Future Prospects: A New Era from Power Assist Steering to Smart Steering

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Automobiles are undergoing major changes as part of the steps being taken to achieve the sustainable society laid out in the SDGs. Steering systems can contribute to this major worldview change in two ways: creating new value by increasing intelligence, and providing the best universal value with high quality at low prices. This paper focuses on human-systems integration, cabin space and styling design, vehicle dynamics control, safety, and weight reduction, and explains the contributions and efforts of JTEKT's latest technologies.

Key Words: *smart steering, power steering, EPS, AD, ADAS, UX, DX, functional safety, integrated control, Pairdriver™, J-EPICS®*

1. Introduction

As shown in **Fig. 1**, two major trends have emerged in the steering environment. One trend is the creation of new value as innovation, and the other trend is the enhancement of traditional universal values such as energy saving and efficiency for providing products with high quality and at low cost.

For innovation, technologies that contribute to the transition to a people-centered sustainable society as advocated in the SDGs will become mainstream. As a part of the social trends represented by Society 5.0, the expectations for automobiles are becoming more diverse and sophisticated, and the role and form of automobiles are changing from traditional vehicles to "mobility for the safe and comfortable movement of people and objects." As shown in **Fig. 1**, new usages and new functions are continually being proposed, and the evolution toward an affluent society continues unabated[1)]. On the other hand, the traditional POV[*1] will also exist in the same transportation society. Also, the value that people expect has shifted to the pleasure that can be felt through usage, and a new concept called the smart car, which is full of information communication UX[*3] based on the concept of DX[*2] like a smart phone, is attracting attention.

As shown in **Fig. 2**, the steering system can contribute to this kind of automotive innovation by providing "freedom in the design of the cabin space"

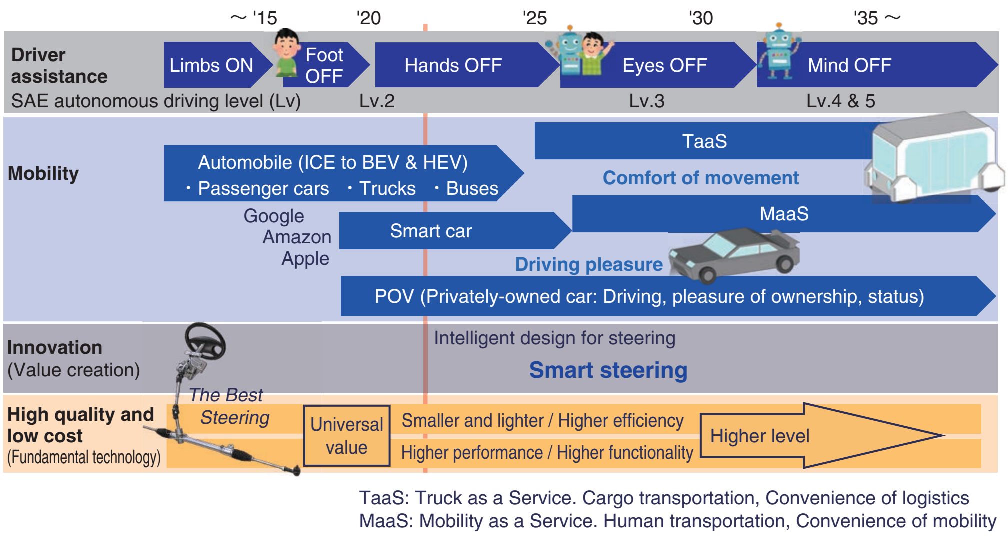

Fig. 1 Advances in vehicles and steering

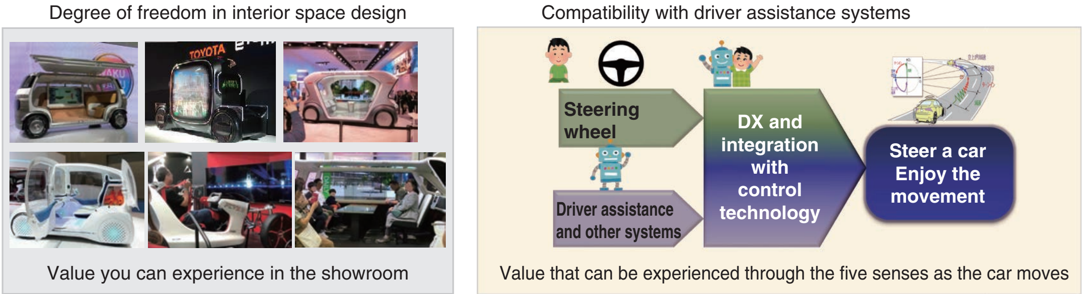

Fig. 2 UX contributions through steering technology

and "compatibility with driver assistance systems[2), 3)]." Both are made possible mainly by the digitization of mechanical components through the concept of DX, control technology that integrates the operations of humans and systems, and collaboration with other systems. In addition to pursuing the "Best" of universal value such as power assist and weight reduction, we believe that the future steering system will enhance its value as a more intelligent, or smart, system.

In this report, we present our approaches to smart steering and fundamental technology as a universal value.

*1 POV (Personal Owned Vehicle): A vehicle for status and enjoying driving as a personally owned vehicle.

*2 DX (Digital Transformation): The process of digitizing functions into software. In this report, we use the term "DX" in a broad sense to include the conversion of hardware to software[4)].

*3 UX (User Experience): Satisfaction and quality of the experience gained from using the product.

2. Functional Safety and Cybersecurity

Safety is the most important issue for both trends of "new value creation" and "high quality at low cost." In response, we have incorporated the concept of systems engineering[5)], which incorporates the logical (theoretical) representation of functions into the physical representation as shown in **Fig. 3**, and we are working to clarify the "derivation of steering system to subsystem requirements from the functions required for the vehicle" and "functional coordination with other systems." The details are described on page 43 of this report, "Sophistication and Efficiency of Functional Safety Activity by Applying Systems Engineering."

Also, as shown in **Fig. 4**, the system for information communication needs to be resistant to cyberattacks. Cybersecurity was standardized through ISO/SAE21434[6)] and UN-R155/R156[7), 8)] from July 2022. We complies with these standards by applying an "electronic key" to the ECU's main functions (communication, reprogramming, and data access).

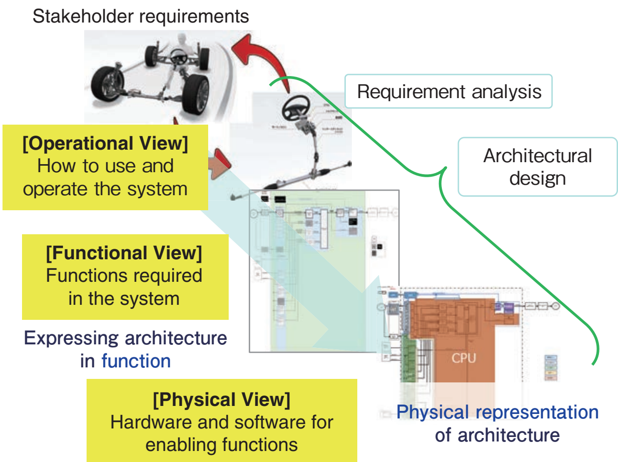

Fig. 3 Systems engineering process

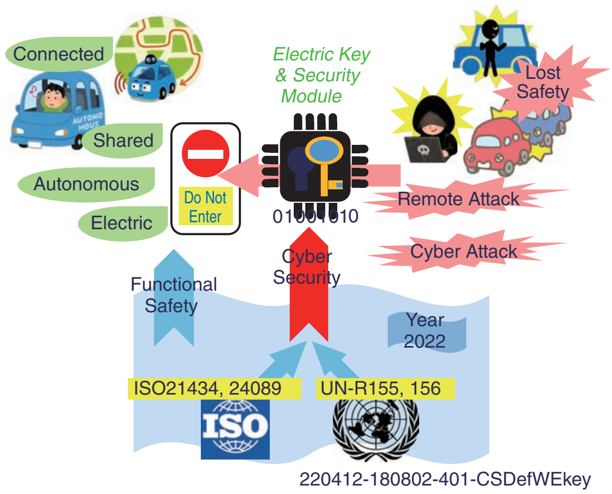

Fig. 4 Actions to address cyber risk

3. Control Technology: Integration of Humans and Systems and Separation of Software and Hardware for the Future

The integration and harmonization of both operation including assist and autonomous systems and human driving is a new value for giving a sense of security to the human driver. Many driving assistance systems up to autonomous driving level 3 (Eyes Off) have an operation system that selectively switches between human driving and system driving. We have developed a control technology, Pairdriver™, which enables the driver and the system to always coexist and provides more comfortable advanced driving assistance. Pairdriver™ is a control technology that feeds back the steering intervention by the system to the driver as a steering feel through the steering wheel as shown in **Fig. 5**. The degree of system intervention according to the driving conditions can also be communicated to the driver through the steering feel. The details are described in this report "Pairdriver™ Steering Collaborative Control for Automated Driving" on page 22.

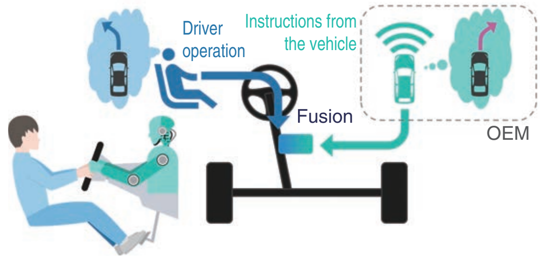

Fig. 5 Image of Pairdriver™

The vehicle E/E architecture is expected to evolve to ZONE type architecture integrated with a high performance computer to manage the complexity of advanced functions. For compatibility with this next generation E/E architecture, we have to consider software and hardware separation and a location-free software design[9]. For the next-generation system, as shown in **Fig. 6**, we will develop a servo control law that can absorb the required assist force differences for each vehicle's settings, differences in mechanical characteristics for each EPS gear, and vehicle differences, as well as a software application platform that supports software updates and location-free design for control algorithms.

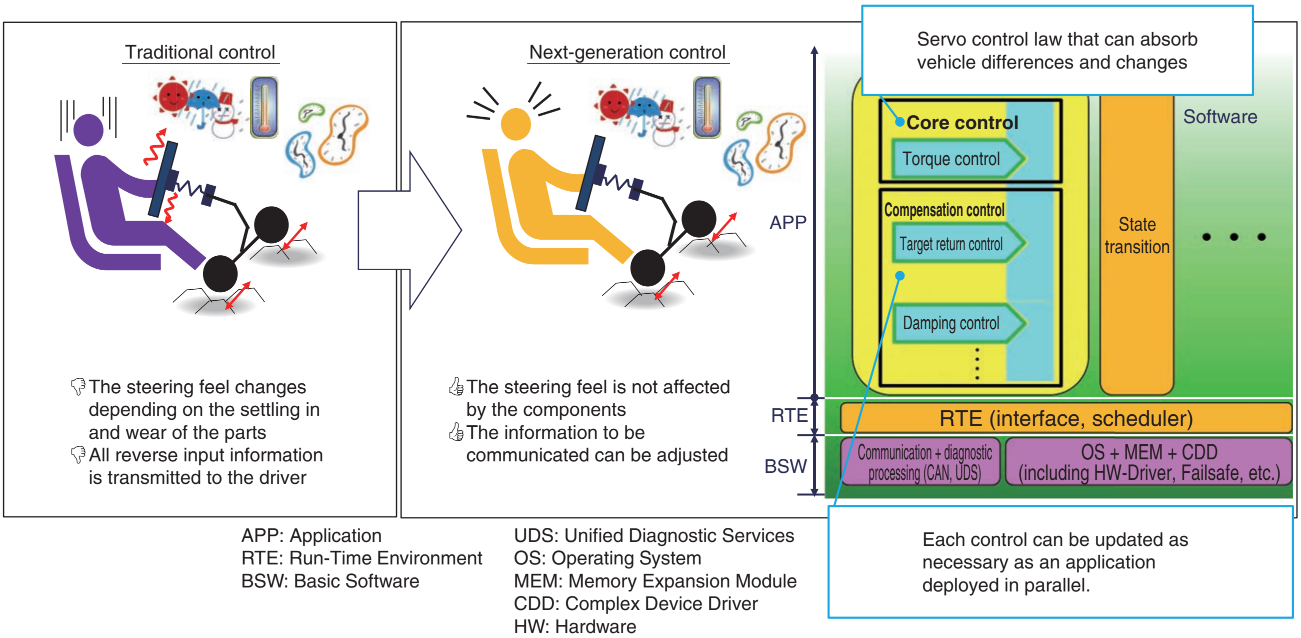

Fig. 6 Next generation control and software structure

4. Linkless Steer-by-Wire System (J-EPICS®: JTEKT Electronics Performed Intelligent Control Steering)

The basic shape of the interior space (cabin) has not changed since the first automobile was introduced to the world. J-EPICS® is a system that digitizes the intermediate shaft of the steering system by applying the DX concept to the steering system, and it is a technology that can significantly change the appearance of the cabin. The steering wheel in this system serves as a controller to input the direction that the vehicle will move as shown in **Fig. 7**. This smart steering system provides safety and driving pleasure by providing the needed steering feel feedback of road information and control of the steering gear ratio that takes into account the vehicle dynamics. Furthermore, the steering wheel as a controller frees designers from the traditional ring-shaped steering wheel and has no mechanical linkage mechanism, which provides a large degree of freedom in vehicle styling design and cabin design, and it contributes to the creation of new value for automobiles. This design also enables the steering wheel to be stowed in the dashboard, which was not possible with traditional steering systems. Details of this technology are described in this report, "Development of Steer-by-Wire System (J-EPICS) with No Mechanical Link" on page 36.

In order to realize these values to the maximum extent possible, we are actively working on value creation in cooperation with related partner companies. As an example, we participated in a collaborative initiative led by Toyota Boshoku Corporation with five other Toyota Group companies (the five other companies were Denso Corporation, Aisin Corporation, Toyoda Gosei Co., Ltd., Tokai Rika Co., Ltd., and JTEKT Corporation), proposed a "Vehicle interior space concept for the MaaS market," and exhibited the concept online at CES[*4] 2022. In that initiative, as shown in **Fig. 8**, we proposed a means of temporary manual operation (e.g., evacuating the vehicle to a safe place in an emergency) in an automated vehicle without a steering wheel, assuming a MaaS vehicle MX221 with autonomous driving level 4 (Mind Off) or higher after 2030. We will continue to proactively work with our partners to create UX for new mobility.

*4 CES: Consumer Electronics Show organized by the (U.S.) Consumer Technology Association

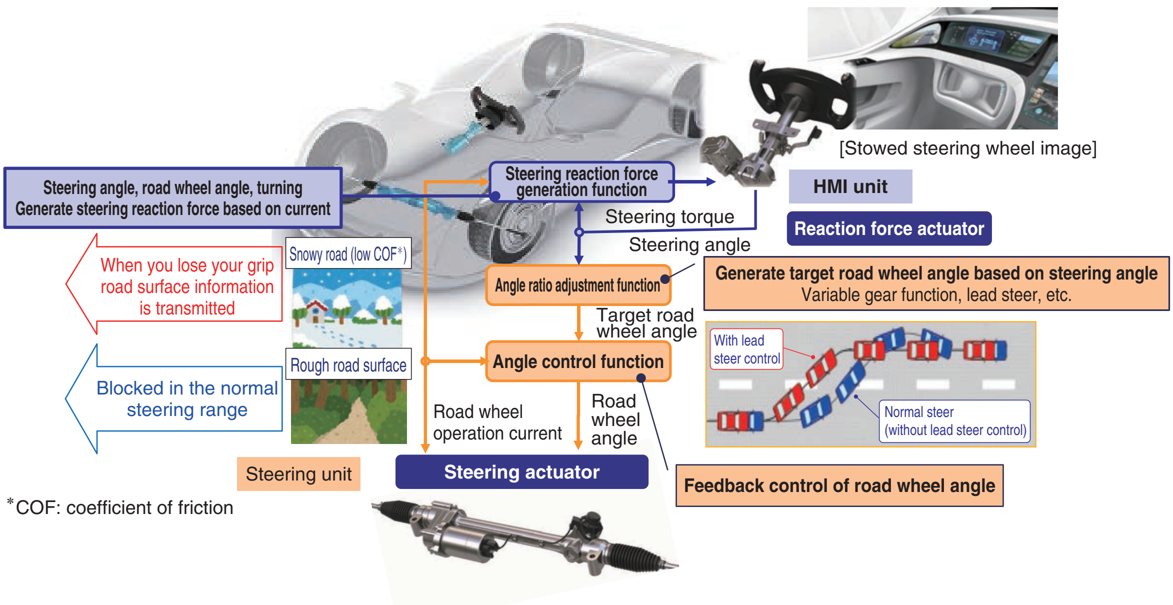

Fig. 7 UX created with linkless steer-by-wire technology

Fig. 8 New cabin proposal by TOYOTA group activities MX221

5. Vehicle Dynamics Control

Because the driver assistance system can directly control the actuators that control the vehicle motion, it can make the vehicle motion more comfortable for human drivers. Vehicle dynamics control has been developed mainly to improve the plane motion of a vehicle for the purpose of achieving “extreme handling performance ” of the vehicle. The future vehicle dynamics control collects the state quantities of each related component into one logic, controls the six-axis motion shown in **Fig. 9**, and improves the comfort level. The control system estimates the state of the vehicle body and tires from the vehicle model, and optimizes the amount and timing of driving, braking, and steering according to their availability for controlling the pitch, bounce, and roll of the vehicle body. Furthermore, as shown in the integrated architecture in **Fig. 10,** the system can be extended beyond comfort, such as FOP (Fail Operation), which complements the performance of each component in the event of a failure between cooperating systems. The steering system improves the accuracy of the driving path by generating the steering-related state quantities necessary for control as smart steering and by performing control that

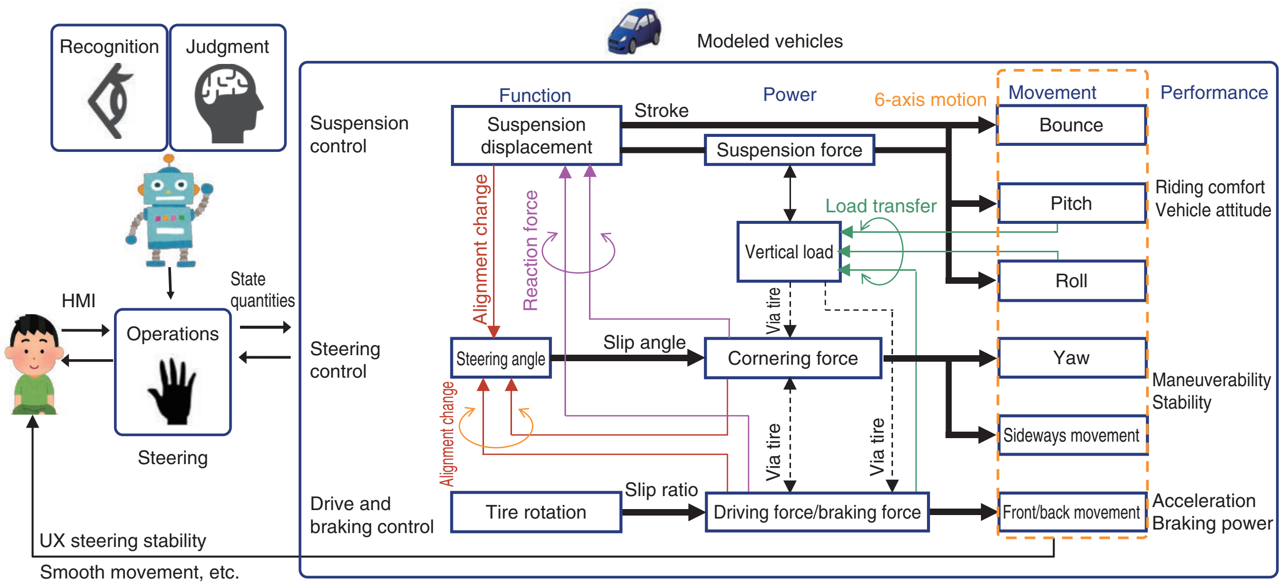

Fig. 9 Vehicle dynamics control

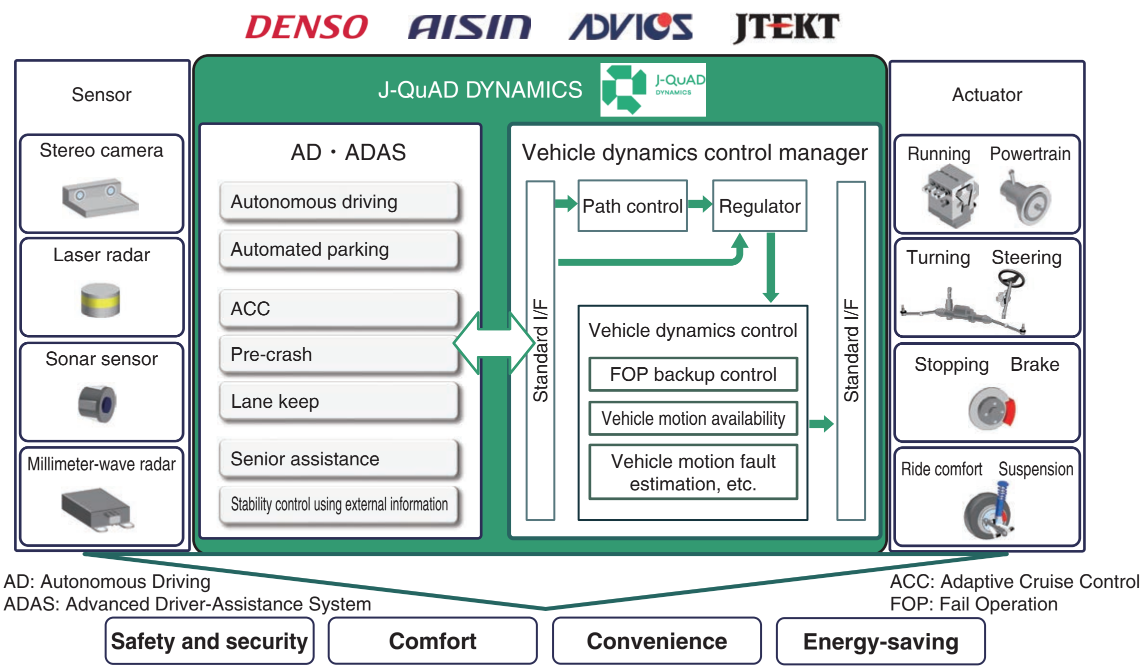

Fig. 10 Integrated architecture

compensates for road disturbances and other factors.

This initiative is a shared objective of four companies (Denso Corporation, Aisin Corporation, ADVICS Co., Ltd., and JTEKT Corporation) that are in the business of driving, braking, and steering components, and J-Quad Dynamics Inc., which was jointly established to conduct integrated control development.

6. Medium- and Large-sized Mobility Initiatives

The new value creation described so far is based on electrification. For medium-sized mobility vehicles, we are studying EPS (electric power steering) that does not use hydraulic pressure, but for large-sized mobility vehicles, due to the large amount of power required, we developed a hybrid-type steering system that combines the existing HPS (hydraulic power steering) shown in Fig. 11 with an electric steering actuator that performs the function of a smart steering system. In today's large buses and trucks, this system can improve safety functions such as LKA (Lane Keeping Assist System) and can reduce driver fatigue by improving the steering feel. This system was adopted as an autonomous driving level 2 (Hands Off) system for the Kesennuma Line BRT (Bus Rapid Transit) of East Japan Railway Company (abbreviated as JR East in the figure) as shown in **Fig. 12**. The social effectiveness and reliability of the system will be confirmed through joint verification experiments with other companies that form the infrastructure system, and commercial operation as a public transportation system is scheduled to begin in the winter of FY2022.

While being aware of the needs of large-sized mobility vehicles, we will develop technologies which enable acceleration and jerk suppression that are friendly to passengers and cargo, hydraulic failure detection, and evacuation operation while taking into account the steering response delay and load changes that are unique to today's buses and trucks.

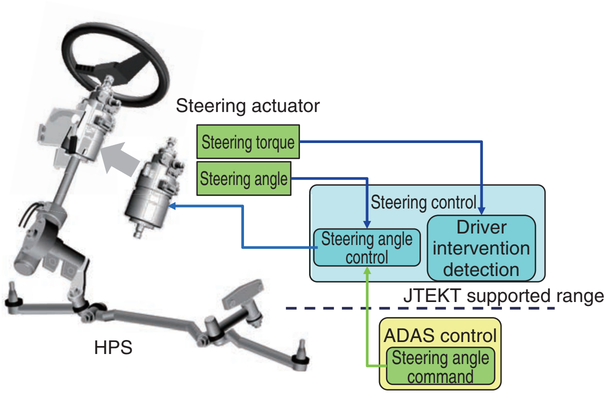

Fig. 11 HPS and steering actuator hybrid system

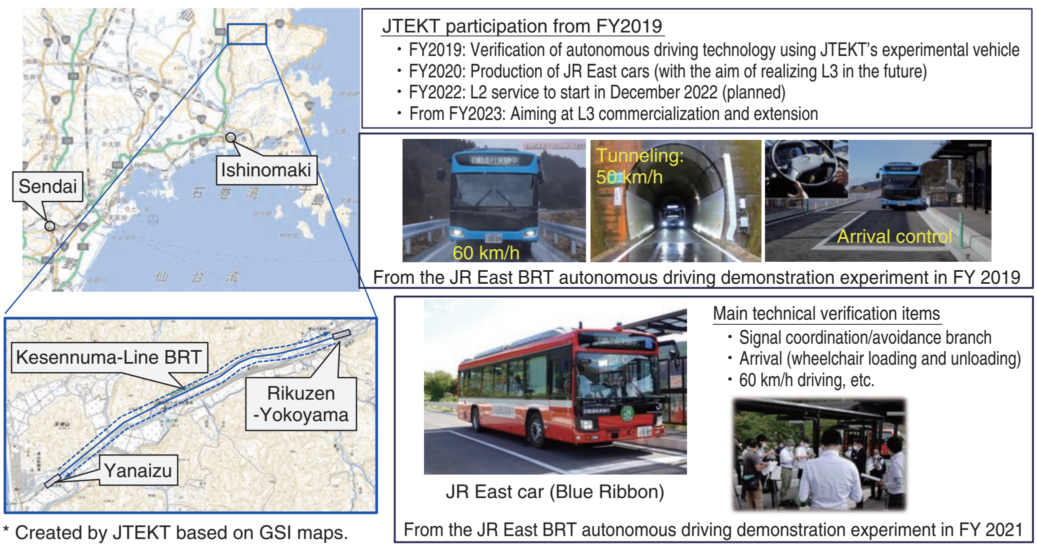

Fig. 12 JTEKT work with the BRT demonstration experiment

7. Fundamental Technology

In electric vehicles, the laden capacity for batteries has increased for enabling long range trips, resulting in an increase in weight compared to previous vehicles in the same segment. Weight reduction is becoming increasingly important as a fundamental technology in the development of high-quality steering systems at low cost. Sensor technology and CAE are presented here as examples.

7. 1 Torque and Angle Sensor

Traditional EPS systems have provided an optimal steering feel by detecting the driver's steering force with a torque sensor and controlling the necessary output motor power. In vehicles with autonomous driving level 2 (Hands Off) or higher, it is necessary to accurately control not only the assist force but also the tire steer angle. Therefore, as shown in **Fig. 13**, a single sensor unit is equipped with a function to detect both steering wheel angle and torque, and these output signals are digitized to reduce the amount of vehicle wiring harnesses and improve reliability. The system is designed to be redundant so that it can continue to function in the event of a single system failure.

7. 2 CAE

Lightweight technology is indispensable to improve the fuel efficiency and enable long range trips by vehicles. As shown in **Fig. 14**, we have introduced a phase optimization method (topology optimization method)[10] as a CAE method for producing a design of the steering gearbox with the necessary strength and a stiffness with the minimum weight, and have obtained demonstrated results. For the EPS used in pickup trucks and other vehicles operated under severe conditions, we have achieved a weight reduction of more than 30% compared to the traditional FEM design, and mass-produced the EPS.

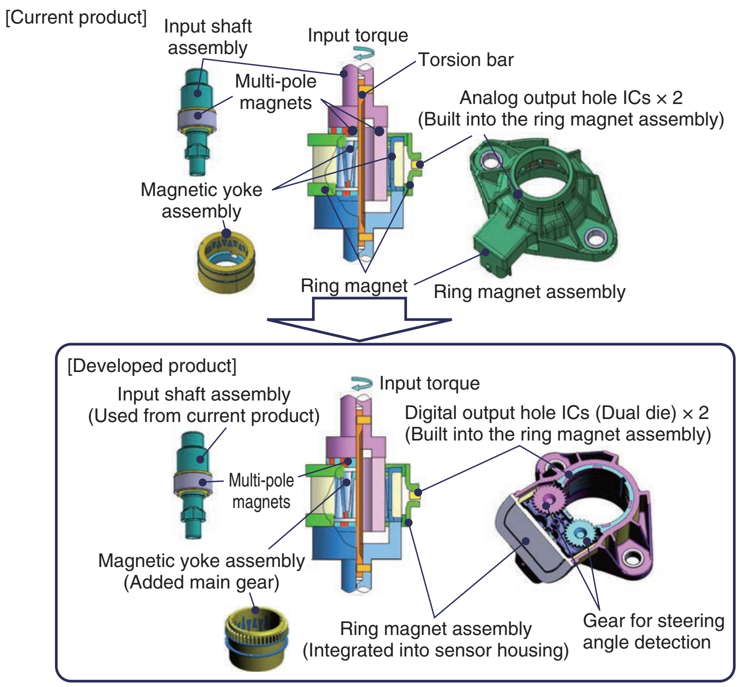

Fig. 13 Torque and angle sensor

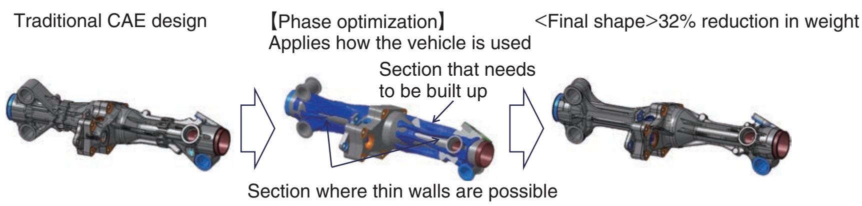

Fig. 14 Examples of CAE study

8. Conclusion

It has been a long time since the automobile industry has undergone an era of great change that occurs once in a century, but we believe that this "once" will not be transitory, but will continue over a very long span. We must constantly think about UX as an innovation based on the future of mobility in line with the SDGs and to view it as something that changes in conjunction with various people's lifestyles. This means that technology that was correct yesterday will be incorrect today, suggesting a change in the field from "competition to improve performance by accumulating technologies," which is an area where we excelled, to "competition to create innovations." The individual technologies introduced in this report are refinements of traditional technologies, but they will produce innovations by integrating them with vehicle design and the perception and decision functions of other systems.

We would like to develop more and more new products that will make people say, "We need JTEKT's steering technologies to realize this innovation," while bring together new partners as corporate collaborators. We are strongly committed to developing products that are beneficial to the earth, the world, and our customers, which is the basic philosophy of our company, and strive to continuously provide them to the market.

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