Outlook for Steering System Technology Aimed at Self-Driving

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As represented by MaaS, the environment surrounding automobiles is entering a dramatic period of change. Even in regards to steering system technology, there is an advancement in the anticipated role from the conventional simple power aid to a traveling aid supporting self-driving. This paper introduces the travelling aid-related technologies JTEKT is promoting, as well as the outlook of steering system technology aimed at self-driving.

***Key Words**: EPS, CASE, functional safety, SBW, HMI, integration control*

1. Introduction

In the late 1960s, as passenger vehicles became increasingly widespread in Japan, hydraulic power steering (HPS) was put into practical application in order to improve heavy steering, and light, comfortable steering began to spread. After this, motorization advanced further, and amidst increasing demand for second cars and a rise in female drivers, there was a requirement for power steering on light vehicles which were difficult to equip with HPS. In 1988, JTEKT was the first in the world to mass produce electric power steering (EPS) in the form of Column type Electric Power Steering (C-EPS). EPS, which began with mounting of power steering on light vehicles difficult to fit with HPS was also consistent with the market needs of added value in the form of environment preservation, such as better fuel economy. EPS began being adopted on vehicles other than light vehicles, and JTEKT also significantly helped spread EPS to the scale as it is today.

In line with the expansion of EPS-mounted vehicles, as a steering system maker, JTEKT developed and proposed the Dual Pinion type Electric Power Steering (DP-EPS), and Rack Parallel type Electric Power Steering (RP-EPS) as rack-assist type EPS supporting medium to large passenger vehicles, along with numerous other products meeting various market needs, including areas other than passenger vehicles, such as buses and utility vehicles.

2. Technologies Surrounding Automobiles

In recent years, the environment surrounding automobiles is facing a dramatic period of change. As represented by MaaS (Mobility as a Service), to achieve creation of new values in the automobile industry, there is a demand for contribution to the realization of a mobility society that is safe, secure, and highly convenient. CASE (Connected/Autonomous/Shared/Electric) is attracting a lot of attention as technologies for the manifestation of this. In the case of a self-driving society, for example, the technologies could be grouped into two types; (1) self-driving automobile technologies and (2) technologies utilizing self-driving by offering various services based on such self-driving technology. For the former, various technological initiatives are being carried out in the three fields of “cognition, judgment (characteristics), and operation,” while for the latter, a variety of companies are entering the area including different business types, such as mobility service providers (**Fig. 1**).

Moreover, there is a belief that self-driving should be proceeded with in stages to match society’s needs and technical advancements, and **Table 1** indicates the concept of self-driving levels. As **Table 1** shows, definitions have been established from Level 2 self-driving, which is known as “driver assistance” and is currently increasing in popularity, through to Level 5 self-driving, which is full autonomous driving. The self-driving technology and safety demanded at each level differs. The role of a steering system to suit the required self-driving level is also changing from the conventional power assistance for steering operations (reduction of steering force, improved steering feel) to driver assistance supporting self-driving.

As a steering system manufacturer presiding over “operation,” JTEKT engages in various technological initiatives relating to driver assistance. Amongst such

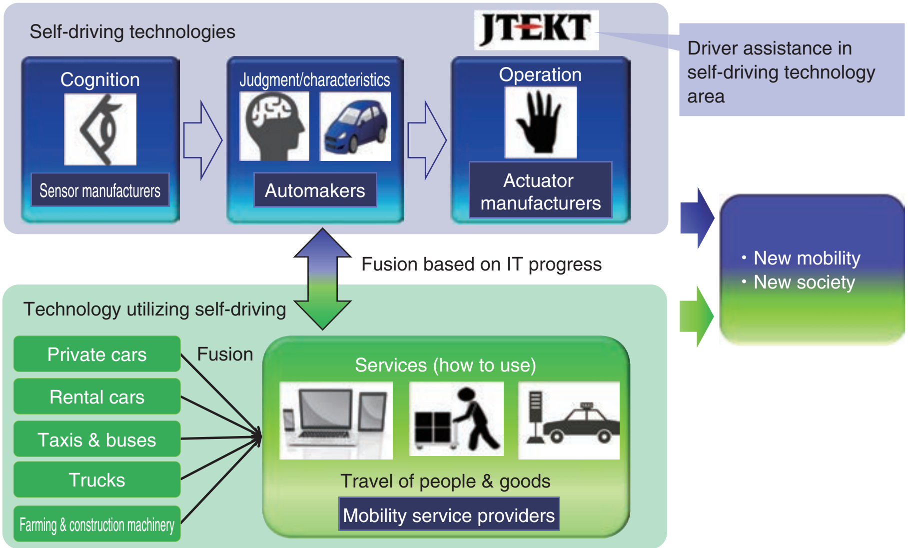

Fig. 1 Rough sketch of a self-driving society

Table 1 Self-driving level

Self-driving level	Level 2	Level 3	Level 4	Level 5
	Driver led	System-led		
	Partial automation	Conditional automation	Advanced automation	Full automation
Way to achieve self-driving level	Software backup	Hardware redundancy	Complete hardware redundancy including power source	
Safety concept*	JFOPS2	JFOPS3	JFOPS4	

*JTEKT's safety concept: JFOPS (JTEKT Fail OPerational System)

Note) **Table 1** was prepared by JTEKT based on SAEJ3016

initiatives, this report covers functional safety, which is the foundation of all self-driving levels, as well as technologies related to Steer By Wire (SBW), Human Machine Interface (HMI), which is mainly required from Level 3 self-driving onwards, integrated function for vehicle dynamics as an extension from the steering system area, as well as steering systems supporting ADAS (Advanced Driver Assistance System) for large vehicles and a precise docking function for large city buses which anticipates support for MaaS.

3. Functional Safety Requirements and Safety Concept

3. 1 EPS Functional Safety

Because EPS is a critical safety part to "turn" an automobile, in terms of safety, there is a need to comply with the requirements of ISO26262, an international standard for the functional safety of automobiles, just as is the case with the electrification of systems. To date, the most serious EPS failure mode of ASIL (Automotive Safety Integrity Level) -D was divided into the below two definitions, and there were no differences in the way individual automakers interpreted these.

<EPS failure mode defined as ASIL-D>

1) Self steering: The steering wheel turns without driver operation.
2) Steering lock: The lock prevents the steering wheel from turning.

JTEKT has been responding to EPS functional safety since 2005, and exerting every effort to secure design and production quality in order to prevent the above two failure modes. To achieve this, our primary approaches have been to build in quality at the development and manufacturing stages complying with functional safety requirements, making the failure occurrence rate comply with safety requirements by selecting electronic components with low failure rates, strengthening computational monitoring by adopting a dual core microcomputer and using a fail-safe to limit/stop system functions upon failure detection. Through such efforts, we have successfully prevented our EPS from entering any of the failure modes defined in ASIL-D.

3. 2 Changes in Functional Safety Requirement

The scope of EPS application in passenger vehicles is rapidly expanding from small to large passenger vehicles. Large passenger vehicles are equipped with high-output EPS and, in line with a shift to even higher output, if the system stops due to failure, the driver must operate the steering wheel themselves and this demands greater strength than before. Moreover, with the accelerated movement toward full autonomous driving in recent years, in the case of the advanced self-driving function it is presumed that the driver may not use the steering wheel, therefore a situation where the EPS stops due to failure must be avoided. In this way, the safety requirement level during system failures has risen in recent years, and it is essential that we evolve from using a fail-safe system that helps the function to stop safely in the case of a system failure to a fail operational system enabling the system to function at the bare minimum in the event of a failure. As such, JTEKT currently proposes a safety concept defined as JFOPS (JTEKT Fail Operational System) (**Table 2**).

Starting with the securing of partial redundancy through software backup at JFOPS1, the respective levels of JFOPS gradually broaden the redundant area and secure greater safety in development; with JFOPS4 entailing software backup in addition to dual systemization of hardware including power sources.

At JFOPS3 and JFOPS4, more electronic components are used due to the hardware redundancy design (**Fig. 2**), therefore the regular motor control unit (MCU: Motor Control Unit) is larger, and it becomes more difficult to mount the EPS system on a vehicle. In light of this, JTEKT has designed the portion of the MCU where electronic components are mounted to be as compact as possible, and created a single package the same size as the conventional model.

Table 2 JFOPS definition

	Design concept	Supported self-driving level				
		1	2	3	4	5
JFOPS4	Completely redundant design based on hardware			●	●	●
JFOPS3	Redundant design based on hardware (excluding power sources, microcomputers)		●	●		
JFOPS2	Expand backup scope from JFOPS1	●	●			
JFOPS1	Backup for breakdowns based on software (sensor, driver)	●	●			

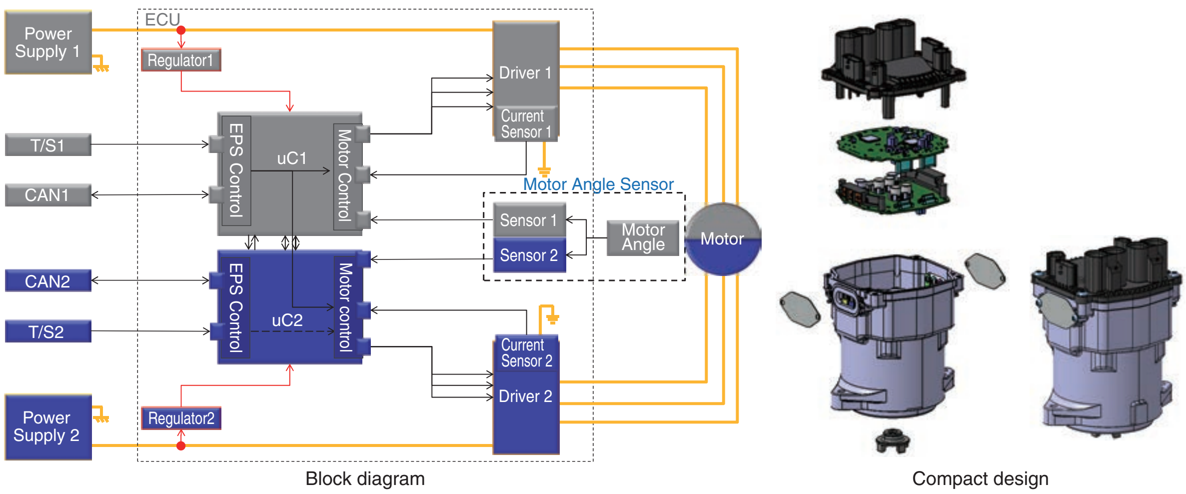

Fig. 2 JFOPS4 MCU

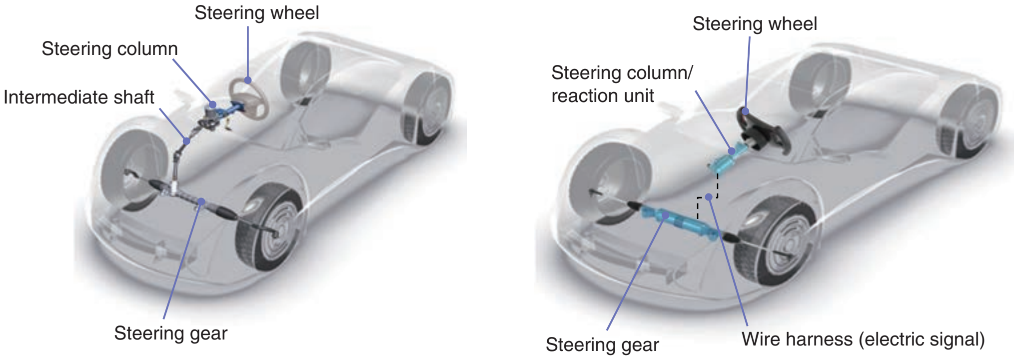

Fig. 3 Conventional steering system (left) and SBW system (right)

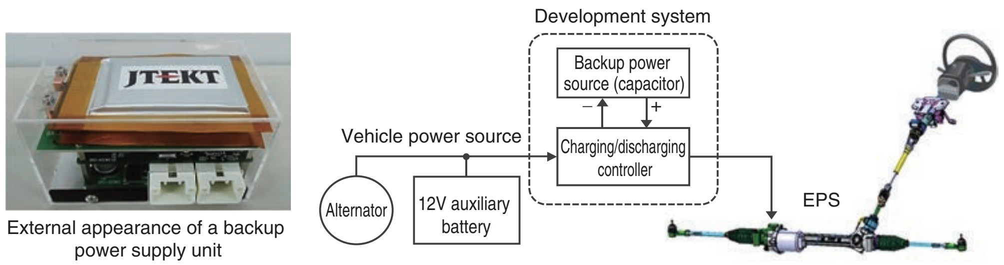

Fig. 4 Backup system for EPS electric power

4. SBW System

As the left portion of **Fig. 3** shows, in the case of conventional EPS, the steering column connected to the steering wheel and steering gear that turns the tires were connected mechanically by an intermediate shaft. Considering the future advancement of self-driving, there will be a need for a technology to eliminate mechanical links such as the intermediate shaft as a system making it easy to determine when driver intervention is required during self-driving mode, and to isolate erroneous (hazardous) operations by the driver.

As the right portion of **Fig. 3** shows, the mechanical link has been eliminated on the SBW system, and it is instead comprised of a reaction unit (which generates steering reactive force when the steering wheel is operated) integrated with the steering column, and a steering gear, which are connected by an electrical signal via a wire harness. Because the steering wheel side and tire side are not connected mechanically, we can propose a variety of functions not possible with the conventional steering system, such as arbitrary adjustment of steering feel, compatibility with irregular-shaped steering wheels, and steering wheel storage during self-driving.

Meanwhile, due to the elimination of a mechanical link, there will be a need to secure reliability at a high dimension. Moreover, advanced technology will be required to provide the driver with kickback information from the tires/steering gear caused by changes in the road conditions through the reaction unit in as natural a way as possible.

In addition to steering wheel angle control and torque control, JTEKT is pioneering development of an SBW system which responds to the above-mentioned issues by connecting units with high-speed communication, thus creating new values.

JTEKT has also developed a backup power supply unit adopting a lithium-ion capacitor. This unit aims to monitor and back up the power source system to further increase safety of the SBW system. JTEKT's lithium-ion capacitor exhibits stable performance across a wide temperature range and, due to its ability to be installed in the engine compartment without a cooling system, significantly contributes to improving safety of the steering system (**Fig. 4**).

5. Initiative for HMI-based Steering Control Transfer Technology

In line with the sophistication of self-driving technology, there is a shift toward integration control of individual functional systems, and from the perspectives of safety and comfort, the connection between humans and automobiles (machines) is becoming a crucial element. In regards to operation systems, steering systems in particular are products with which human drivers must sensitively interact; therefore HMI plays a major role in the steering function.

As **Table 3** shows, rather than merely providing power assistance for steering operations, in line with advancing

Table 3 HMI steering function

Assistance status	Required function	Self-driving level 0	1	2	3	4	5
Steering (power assistance)	Steering feel	●	●	●	●	●	
Easy switchover between steering and system	Steering control transfer		●	●	●	●	
Hands-free steering	Hands-off detection			●	●		
Steering status	Hands-off/on detection				●	●	
Sharing of manual/automatic steering (seamless)	Shared control				●	●	

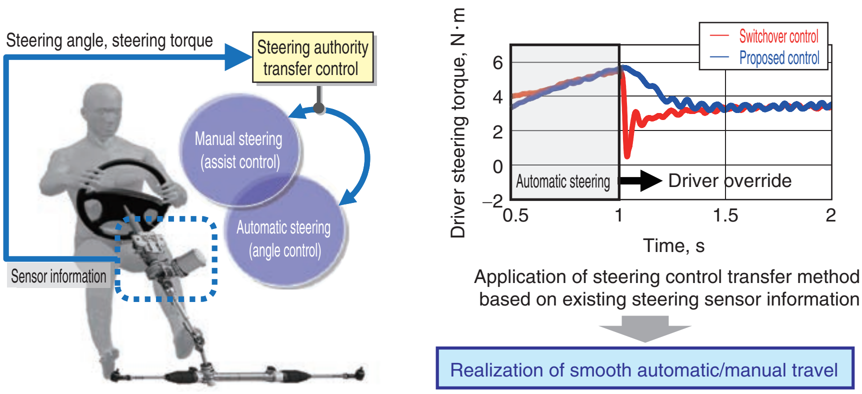

Fig. 5 Steering control transfer technology

self-driving level increases, there will be a demand for a driver assistance function that detects when the driver has taken their hands off the steering wheel, enables smooth steering control transfer to driver assistance or a partially-automated system, etc.

In regards to judgment regarding switching the primary steering from manual to automatic or vice-versa, for example with lane-keeping assist (LKA), the system will switch to manual when an input occurs in steering wheel torque that is greater than a predetermined threshold value. In other words, the switchover mechanism is currently based on some form of judgment criteria.

However, with this approach, the self-driving function will be disabled each time, and there is room for improvement insofar as user-friendliness and comfort. Moreover, in regards to safety and security aspects also, there is a need to develop a new steering function responding to automation levels, to enable smooth manual/automatic switchover (steering control transfer), perform manual/automatic operation sharing (shared control), and offer a seamless function whereby free, safe steering operation is possible without the driver needing to be conscious of it. **Figure 5** shows an example of JTEKT's development activities.

6. Initiative for Integrated Function for Vehicle Dynamics

Amidst promotion of Level 3 self-driving and higher, in regards to vehicle movement, there is focus on not only so-called "vehicle dynamic performance," but also the quality of mobility (how easy a vehicle is to drive, passenger comfort). To make this happen, an important element in addition to control of the steering system independently will be the so-called integration function for vehicle dynamics (**Fig. 6**), which links steering with other functions.

For the steering system, which controls the sideways movement of a vehicle, there are development efforts being made to achieve vehicle dynamic performance whereby the steering system collaborates with drive and braking systems which control the forward/backward movement of a vehicle, as well as efforts to improve mobility. At the same time, from a safety aspect, there is a need for initiatives considering mutual compensation when individual functions fail.

In April 2019, JTEKT, DENSO Corporation, Aisin Seiki Co., Ltd and ADVICS Co., Ltd. established a new company, J-QuAD DYNAMICS Inc. This company's objective is realizing vehicle dynamics control aimed at fusion with self-driving control at an advanced level. J-QuAD DYNAMICS combines the technical knowledge of the four companies to increase the efficiency and speed

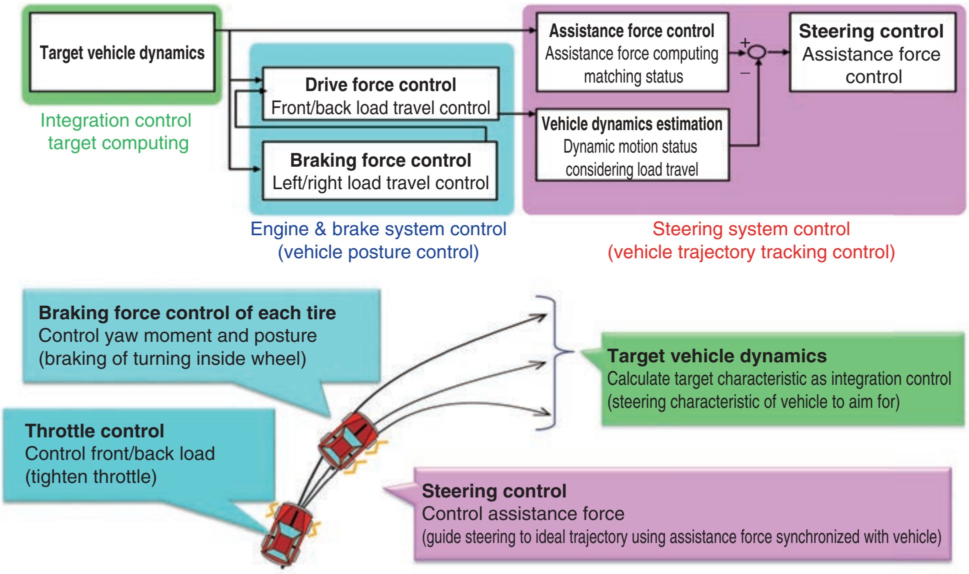

Fig. 6 Integrated system for vehicle dynamics

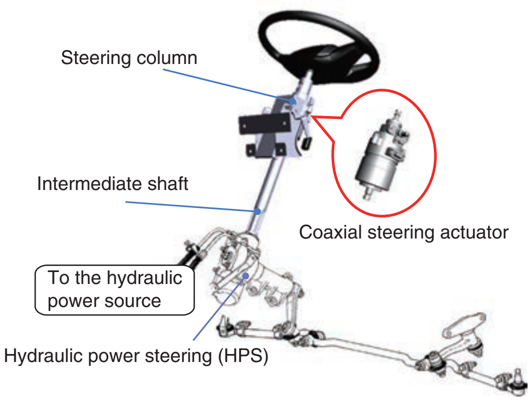

Fig. 7 Steering system of mid/large-sized vehicles for ADAS (Image)

of software development necessary for the integrated function of vehicle dynamics. Moreover, automakers are aiming to offer a one-stop service so that it will not be necessary to establish technical specifications or inter-functional adjustment for each functional system.

7. Technology Supporting Truck/Bus Self-driving

7. 1 Steering System Supporting ADAS in Medium/large Vehicles

Medium/large vehicles such as trucks and buses require a large output for steering therefore, conventionally, it has been difficult to adopt EPS on such automobiles, and HPS is used instead. However, it is difficult to support self-driving with HPS alone, therefore JTEKT is developing a steering system (coaxial type steering) supporting ADAS for large vehicles which controls HPS using an electric actuator. In this system, the steering actuator is located on the same axis as the steering column (**Fig. 7**).

The system involves the self-driving steering command being given to the coaxial type steering, the coaxial type steering then inputting the angle into the HPS based on this command then, ultimately, the tires being turned. This system enables self-driving on large automobiles such as trucks, sightseeing buses, and city buses. This function can support JTEKT's existing C-EPS and HPS technologies, however in the case of buses and trucks, the steering column and intermediate shaft are located between the driver's knees, therefore we have positioned the steering actuator and the steering column on the same axis with consideration to driver safety in the knee vicinity in the event of a collision and securing ample space for footwork.

7. 2 Precise Docking Function for Large City Buses

Of large vehicles, city bus transit systems are of the highest relevance to people's everyday lives. Studies are being carried out regarding a Bus Rapid Transit (BRT) and an Advanced Rapid Transit (ART) to improve the convenience of mobility, and JTEKT is involved in ART development of the Strategic Innovation Promotion Program (SIP) spearheaded by Japan's Cabinet Office. This involves the development of a precise docking function. Efforts are being made to develop a precise docking system for buses & trucks, which is a technology contributing to smooth boarding/alighting as a barrier-free initiative, and on-time bus operations, etc. by ensuring the bus stops precisely at stops so that the gap between the bus doors and stop is as minimal as possible. The SIP Program also requires that the gap between buses and bus stops is kept as minimal as possible, and sets a high accuracy target of ± 20 mm (**Fig. 8**). JTEKT is developing high-accuracy precision docking technologies such as cameras, LiDAR (Light Detection And Ranging), and GNSS (Global Navigation Satellite System), has participated in verification tests as part of the SIP program in Okinawa, and has identified issues for practical realization of precise docking systems as well as confirmed function feasibility.

Fig. 8 Demonstration experiment in Okinawa (Feb. 2019)

8. Conclusion

The environment surrounding automobiles is changing at a tremendous pace, and companies unable to keep up with this change are being forced to withdraw from the industry in the blink of an eye. As this paper has discussed, it is JTEKT's mission to draw upon our foundation as a steering system supplier with one of the world's highest shares in monozukuri to advance technological innovation from the conventional steering systems with simple power assistance to steering systems capable of driver assistance supporting self-driving, thus contributing to the advancement of society.

Moreover, we cannot achieve our goal all on our own. Rather, it will become even more necessary moving forward to enter flexible industry-government-academia alliances and corporate tie-ups. The world we aim for is one with a smart mobility society that is safe, secure and convenient for all, at the same time as being gentle on the environment. Toward this wonderful goal, JTEKT wishes to refine our technology and continue being a company essential to society.

* H-EPS, C-EPS, P-EPS, RD-EPS, DP-EPS and RP-EPS and JFOPS are registered trademarks of JTEKT Corporation.

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