluding firms in automobile-related fields.

To evaluate their impression of the driver agent, the participants replied to a seven-point scale subjective evaluation that covered whether they wanted to use the agent, whether the support (attention awakening) was useful, whether the review function was useful, whether it was easy to accept the support, whether it could be trusted, whether an familiarity was experienced, and whether the agent could facilitate safer driving.

4.3 Results and Discussion

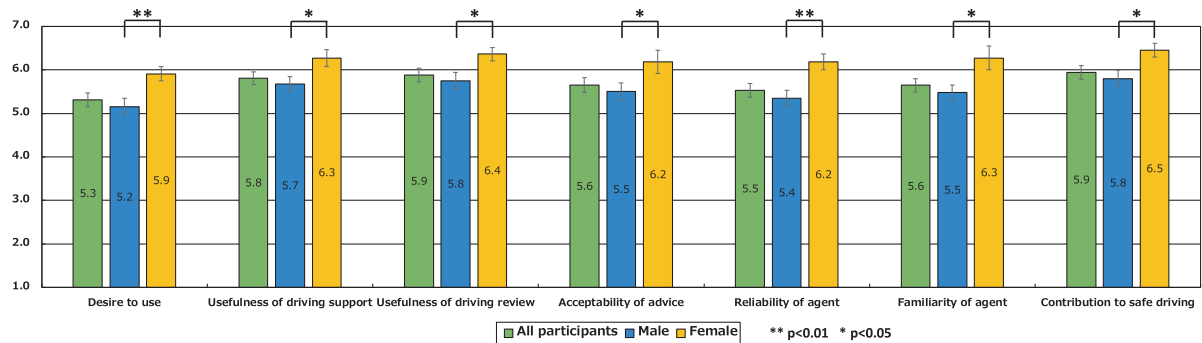
The evaluation results for all participants are shown in



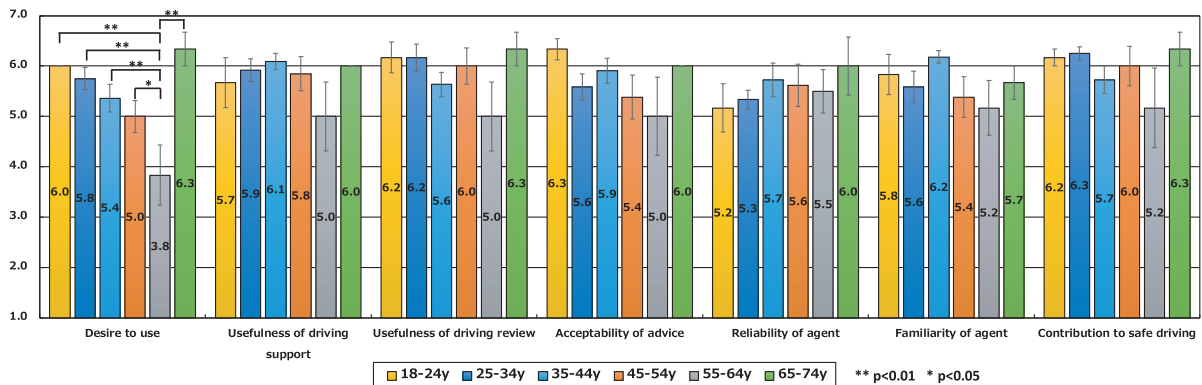
Fig. 9 Image of prototype agent demo.

Fig. 10(a). The average of evaluation exceeded evaluation 5. Furthermore, we conducted Welch's t-test to compare evaluation of both group. Then, the significant differences were confirmed about all evaluation items as shown in Fig. 10(a). The comparison of males and females reveals that the female evaluations exceed the male evaluations. The introspective reports indicate a difference in self-assurance of good driving skill between males and females. Moreover, the impression of the robot's appearance was higher for females than for males. We consider that a positive bias of appearance could affect functional evaluation. The results suggest that increased acceptability for driving support can be created if a sense of affection and trust can be generated through daily use of the agent.

The evaluation results by age are shown in Fig. 10(b). The desire to use and effectiveness decreased over time for subjects in their 18-24y; however, the lowest result was observed for individuals in their 55-64y. We conducted One-way ANOVA to compare evaluation value between age groups. The main effect was confirmed about "desire to use" evaluation ($F(5, 45) = 4.83, p < 0.01$). Bonferroni's multiple comparison showed significant differences between 55-64y and other age groups as shown in Fig. 10(b). Acceptability of new technology usually tends to be lower for the elderly. In addition, a potential reason for accidents in elderly drivers was stated as being overconfidence with respect to an individual's own driving [22]. We speculated a possibility that the result was influenced by confidence fol-



(a) Total average, male average, and female average



(b) Average by age

Fig. 10 Result of evaluation of driving support demo.

lowing several years of driving experience and linked to the lowest result of 55–64y. Conversely, the result showed the possibility that the evaluation for 65–74y is higher than 55–64y. We expect that this result may be from as a result of self-recognition of the weakening of their own abilities by aging in elderly participants. To analyze these possibilities, we will conduct the experiment with more elderly drivers as future work.

Conversely, the evaluation in terms of reliability and familiarity with the agent did not show the possibility of disparity in age when compared to items such as desire to use. Therefore, the evaluation implies that the existence of the accompanying agent (robot) was acceptable irrespective of age. This is considered to correspond to a trend that is shared with the results shown in Fig. 5. Adoption of the support content and frequency by a robot based on individual features, experience, and character have the possibility of achieving driving-support agents that can be accepted regardless of age in the future.

4.4 Limitations

This paper proposed a prototype driver agent with various functions. As future work, evaluation of users' impression about its usefulness will be performed. In the demo, we could not control the age group of the participants in advance. There were only three elderly participants; in future evaluation of the agent, more elderly participants will be needed.

5. Conclusion

In this paper, analysis of driving instruction data and users' impression of the instructions was discussed. Then, with the objective of promoting a shift toward safer driving through the recognition of a user's own driving behavior a driver agent was proposed to reduce accidents by elderly drivers. This study also involved a questionnaire evaluation of demo participants that used the prototype system. The analysis results implied the possibility of acceptability for driving support by an accompanying robot. Future studies will include investigation of the influence of agent forms (voice only, images, and robots) on acceptability/impression of driving support in the elderly, the possibility of distraction caused by using a robot and investigating the effect of driving behavior change using driving support and review support.

Acknowledgments

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