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Paper:

Effects of Demographic Characteristics on Trust in Driving Automation

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With the successful introduction of advanced driver assistance systems, vehicles with driving automation technologies have begun to be released onto the market. Because the role of human drivers during automated driving may be different from the role of drivers with assistance systems, it is important to determine how general users consider such new technologies. The current study has attempted to consider driver trust, which plays a critical role in forming users' technology acceptance. In a driving simulator experiment, the demographic information of 56 drivers (50% female, 64% student, and 53% daily driver) was analyzed with respect to Lee and Moray's three dimensions of trust: purpose, process, and performance. The statistical results revealed that female drivers were more likely to rate higher levels of trust than males, and non-student drivers exhibited higher levels of trust than student drivers. However, no driving frequency-related difference was observed. The driver ratings of each trust dimension were neutral to moderate, but purpose-related trust was lower than process- and performance-related trust. Additionally, student drivers exhibited a tendency to distrust automation compared to non-student drivers. The findings present a potential perspective of driver acceptability of current automated vehicles.

Keywords: driving automation, human-machine trust, supervisory control, gender, acceptance of automation

1. Introduction

New technologies and smart interfaces have been successfully introduced into a variety of automation domains, such as healthcare [1], surgery [2], and manufacturing [3]. Among them, ground surface transportation is one of the representative domains [4]. Over the last decades, advanced driver assistance systems (ADAS) have contributed to road safety, driving comfort, and energy consumption reductions [5, 6]. With the development of ADAS, vehicles with driving automation technologies have been introduced through various media campaigns, and some of them have been released onto the market. Current commercialized vehicles with driving automation technologies are at level 2 on the SAE scale [7], i.e., driving automation that executes primary vehicle controls, such as maintaining longitudinal and lateral vehicle position in limited driving situations. With these technologies, human drivers are still expected to monitor the road condition and to resume control of the driving task when necessary. As driving automation shifts the role of drivers from a primary to supervisory role, automated vehicles are expected to have the potential to improve road safety and reduce human error [8]. Previous research on general users' attitudes toward automated vehicles described a positive intention to use automated vehicles and the expectation of such benefits [9]. However, methods for examining the social acceptability of automated vehicles remain a substantial concern today.

Demographic factors, such as age, gender, or nationality, have been utilized to investigate driver acceptance of automated vehicles. Older drivers' general attitude toward self-driving cars is relatively negative compared to that of younger drivers [10, 11, a]. Surveys in terms of driver age such as that conducted by Lee et al. [12] have revealed that younger drivers showed a more positive attitude towards fully automated vehicles than older drivers. Payre et al. [13] showed a contradictory view that older drivers were likely to adopt automated vehicles. Rödel et al. [14] reported that drivers' intention to use automated vehicles increased with increasing drivers' age. With respect to gender, female drivers are less likely to adopt automated vehicles than male drivers, indicating that women were uncertain about the use of autonomous cars rather than men [a]. However, KMPG [b] found that females were more interested in self-driving cars owing to their benefits than males. Hulse and his colleagues [10] found no differences in general attitudes toward self-driving cars between respondents, driver, and non-drivers. In addition, the trip characteristics influence driver acceptance of automated vehicles [15–17, c]. Recent studies on driver acceptance in terms of demographic traits suggested recommendations for policymakers, but the exploration of driver acceptance from various perspectives is still needed.

Other factors besides demographic traits influence drivers' intentions and willingness to adopt new technology. Human-machine trust in automation is playing an important role in shaping driver acceptance [18, 19]. Indeed, Hillary et al. [20] investigated consumers' trust, finding a willingness to adopt autonomous vehicles as alternatives to their vehicle. Trust is a multidimensional concept, i.e., it is shaped by several bases, such as dependability, predictability, or robustness [21–23], and it dynamically changes through human-automation interaction [24, 25] or by obtaining information about automation [26, 27]. To describe the basis of trust with respect to goal-oriented information that needed to support appropriate trust, Lee and Moray [28] proposed a three-dimensional (3D) model: purpose, process, and performance. Purpose refers to why the automation was designed, the process represents how the automation functions, and performance refers to how the automation is operating. Therefore, automation designers are expected to consider these three categories to determine an operator's trust in automation. Given that myriad studies are investigating general users' acceptance of and trust in automated vehicles [29, 30], various insights have been suggested with respect to the high levels of driving automation. To the best of our knowledge, however, there has been little discussion about relationships between demographics and the trust dimension in contemporary automated vehicles that are designed following the SAE level 2. In addition, while the 3D model by Lee and Moray [28] has been applied in many studies about human-machine trust (e.g. [31]), the information that should be provided to drivers during partially automated driving has not been closely examined with empirical data.

The purpose of this study is to explore the relationship between demographic factors and driver trust in driving automation. The driving simulator manipulated the partial driving automation as well as situations that required drivers' immediate intervention. Drivers' subjective ratings of trust were interpreted regarding the 3D model [28] to determine the information needs for appropriate automation design. Additionally, the attribute of distrust, which is an opposite concept of trust and refers to a negative expectation of consequences by automation, was measured to explore comprehensive understandings of trust.

2. Methods

This research complied with the University of Tsukuba's ethics code and was approved by the ethical review board. Informed consent was obtained from each participant. The entire experiment was conducted in Japanese.

Fig. 1. Fixed driving simulator.

2.1. Participants

56 participants with a valid driver's license, aged between 19 and 75 years ($M = 31.9$, $SD = 14.7$ years), participated in the current study. The participants were split evenly in terms of gender (28 females). No participant had taken part in a driving simulator or on-road experiment in terms of driving automation. Furthermore, they were comfortable speaking and reading Japanese. All the participants were compensated with reimbursement for their participation (JPY 1660).

The mean number and standard deviation of the years of licensure was 12.6 and 14.4 years, respectively. In response to the question regarding how often the participants drove per week, 16 drove every day, 10 drove 4–6 days a week, 4 drove 1–2 days a week, and the remaining 26 never drove. With respect to the answer regarding how many kilometers the participants drove every week, 15 participants reported over 100 km, 7 reported between 50 and 100 km, 9 reported between 10 and 50 km, 1 reported 6 km, and the remaining 24 participants reported that they did not drive after obtaining the driver license. The average mileage driven per week was 63.32 km ($SD = 107.87$ km).

2.2. Apparatus

The experiment was carried out using a driving simulator at the University of Tsukuba, which consisted of a driving sheet, a steering wheel, an accelerator, and a brake pedal (**Fig. 1**). The driving scenarios generated by the D3Sim (Mitsubishi Precision Co., Ltd.) were projected on five displays. A monitor was used to present the speedometer and human-machine interface (HMI), and the audio was paired with the driving environment and played through two speaker systems.

2.3. System Description

Driving automation in the present study included both longitudinal and lateral vehicle controls. The longitudinal control resembled an adaptive cruise control system and followed indicated speed limits, maintaining the vehicle speed at 80 km/h, which was the maximum velocity. For instance, when a merging vehicle appeared in front of a host vehicle, the automation automatically reduced the speed of the host vehicle to avoid a rear-end collision. The lateral control was designed like a lane-keeping assistance system, and the automation was able to adjust the position of the vehicle in the middle of the driving lane. Furthermore, the automated driving system carried out lane changes when there were slow leading vehicles rather than when the vehicle velocity was 80 km/h. The drivers were able to activate the automation by pressing a button next to the driving seat. Each driver was instructed to disengage the execution of driving control, e.g., grasping a steering wheel or pressing pedals. The highway road with two lanes was simulated by the driving simulator, and four trials were presented to all the participants. Each trial encompassed several events that the automated driving system was able to handle.

The HMI consisted of a visual display and acoustic outputs. Instrument clusters were displayed on the dashboard, and acoustic signals were projected by two speakers. The visual cluster was projected at the onset of system activation and changed depending on the situation: detecting a leading vehicle and merging vehicle, and when the system requested the driver to intervene in tasks owing to system failure. In the event of system failure, an acoustic output was generated with a change in the presented visual cluster.

2.4. Driving Scenario

The driving simulator generated a Japanese highway road with two lanes, and four trials were presented to all participants. The driver was required to supervise the system status and situations during the simulation. In the first, second, and fourth trials, the participants experienced error-free automation, which indicates that the system would be able to handle all situations safely. These trials included several traffic events: overtaking slow leading vehicles, reducing vehicle speed, and changing lanes when a merging vehicle appeared and reducing speed when another vehicle attempted to cut ahead of the host vehicle in the driving lane. Unlike these three trials, the intervention task was presented to the driver in the third trial. The system issued the request to intervene with the drivers on the curve road.

2.5. Questionnaire

In the current study, the levels of trust were measured with a questionnaire proposed by Muir and Moray [25]. This questionnaire has been frequently administrated in studies on human-machine trust. All the drivers responded to the question "To what extent do you trust the driving automation?" with scales between 0 to 100. This study used the questionnaire of trust dimension proposed by Chien et al. [31]. The participants were asked to rate their likelihood using a seven-point rating scale (where 1 = "Disagree completely," 2 = "Disagree moderately," 3 = "Disagree somewhat," 4 = "Neither agree nor disagree," 5 = "Agree somewhat," 6 = "Agree moderately," 7 = "Agree completely"). The questions required the participants to rate the automation on the following aspects: distrust, purpose, process, and performance. Chien and his colleagues developed this questionnaire by adopting existing questionnaires in terms of technology acceptance [32] as well as human-automation trust [33]. They performed the validations of the questionnaire to examine the relationship between cultural factors and the three trust dimensions [34, 35]. **Table 1** describes the constructs and statements of the trust questionnaire.

Table 1. Statement summing up four attitudes toward the automated vehicle.

Construct	Statement
Purpose	• I can rely on automation to ensure my performance. • I am confident in automation. • Automation does not fail me.
Process	• It is easy to follow what automation does. • Automation is friendly to use. • Automation uses appropriate methods to reach decisions. • I understand how automation works.
Performance	• Automation improves my performance. • Using automation increases my productivity. • Using automation enables me to accomplish tasks more quickly.
Distrust	• Automation may result in unpredictable situations. • I believe automation could make errors. • I am wary of automation. • I am suspicious of automation's intent. • Automation is deceptive. • Automation behaves in an underhanded manner.

2.6. Procedure

Upon arrival, the participants signed informed consent forms and were then given instructions regarding driving automation. Next, participants practiced a drive to familiarize themselves with the simulated driving automation for 5–7 min. Afterward, the participants moved onto trials. All the participants carried out four trials, and the trials included several traffic situations, such as a merging car and overtaking events. In the first, second, and fourth trials, flawless driving automation was simulated. In the third trial, the automation alerted the driver through a short notice that the system was going to disengage vehicle controls and that the drivers should resume the control immediately. It requested for the driver to intervene. After completion of all the simulations, the participants reported demographic information, filled out questionnaires in terms of trust in the driving automation, and took a brief interview on their general impressions of automation and simulation. Interview questions included questions like "What did you feel about driving automation throughout this simulation?"

2.7. Statistical Analysis

As mentioned, data collection of drivers' subjective rating of trust and self-reported demographic information after the driving simulation was achieved. We classified three factors affecting their trust: gender (female and male), occupation (student and non-student), and frequency of driving (daily and non-daily). In this study, the occupations of the participants were used to categorize the participants. Because the driving simulator experiment was conducted at the University of Tsukuba, 36/56 participants were students at this university (64%). To test the hypothesis that students are likely to have an affinity to technology, including driving automation [36], we divided the participants into two groups: student and non-student drivers. Furthermore, the drivers' affinity toward acts of driving was considered an important factor affecting their trust. Regarding the frequency of driving a week, the drivers were classified into two groups: daily and non-daily drivers. Daily drivers (53%) had their own cars or used a family car and had driven the car at least once a week. Non-daily drivers did not have their own car, and most of them had not driven a car after getting the driver's license. The driven mileages a week of the daily and non-daily drivers were 116.2 and 2.31 km, respectively.

We carried out independent-samples t-tests to determine the differences in driver age, years of licensure, and driven mileage across the three demographic factors. A 2×3 analysis of variance (ANOVA) was conducted with the demographic factors as the between-subject factors and the three dimensions as the within-subject factors. For the analysis of the levels of trust and distrust in automation, the independent-samples t-test was conducted.

3. Results

Table 2 shows the number of drivers and descriptive values of the drivers' ages and years of licensure across their genders, occupations, and frequencies of driving.

3.1. Gender

Independent-samples t-tests revealed no significant differences of age ($t(54) = 1.06$, $p = 0.29$), driving experience ($t(54) = 1.01$, $p = 0.32$)), and driving mileage per week ($t(54) = 1.64$, $p = 0.11$) between female and male drivers.

The 2×3 repeated-measures ANOVA revealed a main effect of the three trust dimension on driver trust ($F(2,108) = 6.55$, $p = 0.002$, $\eta^2_G = 0.04$). Post-hoc tests showed significantly lower levels of trust for the dimension of purpose than for the dimensions of process and performance ($ps = 0.01$). There were no effects of gender, ($F(1,54) = 0.01$, $p = 0.93$, $\eta^2_p < 0.001$) and no interaction between gender and dimension factors ($F(2,162) = 1.22$, $p = 0.30$, $\eta^2_p = 0.01$). **Fig. 2** describes the mean ratings of distrust and trust for each dimension across the gender factor.

Female drivers rated higher levels of trust than male drivers ($t(54) = 2.04$, $p = 0.046$, $M = 73.11$ vs. 62.41). An independent-samples t-test did not reveal significant differences in distrust ratings between female and male drivers ($t(54) = 0.18$, $p = 0.86$, $M = 4.58$ vs. 4.55).

Table 2. Descriptive values of drivers' ages and driving experience across gender, occupation, and frequency of driving.

		N	Age M (SD)	Years of licensure M (SD)
Gender	Female	28	33.96 (15.10)	14.58 (14.96)
	Male	28	29.79 (14.30)	10.69 (13.75)
Occupation	Student	36	22.42 (1.65)	3.43 (1.58)
	Non-student	20	48.90 (12.15)	29.2 (12.02)
Frequency	Daily	30	40.17 (15.98)	20.82 (15.52)
	Non-daily	26	22.31 (1.69)	3.21 (1.57)

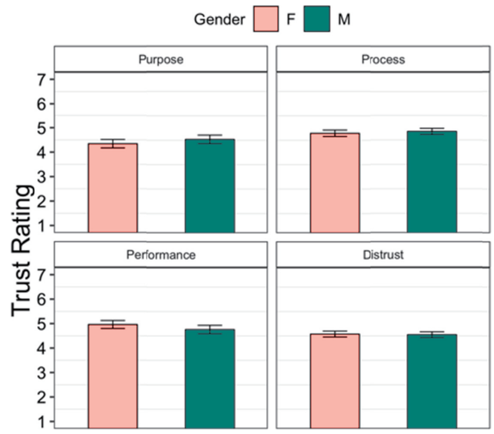

Fig. 2. Female and male drivers' trust across the dimensions of purpose, process, and performance, and the attribute of distrust.

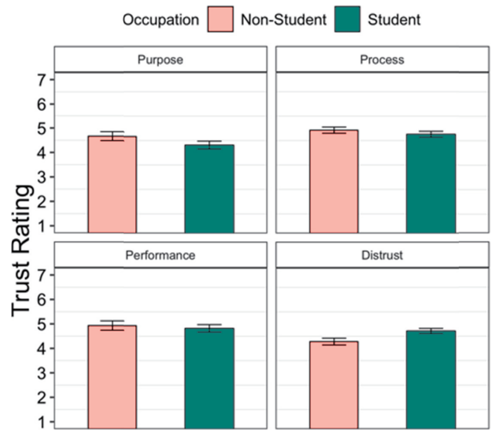

Fig. 3. Student and non-student drivers' trust across the dimensions of purpose, process, and performance, and the attribute of distrust.

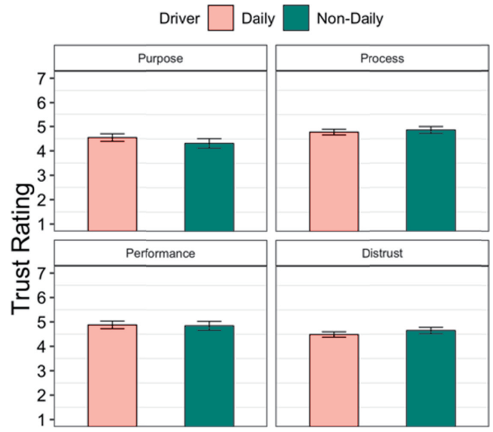

Fig. 4. Daily and non-daily drivers' trust across the dimensions of purpose, process, and performance, and the attribute of distrust.

3.2. Occupation

As shown in **Table 2**, non-student drivers' ages and driving experience were significantly higher than student drivers' ages ($t(54) = 12.96$, $p < 0.001$) and driving experience ($t(54) = 12.76$, $p < 0.001$). The independent-samples t-test revealed that the non-student drivers drove more frequently per week than the student drivers ($t(54) = 3.63$, $p < 0.001$).

Driver trust ratings differed across the dimension of trust ($F(2,108) = 6.46$, $p = 0.002$, $\eta^2_G = 0.04$). The post-hoc comparison also revealed that trust ratings for the dimension of purpose were significantly lower than trust ratings for the dimensions of process and performance ($ps = 0.02$). The remaining effect and interaction were not significant. **Fig. 3** illustrates the mean ratings of distrust and trust for each dimension across the occupation factor.

There was a significant difference in driver trust ($t(54) = 2.81$, $p < 0.01$). Non-student drivers exhibited higher levels of trust than student drivers ($M = 4.72$ vs. 4.28). Accordingly, the t-test also revealed that the attribute of distrust did differ significantly ($t(54) = 2.64$, $p = 0.01$). The student drivers rated higher levels of distrust toward driving automation than the non-student drivers ($M = 4.72$ vs. 4.28). These two statistical results are consistent in revealing that non-student drivers are more likely to trust automated vehicles than student drivers.

3.3. Frequency of Driving

The t-test revealed that the daily drivers' ages were significantly higher than those of the non-daily drivers (independent-samples $t(54) = 5.67$, $p < 0.001$). The year of licensure and mileage of the daily driver were longer and higher than those of the non-daily driver ($t(54) = 5.76$, $p < 0.001$, and $t(54) = 4.61$, $p < 0.001$, respectively).

The trust dimension has a significant effect on driver trust ($F(2,108) = 6.49$, $p = 0.002$, $\eta^2_p = 0.04$). The levels of trust for the dimensions of process and performance were higher than those for the dimension of purpose ($ps = 0.01$). The data did not provide substantial evidence for a significant effect of the frequency of driving ($F(1,54) = 0.09$, $p = 0.76$, $\eta^2_p = 0.001$) as well as interaction between the frequency of driving and the trust dimension ($F(2,108) = 0.67$, $p = 0.51$, $\eta^2_p = 0.01$). **Fig. 4** describes the mean ratings of distrust and trust for each dimension across the frequencies of the driving factor.

No significant difference in trust was found between daily and non-daily drivers ($t(54) = 1.26$, $p = 0.25$, $M =$ 70.9 vs. 64.15). For the attribute of distrust, the same result was found ($t(54) = 0.95$, $p = 0.35$, $M = 4.49$ vs. 4.65).

4. Discussion

The current study examined driver trust in driving automation with respect to drivers' gender, occupation, and frequency of driving. In the driving simulator experiment, all the participants experienced driving automation that executed lateral and longitudinal controls, and lane changing on the highway. The 3D model proposed by Lee and Moray [28] and the attribute of distrust were used to explore which basis of trust most influences driver trust and how demographic factors affect trust. Demographic characteristics, such as age, duration of driver's license possession, and driver mileage, significantly differed across the three demographic factors.

The results of statistical analyses revealed substantial differences in trust ratings across the three demographic factors. This result indicates that driver gender and occupation influence driver trust in driving automation. As mentioned previously, recent studies found that higher trust in automated vehicles is observed in males than in females [10–13, a]; however, opposite results have also been found [b]. In Feldhütter et al. [37], driver trust varied with gender, and male drivers showed higher levels of trust of and intention to use highly automated vehicles than female drivers. Furthermore, females found highly automated driving more uncomfortable compared to males. However, our data revealed that females are more likely to trust driving automation than males. Moreover, the frequency of driving did not affect their trust. This result agrees with the results of Hulse et al. [10], who found that drivers and non-drivers showed similar attitudes toward an autonomous car. Most non-daily drivers in our present study had not driven since they obtained their driver licenses. The effect of daily driving on driver trust may therefore be minimal. Future studies can expand on the sample sizes and the current experimental design used in the current study.

For the distrust attribute, the student drivers showed higher levels of distrust of the driving automation than non-student drivers. Furthermore, the analysis of trust ratings also revealed that non-student drivers were more likely to give higher trust ratings than student drivers, which does not agree with the result that student drivers are likely to trust and have an affinity for vehicle technology [34]. Interestingly, although most non-daily drivers were student drivers, driving-related differences in both trust and distrust were not observed. The result in terms of the occupation may differ according to drivers' affiliation. The students at the University of Tsukuba perhaps strictly rated their trust compared to the non-student drivers. If more students from the engineering departments participated in the next study, the data may reveal higher levels of trust in automated cars for the student drivers than for the non-student drivers. For example, an engineering student driver reported that his previous work on developing sensors led to a distrust of automation; however, a non-student driver who has used advanced driver assistance systems for many years expected rapid commercialization of automated vehicles. A future study should consider drivers with a wide range of occupations. Additionally, detailed participant interviews need to clarify why drivers trust or distrust automation in the next study.

This study investigated the relationship between three aspects of trust in automation. As shown in **Figs. 2–4**, trust across the three dimensions was moderate, with most drivers rating trust with 4 or 5 on the seven-point scale ("Neither agree nor disagree" and "Agree somewhat"). Therefore, this result implies that drivers' attitudes toward driving automation are slightly favorable. The ratings of trust were collected after all trials had been completed in the driving simulator. All the drivers completed four trials with the simulated driving automation, and in one of the trials, the drivers were asked to intervene by the automation. Because the driver was informed about the failure of the automated vehicle, it may be considered that the driver's trust rating was not quite high. In particular, according to the responses given by the drivers in the short interview conducted after completion of the questionnaire, several drivers were concerned about driving safety when unexpected system failures occurred in the urban road because the driving scenario in the present study is less hazardous than the real-life driving situation on an urban road with a high car density. This suggests that automation designers should be concerned about how to ensure driving safety for drivers.

Differences in the levels of trust between each dimension were found in this study. The driver ratings for the purpose dimension were significantly lower than those of the process and performance dimensions across all demographic factors. Information about the three dimensions could be used to determine appropriate levels of trust. This result may be interpreted to mean that information relevant to what the automation is supposed to do needs to be provided to drivers in comparison with information relevant to the actual performance of automation and how the automation works. The finding perhaps suggests that it can make recommendations for automation designers as well as is helpful for maintaining the vigilance of drivers who already purchased contemporary automated vehicles. However, this result should be interpreted cautiously because the number of items varied across each dimension. Therefore, each questionnaire item should be considered to discuss the trust dimension with the basis of trust, such as reliability or understanding. In line with the discussion about the occupation result, further studies require specific questionnaire items to clarify the dimension that most affects driver trust.

The present finding should be discussed considering several limitations. This result may not be necessarily expanded to generalize driver trust in the partially automated vehicle. As mentioned, the driving simulator experiment was conducted at the University of Tsukuba, and over half of all participants were students at the university. Future studies should be designed with a larger number of drivers and a wide variation in driver occupation and frequency of driving. Furthermore, 53 of all participants were Japanese; therefore, this finding may only be generalizable to Japanese populations. Notwithstanding these limitations, this study provides a new perspective in terms of the relation between trust and demographic factors. Most of the studies on the acceptance of automated vehicles have been conducted through online surveys; however, our present study measured the attitudes of drivers who had the experience of simulated driving automation as well as regarded the automated vehicle in the current market. The current study adapted the 3D model to the domain of partial driving automation with empirical data collected by the driving simulator. Our findings may provide insights into the automation design and training method design. In future work, we shall consider not only the factors in the current study but also different factors, such as nationality, driving habits, trip characteristics, or automation experience.

5. Conclusion

The current study explored drivers' trust in current automated vehicles with respect to demographic information and attributes of trust. Overall, the drivers were likely to trust driving automation, and gender- and occupation-related differences in trust were observed. The demographic factors were considered as they were expected to provide additional information about driving automation design for drivers to lead to appropriate levels of human-machine trust. The present finding is an important contribution to literature about driver acceptance of automated vehicles and highlight a need for further study of the influences of other factors affecting driver acceptance.

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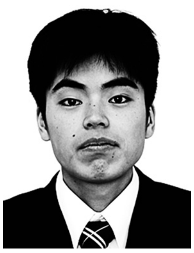

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