Dawn of Automated Driving

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Automated driving is a technology that is expected to bring great change and benefits to automobiles and road traffic. It is a time of life suffering for realizing what was a dream technology in ten years ago. That is also the introduction of a new mobility society, which requires not only technology but also development and remodeling on social systems. In this commentary, it is necessary for people to make efforts and changes in order to benefit from social technology. In addition, I will give personal views on issues from the viewpoint of the people and society receiving automated driving, and issues on technical approaches and strategies for development.

***Key Words**: automated driving, realizing, social system, technical approach, strategy for development*

1. Introduction

The word "automobile" is comprised of the Greek-derived French term "auto," meaning "self," and the Latin word "mobile" meaning "movable," hence has the meaning of "self-moving." Automated driving is believed to be the birth of the automobile in the true sense of the word. When automobiles were first invented, the concept was "vehicles that moved without the strength of animals." Now, over a century later, that dream is gradually becoming a reality. Automobiles are the core existence of mobility, and have extremely great benefits for society, however also entail the highly negative aspects of road accidents, traffic congestion, and exhaust fumes. With the advancement of an aging society, issues such as driver shortages and difficulty of travel in mountainous regions have arisen. There are high expectations that automated driving is the key technology to solve such issues.

The first automated driving concept is said to have been proposed by Bel Geddes at the 1939 World's Fair automated driving highway diorama exhibition. The backdrop to this is "freeing people from the task of driving," as freeing people from mundane tasks leads to effective utilization of time and an enriched life. Due to the expectations that automated driving will bring great change to mobility and solve many issues, technical and social actions are being taken around the world for its introduction. However, cars are a mode of mobility highly dependent on the excellent cognition and judgment abilities of humans, and the traffic society and infrastructure are established based on the premise of human drivers. As such, there are many issues surrounding the social implementation of automated driving. This paper will provide an overview of such issues.

2. Issues Concerning Collaboration between Humans and AI

2. 1 The New Relationship Between Humans and AI

Automated driving is where an information system on the vehicle-side (AI) performs perception, judgment, and operation normally performed by humans, however many differences with humans and functional discrepancies still remain. There are also problems pertaining to social systems, and automated driving will not fully replace human-driving overnight. Hence, a variety of ideas have been proposed to utilize technology at an early stage. One such idea is the concept that realistic systems can be accomplished through some sort of role-sharing between humans and AI.

The "Levels of Driving Automation" we often hear about in relation to automated driving indicate the levels of role-sharing between humans and AI. The 6 Levels established by the SAE are often used (**Fig. 1**).

Driving is divided into the following 3 functions,

1) Sustained lateral and longitudinal vehicle motion control
2) Object and event detection and response
3) Dynamic driving task fall back

and 6 levels have been categorized to indicate whether AI

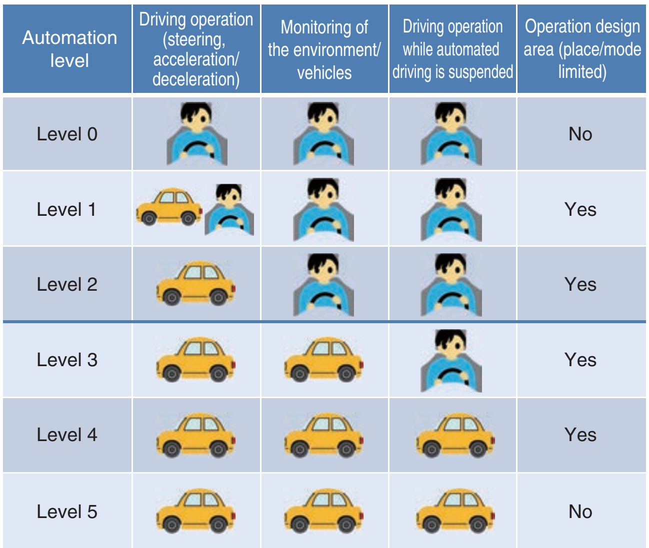

Fig. 1 Levels of Driving Automation

or a human driver has the role.

To date, the only two options pertaining to automobiles was driving one yourself, or being a passenger while somebody else drove, therefore it is not apparent what a good concept is for collaborative driving between people and AI. Level 4, where driving is left up to AI completely, is a straightforward concept equivalent to being a passenger in a car with a chauffeur or in a taxi. However, Levels 1 through 3 involving collaboration between humans and AI are not concepts we are familiar with. The concept of the currently commercialized Level 2 involves AI performing operations and monitoring to the degree it is capable, and, if this is insufficient, any deviation from monitoring and operation conditions (Operation Design Domain: ODD) is taken over by human intervention. The monitoring task that is the role of a human driver is required less frequently the greater the AI's level of completeness becomes. The key to the establishment of this concept is the ability to perform monitoring with low frequency of intervention. Issues such as accidents involving Tesla's Level 2-qualified car and drivers falling asleep at the wheel are becoming apparent, and there is debate regarding the need for people to learn and train, as well as the need for devices such as driver monitors to guarantee monitoring tasks. At Level 3, the human driver only needs to take control of the car if the AI is unable to execute a task, however there remain the questions of how frequent this task will be, the driver's condition, and in which traffic situation it would be executable. As such, there is an issue of clarifying whether or not training and driver monitors are necessary.

Advanced Driver Assistance Systems (ADAS) are considered to be where a human driver is in charge of vehicle operations, while AI takes care of monitoring and intervention. AI-based warnings and intervention braking when a risk manifests are already in common use; however a trade-off exists in that early intervention would have a greater deceleration affect but could easily be unnecessary intervention. Furthermore, driver assistance systems responding to potential risk are systems performing deceleration warnings and intervention in the case of an emergency, and the probability of such risk actually manifesting is low. This makes it difficult to persuade consumers that such systems are attractive, therefore commercialization is yet to be achieved. One realistic concept is a safe driving training system with a concept of providing coaching at the scene or post-incident.[1] A shared control system in which the human driver takes the lead and AI provides supplementary control has also been proposed. Another feasible concept is likened to a horse and rider moving as one wherein the AI possesses low-level tracking and avoidance functions, and the human driver gives upper-level commands and monitors the situation, much like a rider instructing a horse. This is also considered another Level 2 concept, however just as a person needs to learn to ride a horse, it is believed that training would be required to achieve horse-rider type Level 2. Up until now, we have considered human-AI collaboration with a focus on individually-owned cars, however in the case of service cars, the collaboration would be between AI and a passenger operator or a remote operator. In the case of a service car, the aim would be covering driver shortages and reducing driver labor costs, and it is believed Level 3 or higher would be necessary so that one person could monitor multiple vehicles or an operator could perform other tasks.

2. 2 Issues Relating to User Interface (UI)

At Level 3 or below, where a human driver and AI collaborate closely, the user interface (UI) is important. Like Level 2, whereby the driver must monitor AI, the driver not only has to monitor the situation of the actual vehicle's surrounding environment, but also monitor whether or not the AI is appropriately performing cognition, judgment, and operation. If the environment is relatively straightforward, such as an expressway, there are cases of simple icon displays, etc. in practical use, however the circumstances are presumed to be more complicated on general roads. If the monitoring frequency is high, an issue will be who bears the burden of monitoring. On the other hand, if monitoring frequency is low, continuity will pose an issue.

It is presumed that a separate design will be necessary for intervention UI depending on whether the driver is, or is not, gripping the steering wheel in the case of Level 2, or if the operator is sitting in the driver's seat or not/or using remote operation in the case of Level 3. Time delay until intervention, controllability, etc. would be used as parameters. Current steering wheel or pedal is not always optimal for operator who is not sitting in the driver's seat or using remote operation.

2. 3 Issues Relating to Operations/Control

In terms of AI-based vehicle control, various forms of ADAS, such as ACC, LKAS, and parking assist have already been put into practical use, however there are also high expectations regarding sensitivity toward human driver control, therefore compared to people who are good at driving, there may be inadequacies felt in terms of shaking, acceleration/deceleration, etc. and many issues still need to be addressed.

Just as people come to understand how to drive a car to suit its various characteristics through experience, automated driving of the future must have technologies enabling AI to acquire smooth driving techniques on par with humans in response to various vehicle characteristics through a learning approach. Moreover, the characteristics which make driving easy differ between humans and AI, therefore there is a need to consider what characteristics make driving easy for AI. When switching from AI operation to human operation, there is a difference in the styles, and it may feel that the human operation is lively. To identify this difference, there is a need to improve the level of AI operation and control.

3. Benefits and Issues Surrounding Social Introduction

3. 1 Benefits Anticipated of Automated Driving

The so-called "CASE" concept comprising the elements of Connected, Sharing, and Electric centered on automated driving (Autonomous) is set to drastically change cars, transportation, and society. There is much debate and analysis concerning the impact CASE will have on society. This entails solutions for the adverse aspects of cars, response to new social issues, and a change in the nature and value of cars.

The adverse aspects of cars are estimated to create an economic loss due to traffic accidents and congestion worth 6 trillion yen and 12 trillion yen, respectively, in Japan alone. These issues could be solved by automated driving in two steps. The 1st step is the elimination of human error. It is said that 90% of traffic accidents are caused by human error and one cause of traffic congestion is irregular driving by humans. Automated driving is expected to remove such mistakes and irregularities. In the 2nd step, under the so-called "Connected" theme, communication technology such as V2X and Dynamic Maps would be introduced, which is a move expected to further solve issues by eliminating blind spots and achieving a mode of transportation where all vehicles cooperate.

Japan is an advanced nation with an aging population, and the problems of a shortage of drivers, elderly persons, and difficulty of driving in mountainous regions have actualized. Substitution of a human driver by automated driving is anticipated as a solution to these problems. This form of substitution would offer freedom to all people with mobility challenges, and the provision of a mobility service to the elderly population is a pressing issue.

From the perspectives of a sharing economy, smart city, etc., debate exists regarding the future vision of a transformation in the nature and value of cars. If the ride sharing and car sharing with improved user-friendliness due to on-demand support also incorporates automated driving, there will be a paradigm shift from the conventional trend of *owning* a vehicle, to *using* a vehicle. Improved traffic efficiency and less parking lots will create a new bustle by the establishment of smarter and streamlined cities. Moreover, analysis results[2)] have demonstrated that ride sharing/car sharing would be a cheaper option for users who travel less than 12 000 km per year, and this movement is being accelerated for economic reasons also.

It is said that the value of a car in the age of fully-automated driving, will shift away from the conventional "Fun-to-Drive" to the value of the service one can enjoy during traveling time. This service is expected to create a major market (passengers' economy)[3)]. Proposals have been put forward whereby cars are considered a movable space in which people could work or be entertained during travel, in addition to taking advantage of various other services.

3. 2 Issues Relating to Safety for Social Introduction

A major goal of automated driving is the reduction of road accidents and, due to the fact that 90% of accidents are said to be caused by human error, there is high expectations that automated driving will be able to achieve this goal. There is a demand for self-driving vehicles to, at the very least, have a lower accident rate than human-driven vehicles. The safety guidelines issued by Japan's Ministry of Land, Infrastructure and Transport state the following;

· More advanced driving than humans, and a reduced number of accidents caused by human error
· Accidents reasonably foreseen to be preventable do not occur

Moreover, top executives of some automakers have made informal comments that "the target of automated driving should be 5 to 10 times greater safety than human-driven vehicles." The accident rate of human drivers on the average is one fatal accident every 1 million kilometers; making it a phenomenon with an extremely small probability. There is a significant degree of variation between individual drivers regarding the characteristics causing an accident, and it is said that drivers can be divided into two groups; a group which are likely to be involved in an accident, and a safe driving group[4]. "5 to 10 times the average human driver," assumes an image of a comparatively more careful, experienced driver in the safe driving group.

Traffic accidents are categorized by cause as shown below;

A) Accidents that humans would cause but AI would not,
B) Accidents that both humans and AI would cause,
C) Accidents that AI would cause, but humans would not.

A) is believed to be caused by reasons specific to humans, such as taking eyes off the road, haphazardness, sleeping behind the wheel, inappropriate operation, violations (e.g. escaping, drink-driving), inability to drive (e.g. stroke, loss of consciousness), etc. B) refers to accidents such as second party accidents (primarily rear-end collisions caused by the other party's negligence), and accidents due to mistaken prediction and communication. These are related to the ability to foresee future risk, and are accidents included under "accidents caused by human error." C) are accidents caused by reasons specific to AI, such as breakdown, degradation, programming bugs, specifications oversights and inadequacies. In order to satisfy the safety requirements for automated driving there is a need for C) to be sufficiently small, and "not cause accidents that are reasonably foreseeable." In other words, B) must reach the level of a careful, experienced driver. The "reasonably foreseeable" element, from the analogy of a human's criminal liability, is judged to be social norm considering the balance with social benefits. For example, a pedestrian jumping out of a hedge in the middle of a road with a median strip is foreseeable, but cannot be considered reasonable as a social benefit. However, predicting that a child on a sidewalk may run out onto the road and decelerating just in case can be described as reasonable. One problem is that social consensus is necessary regarding AI, including whether or not the same rules should apply to AI as apply to humans.

What sort of specifications to make out of such requirements, how to establish these as a system, and how to verify such technologies are believed to precisely equal issues pertaining to the integration of society and technology. If it were possible to express this in the specifications required for development, it is believed this would also amount to establishing new traffic rules.

3. 3 Issues with Rules and Infrastructure

The traffic environment of automobiles is designed for human drivers. This differs to the high-reliability system of railway, or that anticipated for automated driving. For example, the order of priority of competing vehicles is determined by traffic rules, however in reality, these are flexible, and in some cases determined by negotiation between drivers. This is a gray area, and it is not the case that such negotiations are carried out under clear-cut protocols without mistakes.

Traffic control and traffic lights at intersections are sometimes difficult to see for humans due to light conditions such as sun glare, direct light, etc. and a 100% recognition rate is even difficult for AI, therefore establishment of a dual system would be difficult.

Moreover, on the aspect of traffic rules, an issue would be the discrepancy between regulated vehicle speed and prevailing vehicle speed, which is frequently debated as a hindrance to the introduction of automated driving in Japan. If self-driven automobiles are only able to drive at the legal speed, there is an argument that this will hinder traffic flow.

The major social issues and choices we must address are how to integrate machines into the flexible and ambiguous world of rules and infrastructure not designed for high-reliability mechanical systems, and whether or not to use this as an opportunity to revise existing rules or introduce new infrastructure. If the introduction of automated driving progressed significantly, and human driver operation became a rarity, roads, traffic lights, etc. would be built specifically for automated driving, and a safe and highly-efficient traffic system is predicted, however this would undeniably require an approach including revision of rules and infrastructure.

4. Issues with Realization of Driving AI

4. 1 Issues of Technical Approach

This section discusses the issues that must be resolved to establish Level 4 automated driving, which is the level of a careful, experienced driver, as discussed in the previous section. Level 4 was chosen due to the points that there are few issues concerning collaboration with human drivers, as discussed in **Section 1**, and the size of the contribution to society, such as the substitute driver described in **Section 3**.

The automated driving boom that continues to present day was triggered by the 2007 DARPA Urban Challenge, followed by the Google Car public road demonstration. These initiatives turned the dream of Level 4 automated driving applicable to general roads into a reality. The key technical points that made such a feat possible were digital infrastructure (high-precision map) and 3D-LiDAR; in other words, the fruition of a robot-based approach. Such technology was accelerated even further by the machine learning that emerged afterwards.

The recent trend of a system-realization approach, involves attaining direct learning of a human driver's driving techniques. Driving is divided into cognition, judgment, and operation. Learning the cognition portion from humans is precisely an initiative of deep learning, which is an enormous step forward from the world of cognition. Cognition is an unexplained, subconscious process conducted at a high-level using a large portion of a human's cerebrum. A human's cognition is practically always correct; therefore it is possible to make an accurate cognitive device if it can be taught the human cognition process.

But what about the judgment portion? In the past, a driver model or rule-based technique was adopted expressing the parameters which could be understood through analyzing and reflecting open human driving. Then, a new approach emerged of learning as a black box model through deep learning. There are also trials of a method to teach AI via End to End Learning whereby cognition, judgment, and operation are integrated.

Many issues exist with a method of directly learning judgment from a human driver. One issue is whether or not the human-based driving used as the reference for such learning satisfies safety requirements. Another is the issue of the black box model. A time delay exists in an elderly driver's ability to pass judgment and control a vehicle; therefore risk can be reduced by driving at a slow speed. In the same way, AI that has learnt based on a particular human's driving style must adjust its behavior to suit the actual cognition and control capabilities, however such adjustment of parameters is difficult for the black box model. In the case of the conventional model, traffic rules are explicitly expressed in the model, but in the case of the black box model, there is a need to re-learn the rules and driving culture of the specific region from scratch. Also, it is difficult to guarantee that self-driven vehicles will comply with laws, as is the expectation.

Simultaneous to system realization, the need for system evaluation and verification will also arise. In order to verify that automated driving is capable of higher safety than human driving, long-distance driving tests have been carried out, and the results thereof have been compared. The numbers are extremely convincing, however when we consider the dependence on driving conditions and intervention conditions, and that the approach itself will be reset by sensor changes and algorithm corrections, the efficiency is extremely poor, and theoretical verification is difficult. The latest approach to achieve a realistic validation process is using a compilation of evaluation/verification scenes exhaustively arranging traffic situations. In the case of evaluating the judgment portion, by stipulating evaluation/verification scenes and adding any elements lacking while conducting practical operations, it will be possible to raise accuracy. Another proposal put forward as a method of performing some types of verifications is exhaustively entering the appropriate conduct in equations. One example of such numerical models being proposed is the RSS-model (Responsibility-Sensitive-Safety)[5)] presented by Amnon Shashua and co. from MobilEye.

4. 2 Issues with Development Strategy

In the development of automated driving AI, digital infrastructure and evaluation/verification techniques that should be a common platform fall into the collaborative area, however the information processing portions of automated driving AI (namely cognition and judgment), fall into the competitive area; with individual automakers, suppliers, and IT companies are engaging in R&D separately. Automated driving AI is a large-scale system entailing complex environmental and traffic conditions. As such, huge development resources are required and there is a global shortage of developers. There is much waste as a result of the same functional development being carried out by individual companies in parallel.

On this point, recently there has been an increase in M&A and collaborative development as opposed to individual development. An even more advanced approach is OSS (Open-Source Software). If OSS successfully takes ahold, driving AI itself would become part of the collaborative area, and companies would focus the competitive portion on service, style, mounted features, etc., where they can emphasize their uniqueness. There is no need to differentiate driving AI into primary intelligence level, and it is also easier to construct similar behavioral patterns, therefore it is believed that driving AI should be a collaborative area.

Autoware, which was developed at Nagoya University as an OSS and enables Level 4 automated driving for general roads, is one representative example, and is becoming broadly adopted around the world as the de facto standard of OSS driving AI leveraging OSS characteristics. Autoware is an OSS for research operated in a Linux and ROS environment. Recently an international industrial group called the "Autoware Foundation" was established and has launched activities for developing Autoware at a standard of quality enabling vehicle mounting.

5. Conclusion

Now, 120 years after the birth of automobiles, CASE, with a focus on automated driving, is posed to bring about major change in automobiles, transportation, and industry. In order to reap the benefits of automated driving and solve issue related to conventional vehicles, such as accidents and congestion, there is a need to also consider revising the transportation/social systems and rules established under the premise of human drivers.

Self-driven buses and taxis can also be considered new transportation systems. Moreover, if automobiles have intelligence, and a collaborative system is built with such automobiles and humans, this can be considered akin to the birth of a new artificial horse. In order for such an artificial horse and rider to work together as one, there is a need to learn how to ride, just like horseback riding, and cultivate a new relationship.

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