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ADVANCE

Factory Automation and Mobility

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Changes for the Better

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Mitsubishi Electric
ADVANCE
Factory Automation and Mobility

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Mitsubishi Electric Corporation aims to contribute to a sustainable society by solving social issues through its businesses. In the Industry & Mobility Business Area (BA), the company leverages a lineup of products that make full use of digital technologies to maximize technology synergies between the FA Systems Business and the Automotive Equipment Business, while also strengthening mutual business. In this issue, we introduce recent initiatives in both business domains.

Overview

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* *Representative Executive Officer,Executive Vice President, CTO (In charge of Technology Strategies) Industry and Mobility Business Area Owner*

Foreword to Special Issue on Industry & Mobility

At Mitsubishi Electric Corporation Group, we aim to achieve sustainability, with a focus on contributing to a sustainable society by solving social issues through our businesses. We will transition into a circular digital engineering business model with smarter digitization of field knowledge accumulated from customer data, blending it with advanced digital technologies such as AI and modeling, and linking it with our digital platform "Serendie," thereby maximizing our strengths. By integrating our technical assets—Operational Technology (OT), domain knowledge, security, and development and design capabilities—and advancing data collaboration between systems across different business domains, we will continue to create solutions that solve complex social issues and contribute to a better society. In the Industry & Mobility BA, we will maximize technology synergies that support the future of "manufacturing" and "comfortable mobility" through digitally sophisticated core components and digital technologies, mutually reinforcing the manufacturing capabilities of the FA Systems Business and the Automotive Equipment Business, as well as our Digital Solutions Business.

For the industry domain, this feature issue showcases the programmable automated controller "MELSEC MX Controller," a newly released digitally sophisticated component that integrates various control and motion technologies cultivated through sequencers into a single unit, from a software-defined perspective.

In the mobility domain, advanced driver assistance functions in automobiles continue to evolve, and we are developing and providing key components that support these functions and lead their evolution, with the aim of creating a safe and secure society free from accidents. This feature issue takes a closer look at "High Definition Locater" and "Vehicle to everything (V2X)" as technologies for achieving safer mobility with automobiles—technologies that accurately identify the vehicle's own position on the road by leveraging high-precision satellite positioning technology, and that identify relative positions to surrounding vehicles through vehicle-to-exterior communications to avoid collisions. We also explore the "Driver Monitoring System (DMS)" and "in-cabin radar" technologies that sense the condition of drivers and passengers inside the cabin and issue alerts by detecting driver distractions, drowsiness and passenger remaining in the vehicle when parking, enabling people to use automobiles safely and with peace of mind every day. Finally, we also showcase "Microcontroller-less System on a Chip (SoC) control technology" that reduce the cost of these products and enable installation in more automobiles.

In today's complex and rapidly changing society, the Industry & Mobility BA will become a game changer itself and continue to explore the possibilities of the future. To achieve this, we will take the dual approach of backcasting that gains insight into future value from potential future scenarios to formulate a mid-term technology strategy, and forecasting that internalizes technology trends and links them to business expansion in a reliable manner, to take on the challenge of technology development to transform existing businesses and open up new markets and customers.

Mitsubishi Electric Programmable Automation Controllers "MELSEC MX Controller"

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**Nagoya Works*

Abstract

As the required control scale and performance differ at increasingly diverse manufacturing sites, it has become a challenge for controllers to meet such requirements. By integrating the control technologies cultivated with MELSEC into a single unit, we developed the "MELSEC MX Controller" as a new product designed to meet customer requirements and bring further transformation to manufacturing sites.

The features of this product are as follows.

(1) High-precision motion control that enables precise assembly and machining, even with multi-axis equipment

In equipment comprising multiple axes, we made it possible to control a "mechanical configuration that requires high-speed, high-precision machining" and a "mechanical configuration that does not require high precision" with different control cycles. This enables optimization of control for the entire equipment.

(2) Enhanced information processing that promotes adoption of Internet of Things (IoT) at factories

To promote the adoption of IoT at factories, Message Queuing Telemetry Transport (MQTT) and OPC UA[*1] are built in, making it possible to build systems with a high affinity with higher-level systems. And as affinity with higher-level systems increases, the risk of cyberattacks also rises; thus cybersecurity countermeasure functions such as encrypted communication and user authentication have been included, enabling the construction of a robust system.

(3) Scalable lineup tailored to customer equipment scale and applications

The performance and scale of control required for the lineup equipment depend on the products being manufactured. A scalable lineup is offered according to program capacity, number of control axes, and performance so that a controller suited to each piece of equipment can be selected.

1. Introduction

In recent years, manufacturing sites have faced increasingly diverse requirements, such as large-scale equipment resulting from process integration, high-precision equipment resulting from more complex processes, the advancement of IoT, and better measures to combat cybersecurity threats.

With conventional sequencers, distributed control that enables flexible systems to be built by combining multiple units has addressed market requirements. However, with increasingly diverse market demands, addressing equipment that requires high performance has become a challenge, including high-speed, high-precision multi-axis motion control for controlling large-scale equipment, management and computation of large-capacity data for managing lines and devices, and data communication with higher-level systems. To respond to such market demands while driving further transformation at increasingly diverse manufacturing sites, we developed the programmable automation controller MELSEC MX Controller (Fig. 1) that integrates the control technologies cultivated with MELSEC into a single unit.

*1 OPC UA is a registered trademark of the OPC Foundation.

Fig. 1 MELSEC MX Controller

2. Product Features

The MELSEC MX Controller strengthens product capabilities for customers seeking high-precision machining and improved production efficiency, and for customers who want to advance IoT implementation and make effective use of data; by integrating various controls and functions into a single controller, it has been developed to provide optimal products tailored to the scale of the equipment.

Its main features include “high-precision motion control that enables precise assembly and machining, even with multi-axis equipment,” “enhanced information processing that advances factory IoT implementation,” and “a scalable lineup tailored to the customer’s equipment scale and applications.”

2.1 High-precision motion control that enables precise assembly and machining, even with multi-axis equipment

In equipment that requires large-scale, high-precision motion control, there is demand to control 100 or more axes with a single controller. Yet the greater the number of axes to be controlled, the more the computation workload increases,and the control cycle for all axes in the system becomes longer. When the control cycle becomes longer, delays in feedback from drive devices and sensor input, as well as lower resolution of control commands from the controller, make high-precision control difficult. Therefore, the MELSEC MX Controller supports multi-rate control that can achieve both multi-axis control and high-precision control: assigning only specific axes that require high-precision control to a high-speed cycle, and assigning the remaining axes to a medium-speed cycle or low-speed cycle, enables control of a large number of axes while maintaining the control accuracy of specific axes.

An example is shown in which multi-rate control is applied to a winding machine, which is part of lithium-ion battery manufacturing equipment that requires multi-axis control and high-precision control (Fig. 2). The winding machine comprises an unwinding unit, a tension control unit, a cutter control unit, and other components. Cutter control needs to cut the electrode sheet at an accurate position. Any deviation in the cut position can result in product defects; therefore, control at a high-speed cycle is required. In contrast, the unwinding unit has a high level of inertia. Given the responsiveness of this unit, a low-speed cycle is sufficient to deliver the required equipment performance. In this way, by applying multi-rate control, optimal control that meets the required performance of each control unit within the equipment can be achieved with a single controller.

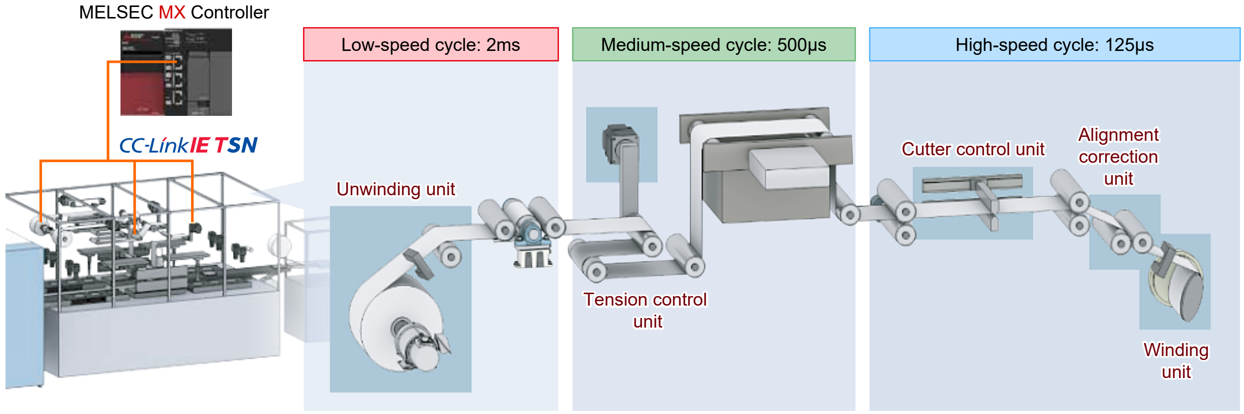

Fig. 2 Overview of the winding machine configuration and an example of applying multi-rate control

2.2 Enhanced information processing that advances factory IoT implementation

At manufacturing sites, improving productivity, improving yield and reducing equipment maintenance costs are always cited as challenges. In recent years, AI has also come to be used to address such challenges at manufacturing sites, and to enable data analysis and learning, better coordination between production equipment and higher-level systems is required. The MELSEC MX Controller promotes better coordination with higher-level systems by incorporating OPC UA and MQTT. For OPC UA in particular, the MELSEC MX controller not only supports server functions, but also client functions and information models, enables easy data linkage with higher-level systems and, as a supervisory controller, achieves centralized management of data within equipment. And while IoT adoption is being advanced, the threat of cyberattacks is also on the rise—the MELSEC MX Controller is equipped with security functions such as encrypted communications and user authentication, enabling the construction of robust systems. An example connection to a higher-level system is shown in Fig. 3.

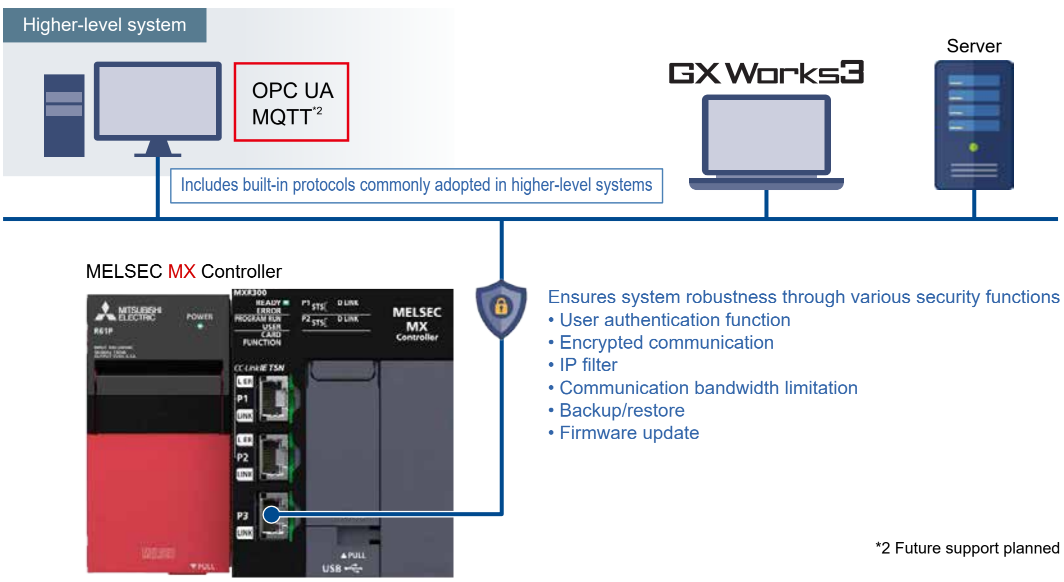

Fig. 3 Example connection to a higher-level system

2.3 Scalable lineup tailored to customer equipment scale and applications

For sequence control, models are selected based on the scale of equipment control, and with the CPU units available with each series of MELSEC, a lineup with different program-memory capacities was provided. Yet for motion control, the number of axes required for each piece of equipment varies widely from a small number to multiple axes depending on the mechanical configuration. The required control performance depends on the machining accuracy and required production volume of the product being manufactured, regardless of the number of axes used or the control scale.

With the MELSEC MX Controller, a scalable lineup is provided so it can meet the performance required by customers.

3. Technologies to Develop the System

The following is an outline of the technologies applied in the development of the MELSEC MX Controller.

3.1 Technologies applied to multi-axis, high-precision motion control

To support having multiple cycles coexisting for the computation processing of conventional models that operated with only a single cycle, the MELSEC MX Controller needed the computation processing to be divided into three cycles—high-speed cycle, medium-speed cycle, and low-speed cycle—and that each be executed with different execution cycle and priority. Furthermore, to make the most effective use of the multicore CPU used with this system, it was also necessary to support parallel execution, where multiple cores work together.

Accordingly, we not only separated the conventional computation processing, which operated on the premise of a single cycle, into three cycles, we also optimized the data structures, processing algorithms, and processing scheduling for parallel processing. In particular, the computation processing in each cycle accessing a large amount of shared data causes competition and reduced CPU cache efficiency, which not only makes performance improvement from parallelization limited, but also reduces the scalability. An example of this is implementing localization to improve data locality—faster processing was achieved by reducing exclusive control during data access and improving CPU cache efficiency (Fig. 4).

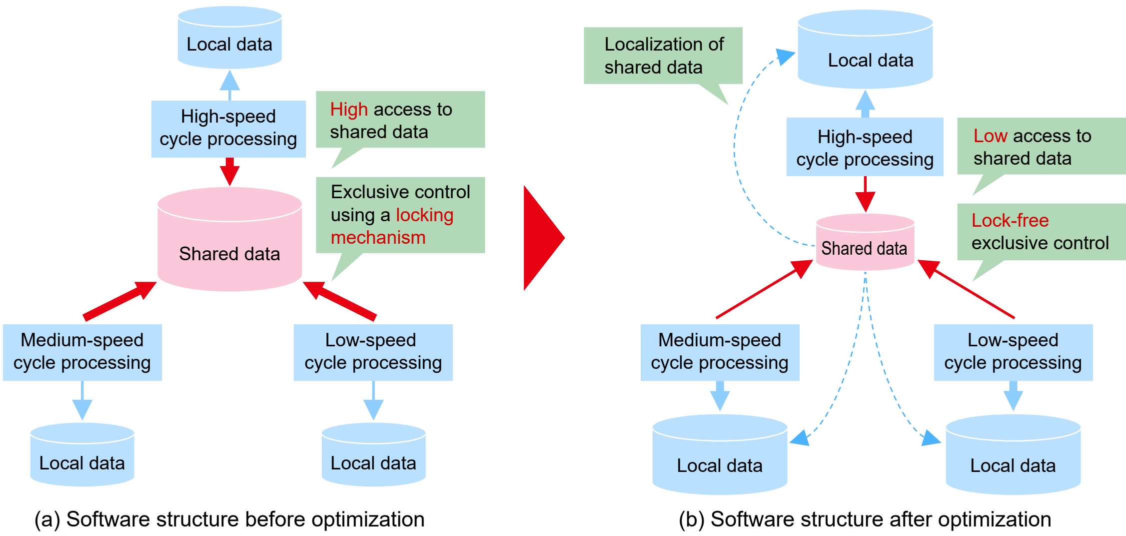

Fig. 4 Software structure optimization

3.2 Technologies applied for advancing factory IoT implementation

Stronger collaboration with higher-level systems is essential for advancing IoT implementation. To that end, the information processing section of the MELSEC MX controller uses Linux*3, which makes it easy to incorporate open networks and general-purpose technologies that are readily adopted on the higher-level system side, and also facilitates a rapid response to vulnerabilities. On the other hand, for control processing that requires real-time performance, such as sequence control and motion control, the timing deviation due to processing jitter affects equipment machining accuracy and tact time, so a real-time OS was adopted for the control processing section. This made it easier to achieve functions and performance in the information processing section and the control processing section respectively, but a key challenge was to minimize the impact on real-time control when the information processing section accesses resources (devices/label data, etc.) managed by the control processing section.

To resolve this issue, we adopted a layered architecture (Fig. 5) comprising a driver layer adapted to suit the OS or hardware, a service layer that provides common processing to the control processing

*3 Linux is a registered trademark of Linus Torvalds.

and information processing sections, and an application layer that implements functions such as the control processing and information processing sections. In this architecture, the service layer employs low-overhead mutual exclusion processing and, when calling the common Application Programming Interface (API) provided by the service layer from the application layer, controls the priority and order of shared memory access depending on the caller, thereby reducing the impact on real-time control.

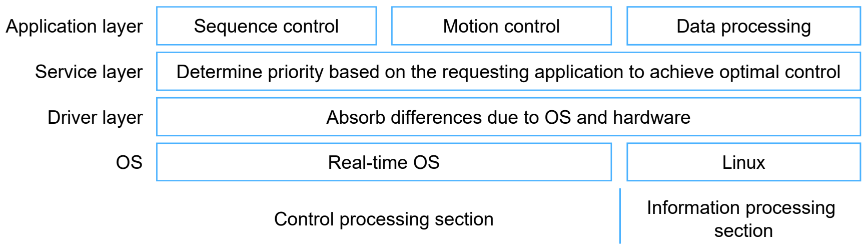

Fig. 5 MELSEC MX controller architecture

3.3 Technologies applied to a scalable lineup

To achieve a scalable lineup of MELSEC MX controllers, in addition to interfaces with a system bus for linking with sequencers and data, and interfaces with devices supporting CC-Link IE TSN, we developed a dedicated IC incorporating a multi-core processor and a general-purpose bus (PCI Express[*4]). The dedicated IC connects to a general-purpose IC via PCI Express, thereby easily expanding CPU functions and performance, and enabling a flexible hardware configuration that makes it easy to implement software (Fig. 6).

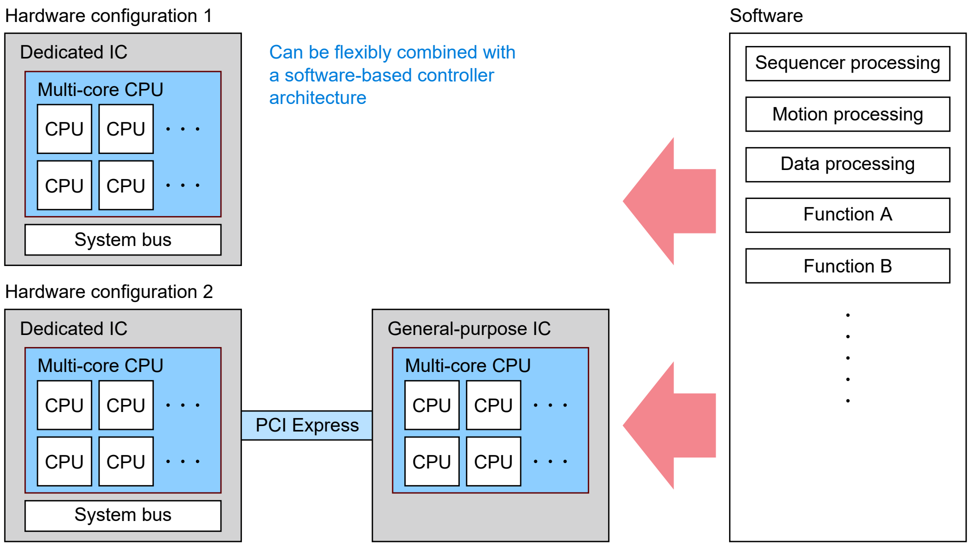

Fig. 6 MELSEC MX controller hardware configuration

Development of a dedicated IC implementing a multi-core processor faced challenges including improving the efficiency and performance of parallel computations for each CPU and managing the power consumption that accompanies higher performance. To improve the efficiency of parallel computations for each CPU, we maximized the efficiency of parallel computations on the multi-core CPU by optimizing the internal bus configuration and the allocation of software processing to each port of PCI Express, through front-loading design such as operation simulation and prototype verification. In terms of power consumption, we implemented circuits that allow the power supply to each function to be shut off individually, and with power management to suit the applicable hardware configuration and the software to be implemented, we achieved both higher performance and lower power consumption for the IC.

With the scalability and flexibility of the dedicated IC, we achieved optimal functions and performance for the information processing section and the control processing section tailored to customer equipment scale and applications, enabling a rapid response to diversifying market needs and technology trends.

*4 PCI Express is a registered trademark of PCI-SIG.

4. Conclusion

This paper outlined the features of the MELSEC MX Controller and the technologies applied to develop them. With the MELSEC MX Controller, whereas previously line and equipment design was performed by prioritizing either product machining accuracy or production takt time, it is now possible to select both, making it possible to improve the cost performance of facilities. Looking ahead, we will continue to firmly identify advances in technology and changes in customer requirements, and lead transformation at manufacturing sites.

Relative Zone Classification in V2X by HDL Technology

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Abstract

In the midst of a phase of major change said to occur once in a century throughout the automotive industry, technological development in the Connected, Autonomous, Shared & Services, Electric (CASE) domains has been accelerating in recent years. Vehicle to everything (V2X) is a key technology for connecting the ego vehicle to remote vehicles and infrastructure, and there is growing anticipation for it as a technology to improve recognition performance for Advanced Driver Assistance Systems/Autonomous Driving (ADAS/AD) aimed at safety and security, and to smoothly implement cooperative control between vehicles. Studies and development are actively being conducted globally, mainly in Europe and the United States—in Japan too, institutional frameworks and feasibility studies are being implemented, and verification tests on expressways are also underway.

Mitsubishi Electric Mobility Corporation (MELMB) has developed a V2X technology to achieve safer and more secure ADAS applications (such as collision warnings) by improving the estimation accuracy for the relative positional relationship with remote vehicles based on position information of the ego vehicle and remote vehicles, thereby enhancing the warning accuracy for collision risk. This technology uses highly accurate position information and map information—features of High Definition Locator (HDL) technology—to more accurately recognize the situation of remote vehicles around the ego vehicle and achieve relative zone classification and warning accuracy.

1. Introduction

ADAS and autonomous driving systems have been installed in various vehicles in recent years. The main vehicle control is based on detection results from vehicle sensors such as cameras and millimeter-wave radar, and ranges and use cases that are difficult for sensors to detect, such as when objects obstruct the view or in blind spots, need to be considered. To address these issues, using V2X to connect outside the vehicle makes it possible to identify vehicle behavior in advance between the ego vehicle and remote vehicles, powered two wheelers (PWTs), infrastructure such as traffic signals (roadside units RSUs), and pedestrians, and to provide collision-risk warnings. The result is increased safety, convenience, and comfort, and effects such as reducing traffic accidents, alleviating congestion, and reducing environmental impact are anticipated.

One technical challenge for V2X is when understanding vehicle behavior mutually and issuing collision-risk warnings—the relative positional relationship between the ego vehicle and remote vehicles need to be identified with a high level of accuracy, from the geographic coordinates and status of remote vehicles. In this regard, for the ego vehicle, high positioning accuracy and reliability can be maintained through map matching using Global Navigation Satellite System (GNSS), sensor information, and map information via the High Definition Locator; however, for position information received from remote vehicles, the reliability of position accuracy cannot necessarily be considered high because it depends on those vehicles' positioning accuracy and reliability. Therefore, technology to improve the accuracy of position estimation for remote vehicles is required.

This paper outlines MELMB's initiatives toward technology for improving the estimation accuracy of relative zones with remote vehicles by using highly accurate position information and map information, which are features of HDL technology, in order to improve these issues.

2. Initiatives with V2X Development Using HDL Technology

2.1 Issues with conventional V2X technology

With V2X technology, the ego vehicle and remote vehicles transmit position information such as latitude/ longitude and altitude mutually. The system estimates the relative position between the ego vehicle and remote vehicles in real time, using the received position information of remote vehicles. In addition to relative position estimation, the system then determines whether to provide information, caution, or warnings to the driver depending on the use case by performing a risk assessment of hazards such as collisions based on the ego vehicle's and remote vehicles' headings, speed, distances to an arbitrary destination point, and estimated times of arrival.

Challenges with V2X technology include difficulty estimating accurate position using only the position information transmitted from remote vehicles, and difficulty estimating whether remote vehicles exist on a road related to the ego vehicle or in the driving lane. Therefore, technology is required to improve the accuracy of position estimation for remote vehicles; however, with position estimation based on remote vehicles' route history, which has been used in the past, accurate estimation is not always possible depending on the accuracy of the remote vehicles' position information and the geometry of the road being driven on.

Possible problems that may arise include cases where there is no actual possibility of a collision between the ego vehicle and remote vehicles, yet the system performs a risk assessment and notifies the driver of false alarms (false positives), and conversely, cases of incorrect detection (false negatives) where the system estimates that there is no possibility of a collision, but a collision risk does actually exist.

Such false alarms and missed detections could make it impossible to provide a safe system for vehicle drivers and traffic. To reduce these factors and achieve highly reliable V2X technology, highly accurate estimation of the positions of remote vehicles is required. Thus at MELMB, we implemented map matching for remote vehicles and developed relative zone classification technology that uses it, as shown in Fig. 1.

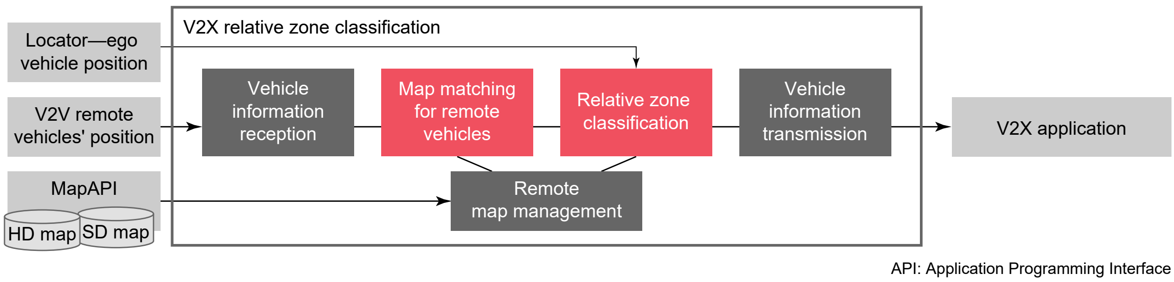


Fig. 1 System architecture of V2X relative zone classification using HDL technology

In this paper, Section 2.2 outlines improving position estimation through map matching for remote vehicles using HDL technology, and Section 2.3 outlines a method for relative zone classification between the ego vehicle and remote vehicles using HDL technology. Section 2.4 also outlines the evaluation results regarding V2X relative zone classification using HDL technology.

2.2 Map matching for remote vehicles using HDL technology

With the High Definition Locator, high-accuracy positioning is performed through GNSS positioning and Dead Reckoning (DR); furthermore, because lane level information is maintained in a high-definition map ("HD map"), it is possible to identify the driving lane on a lane level basis, and related forward and surrounding maps also become available for use. It also features a map used in conventional navigation systems (hereinafter referred to as an "SD map"), which is used during driving on urban roads. The HD map is mainly used on limited-access roads (e.g. motorway/highway) (Fig. 2).

	HD Map		SD Map	
Information granularity	Lane level		Road level	
Map accuracy	50cm or less		5 ~ 10m	
Target roads	Limited-access roads (e.g. motorway/ highway)		All roads	

Image ©2024 Airbus, Maxar Technologies, Map data ©2024 Google

Fig. 2 Data content of HD maps and SD maps

With conventional map matching using map information, the nearest neighbor point on the map to the positioning location was used as the map-matched position. However, depending on road geometry and positioning errors, the calculated position often differs from the actual driving position. Accordingly, with MELMB's HDL technology, candidate positions are set as points on roads within a prescribed range centered on the ego vehicle's positioning location that satisfy the conditions of the ego-vehicle heading. In addition, when the ego vehicle is driving and position updates occur, the travel distance is calculated from vehicle speed information, making it possible to stabilize map matching accuracy associated with ego-vehicle movement. By also applying this technology to remote vehicle information in V2X technology, it becomes possible for remote vehicles to achieve map matching accuracy equivalent to that of the ego vehicle when using HD maps and SD maps (Fig. 3).

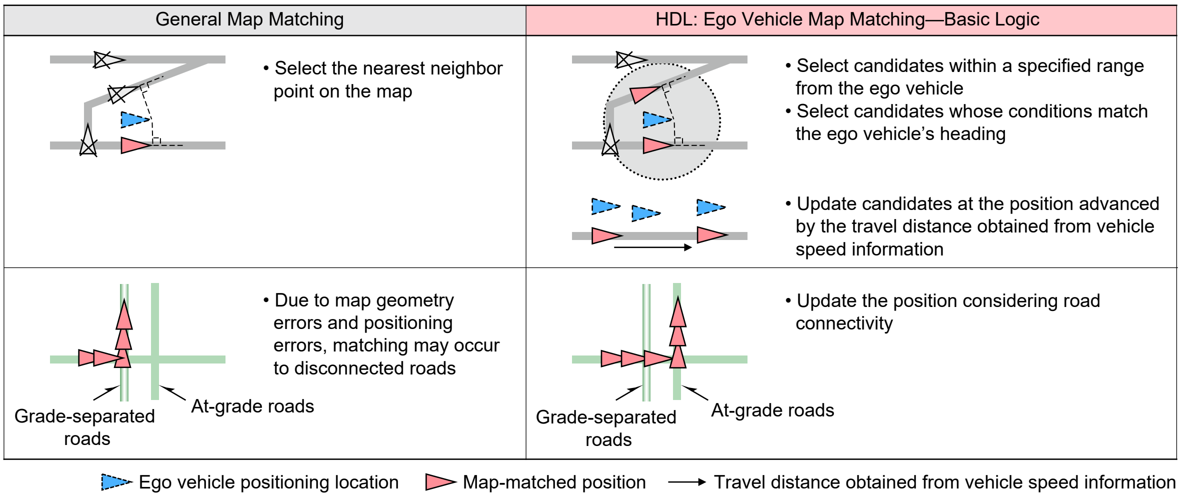


Fig. 3 Map matching methodology for HDL technology

2.3 Relative zone classification logic using HDL technology

Relative zone classification is the process of determining the relative position of remote vehicles with respect to the ego vehicle. When conventional methods do not use map information, a predicted route history is calculated based on the received position information of remote vehicles, and position estimation is performed such as whether they are located in front of or behind the ego vehicle. In this case, there are situations where relative zone estimation based on route history cannot be performed accurately amongst complex road geometries such as interchanges, merges, and splits. There are also cases where it is not possible to accurately estimate whether there is a possibility of a collision with remote vehicles approaching from the ego vehicle's oncoming direction, or whether it is simply a vehicle traveling in the opposite lane (Fig. 4).

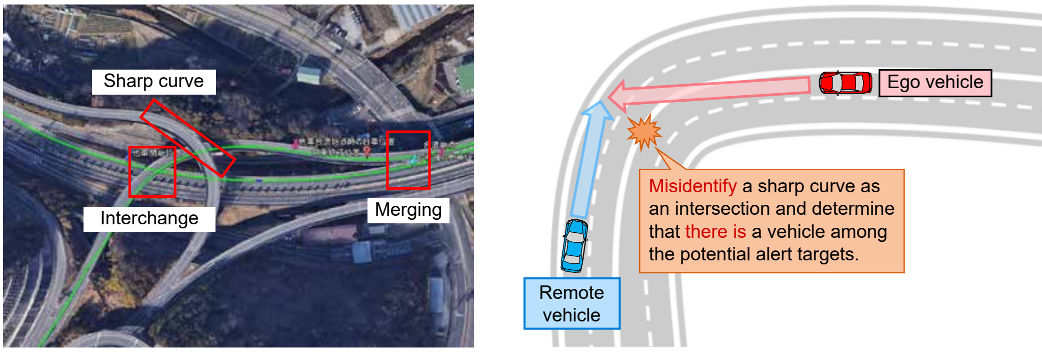


Image ©2024 Airbus, CNES/Airbus, Maxar Technologies, Map data ©2024 Google

Fig. 4 Examples of complex road geometries and challenges in relative zone classification without maps

At MELMB, V2X technology leverages highly accurate map-matching results for the ego vehicle using a High Definition Locator. HDL technology is also leveraged to improve the accuracy of relative zone classification for remote vehicles, enabling classification at the lane level for HD maps and at the road level for SD maps. With HDL technology, as shown in the path model in Fig. 5, roads ahead of or behind the ego-vehicle position and the roads connected to them are detected, and information on related roads is handled by modeling road network connectivity. With V2X technology, as shown in the recognition model, roads are modeled in the same manner as the path model, and remote vehicles are matched to that road model. This enables classification of candidate roads related to the ego vehicle, classification of whether remote vehicles are present among them, and estimation of relative zones. As a result, in cases where map information is not used, there will be many remote-vehicle candidates among potential alert targets as shown in Fig. 6; however, applying the recognition model using map information makes it possible to filter out remote-vehicle candidates that are not potential alert targets. This makes it possible to accurately determine the relative zones of remote vehicles even for various road shapes and oncoming direction, and helps reduce the computation workload associated with handling information on numerous remote vehicles.

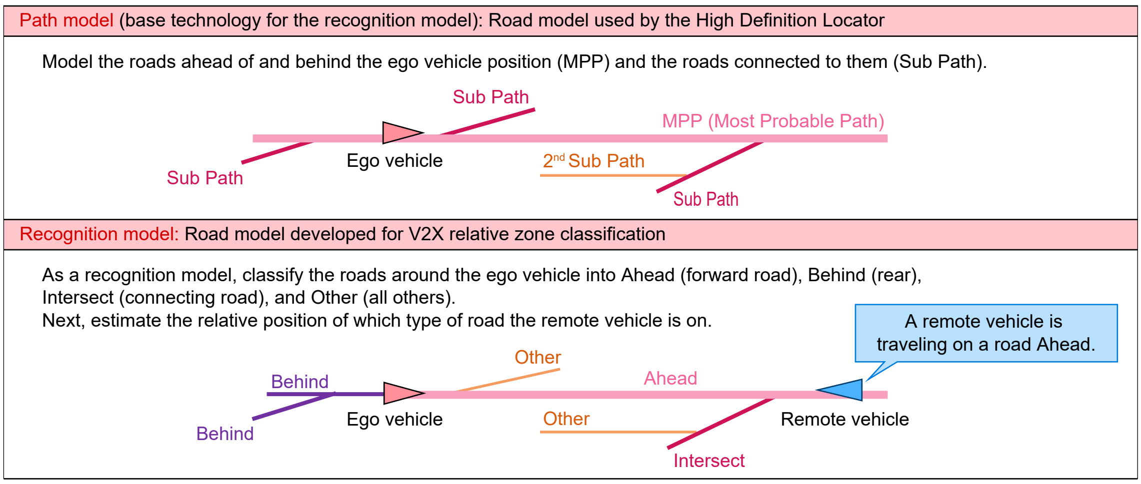


Fig. 5 Recognition model for V2X systems utilizing HDL technology

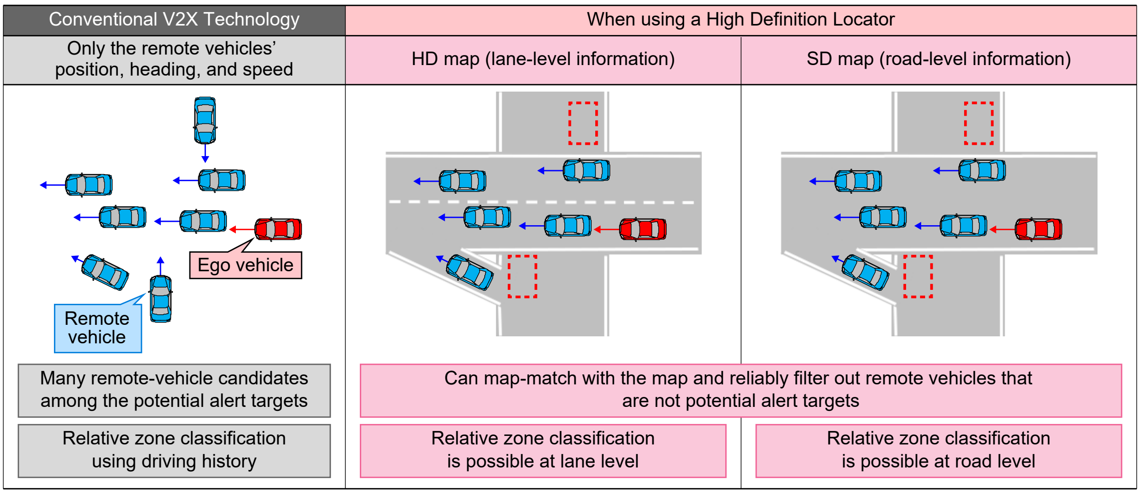


Fig. 6 Filtering effect on remote vehicles using HDL technology

2.4 Experimental evaluation

MELMB developed a simulation environment and conducted simulations based on driving scenarios combining road shapes (straight roads, sharp curves, S-shaped curves, merging/splitting, interchanges, etc.), positional relationships between the ego vehicle and remote vehicles (same direction, oncoming direction, etc.), and driving methods (following the road, turning right/left, etc.), and assessed performance to determine whether the expected classification was achieved. Figure 7 shows the comparative results of relative position classification between the case using an HD map with HDL technology and the case not using map information. By using HD maps, it was found that accurate relative zone classification is possible for patterns of each road shape and positional relationship—especially in cases of merging/splitting, interchanges, and elevated roads/side roads—and similar improvement effects were also observed for roads in the same direction and oncoming direction. Using HDL technology can be said to deliver improvements in the accuracy of relative zone classification for remote vehicles with V2X technology. When using an SD map and when not using a map, the comparative results are also shown in Fig. 8. Improvement effects were observed for sharp curves, intersections, interchanges, elevated roads/side roads, and oncoming direction, but the anticipated improvement effects were not obtained for straight roads, merging/splitting, and the same direction (adjacent lanes). This is because there are points that should be improved in the processing when using SD maps; going forward, we plan to conduct performance evaluations again under an improved environment and verify the improvement effects. The same lane and adjacent lanes for oncoming direction also contain less detailed map data compared with HD maps. As such, in order to obtain improvement effects equivalent to those of HD maps, we will further study SD-map-specific techniques in the future, such as determining road shapes and connectivity relationships.

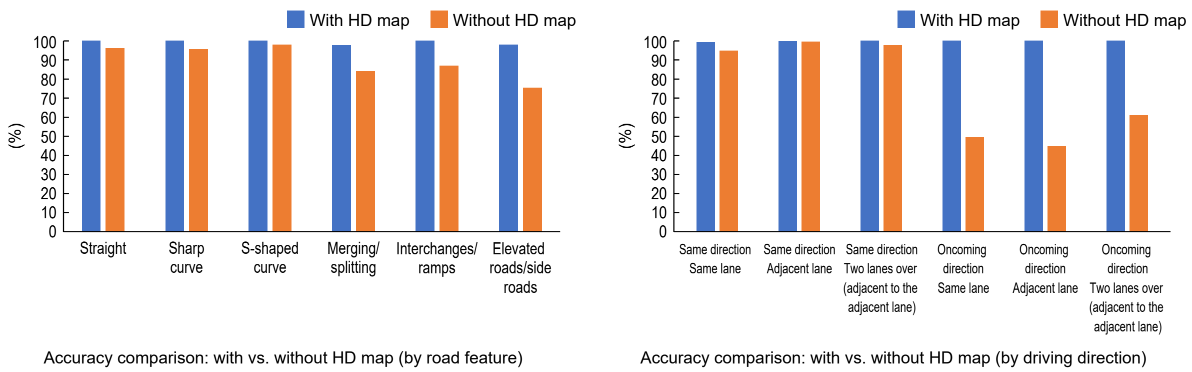
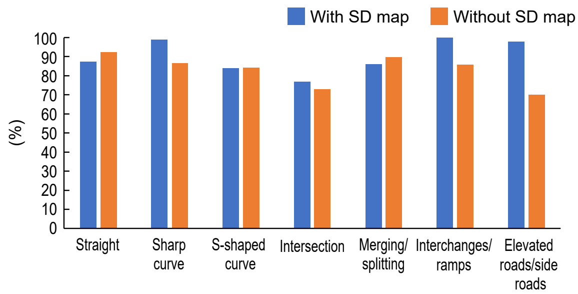
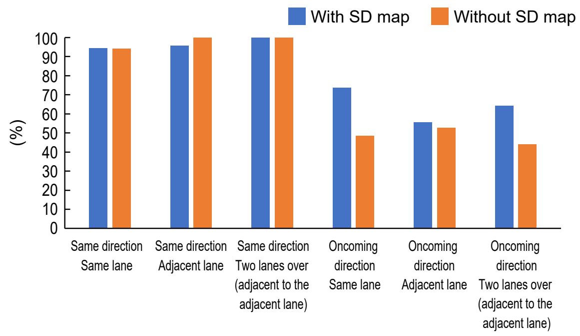


Fig. 7 Results of relative zone classification with HD maps



Accuracy comparison: with vs. without SD map (by road feature)



Accuracy comparison: with vs. without SD map (by driving direction)

Fig. 8 Results of relative zone classification with SD maps

3. Conclusion

We outlined MELMB's initiatives regarding the application of HDL technology to V2X technology. We verified that by performing map matching for remote vehicles and relative zone classification using this technology, it is possible—compared with traditional cases where map information is not used—to achieve effective improvement in classification accuracy for road shapes and driving patterns for relative zone classification, which is a challenge with V2X technology. HD maps also mainly target limited-access roads (e.g. motorway/highway), and SD maps are used for urban roads; however, improvements are being made in relative zone classification for each road shape, connectivity relationships, and driving patterns in order to obtain effects equivalent to those of HD maps. Going forward, we will contribute to achieving a safe and secure transportation society by addressing further performance improvements with SD maps(*) and advancing support for PTW and pedestrians.

* In partnership with map suppliers (e.g. HERE Technologies, etc.)

References

(1) Irie, T., et al.: High Precision Locator, Mitsubishi Denki Giho, 90, No. 3, 187–190 (2016)
(2) Ishigami, T., et al.: High Accuracy Vehicle Locator Using Centimeter Level Augmentation Service, Mitsubishi Denki Giho, 95, No. 7, 425–428 (2021)

Radio Wave Propagation Analysis for In-Cabin Radar

Authors: *Yuichi Goda*, Yasunori Hoshihara*, Takuro Mamiya**, Yuichiro Horiguchi***, Koichi Kai****

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Abstract

Efforts are underway to reduce the risk of accidents such as heatstroke for infants left behind in vehicles, including the addition of child presence detection (CPD) to the European New Car Assessment Programme (NCAP) assessment criteria[*1]. A 60 GHz-band millimeter-wave radar is regarded as a promising in-cabin sensor; however, given that its detection performance is affected by transmission, reflection, and other effects caused by in-cabin structures, it is important to determine during the pre-product-development stage whether factors such as the sensor specifications, installation conditions, and in-cabin layout are appropriate. Mitsubishi Electric Corporation's "radio-wave visualization technology[*2]" was applied for this development to an in-cabin radar, and experimental verification was performed by comparing measured data of human-body scattering. A detection feasibility map for the vehicle cabin was also created to show that radio-wave propagation analysis is effective for determining radar detection performance during the pre-product-development stage.

1. Introduction

In recent years, millimeter-wave radars, which have mainly been used outdoors, have started to be used even in enclosed spaces such as indoors and vehicle cabins, and demand is increasing in particular for in-cabin monitoring in automobiles. One factor behind this is that CPD has been added to the Euro NCAP assessment criteria used to evaluate vehicle safety. As shown in Fig. 1, CPD is intended to reduce the risk of accidents such as infant heatstroke by detecting the presence of an infant left behind in a vehicle cabin and notifying the user or a third party.

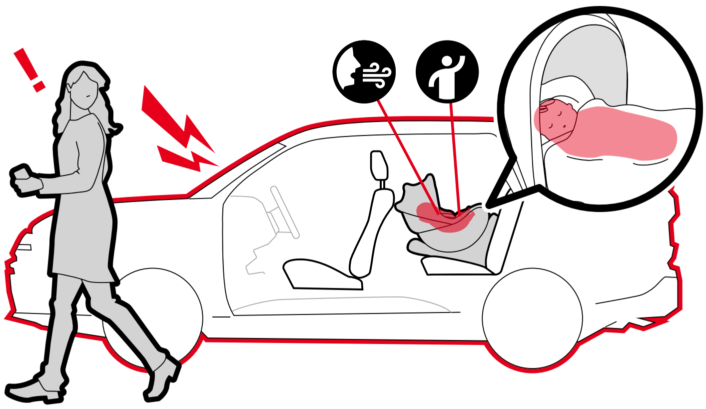


Fig. 1 Child presence detection system

Under Euro NCAP, the presence of an infant needs to detected even under conditions such as when a blanket covers a sleeping infant in a rear-facing Child Restraint System (CRS) with a sunshade, or when an infant has slipped into the footwell area of the seat. Under such conditions, it is difficult for optical sensors such as cameras to detect an infant, whereas radio-wave sensors such as radar are more suitable; accordingly, Mitsubishi Electric Corporation is advancing the development of a CPD system that uses a 60 GHz-band millimeter-wave radar[*3]. Given that radio-wave sensors are able to penetrate objects to some extent as long as they are not metal, they can detect the presence of an infant even in the scenarios described above.

The detection performance of an in-cabin radar varies not only with the specifications of the radar unit itself, but also with changes in the radio-wave propagation conditions resulting from installation conditions such as position and angle, and from factors such as the in-cabin layout. Therefore, optimizing the installation conditions for each vehicle model is essential. One way to achieve such optimization is to acquire data under various radar installation conditions for all vehicle models and optimize those installation conditions and various parameters; yet when factoring in the time and cost required for development, this is not a realistic approach.

To address these issues, Mitsubishi Electric Corporation's radio-wave visualization technology is applied to an in-cabin radar with this development to improve development efficiency. After outlining the radio-wave propagation environment of in-cabin radar and methods of modeling it, this paper presents experimental verification using measured data of human-body scattering taken in an electromagnetic anechoic chamber, as evaluation results of the developed radio-wave propagation analysis for in-cabin radar. Examples of examining installation conditions by creating an in-cabin detection feasibility map are also provided, thereby showing that radio-wave propagation analysis is effective for determining radar detection performance in the pre-product-development stage.

2. Applying Radio-wave Visualization Technology to In-cabin Radar

This chapter outlines the concept for applying Mitsubishi Electric Corporation's radio-wave visualization technology to in-cabin radar.

2.1 Radio-wave propagation environment of in-cabin radar

In open space, the received power P_r of a reflected wave from an object located at a distance R from the transmit/receive antennas of a millimeter-wave radar is generally expressed by the radar equation as follows, where the transmit power is P_t, the transmit antenna gain is G_t, the receive antenna gain is G_r, the wavelength is λ, and the radar cross section (RCS) is σ.

$$P_r = \frac{G_t G_r \lambda^2 \sigma}{(4\pi)^3 R^4} P_t \quad \text{.......... (1)}$$

However, the actual radio-wave propagation environment inside a vehicle is not open space and is extremely complex. For example, radar has directionality, and radio waves are radiated with different strengths depending on direction. That is, the transmit antenna gain and receive antenna gain in Equation (1) vary by direction. In addition, in a vehicle cabin, radio waves may not only reach an infant directly, but may also reach the infant via multipath directions, after passing through seats or other objects, or after being reflected by in-cabin structures. Therefore, designing an in-cabin radar requires not a simple radar equation, but a method to comprehensively evaluate and visualize whether radio waves reach throughout the vehicle cabin for each vehicle model and installation condition. That method is radio-wave propagation analysis technology, i.e., radio-wave visualization technology.

Mitsubishi Electric Corporation's radio-wave visualization technology uses the ray tracing method, and this method is also used for analyzing radio-wave propagation for in-cabin radar. With the ray tracing method, radio waves are represented as rays as shown in Fig. 2; rays are emitted from the transmit antenna, and their trajectories are tracked. In addition, the physical phenomena of radio waves being reflected and diffracted by in-cabin structures is calculated by approximating them as reflection and diffraction of rays. Furthermore, changes in the electromagnetic field are calculated while taking into account the electrical characteristics and shapes of in-cabin structures, enabling calculations that reflect a wide variety of real environments.

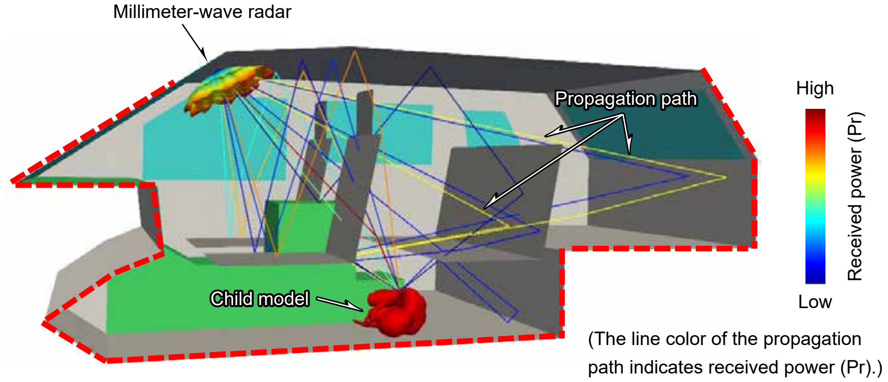


Fig. 2 Conceptual illustration of the ray-tracing method

A feature of the ray tracing method is that it is able to calculate electric field strength with a high level of accuracy based on a geometrical optics approximation for objects and spaces that are sufficiently large compared with the wavelength of the radio wave. In the case of a 60GHz-band millimeter-wave radar, the wavelength (λ) is approximately 5mm, so it can be said that the wavelength is sufficiently short relative to in-cabin structures. In addition, the ray tracing method has the feature of being able to perform calculations faster than complex electromagnetic field analyses such as the Finite-Difference Time-Domain (FDTD) method.

2.2 Modeling for radio-wave propagation analysis for in-cabin radar

As shown in Fig. 3, radio-wave propagation analysis for in-cabin radar requires modeling of the antenna radiation pattern, in-cabin structure, and the reflection strength of the human body. The following outlines the modeling methods for each.

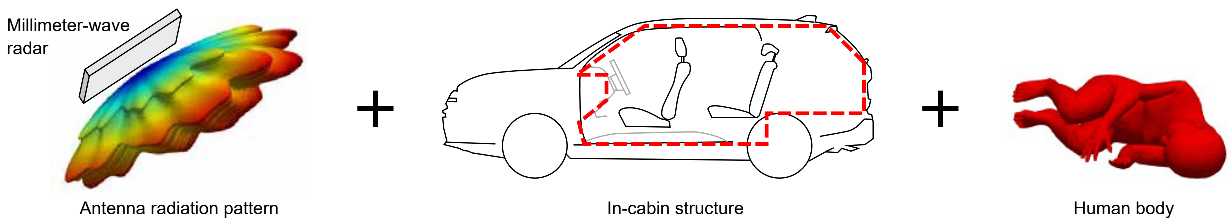


Fig. 3 Modeling elements for radio wave propagation analysis for in-cabin radar

(1) Modeling of antenna radiation pattern

The antenna radiation pattern is one of Mitsubishi Electric Corporation's radar design elements, and it can be quantified using measured data and electromagnetic field analysis results. In addition, if a structure exists near the position where the radar is installed, an antenna radiation pattern that includes the radar and the surrounding structures is derived as needed.

(2) Modeling of the in-cabin structure

One approach to modeling the in-cabin structure is to measure the positional relationships of each part and build a model based on the measurements. In recent years, it has also become possible to reflect detailed shapes using a 3D scanner. In addition to measurements, it is also possible to base the model on an in-cabin 3D model (a surface model is acceptable), and it can be applied even to vehicles in the pre-prototype stage. Note that fine parts may only increase analysis time while having little impact on the analysis results; therefore, the 3D model shape is modified while factoring in analysis time and analysis accuracy. The electrical characteristics of structures such as vehicle seats are tuned based on measured data and other factors.

(3) Modeling of the human body

The human body has features that are small relative to the wavelength (λ), and received power (P_r) cannot be calculated correctly using a simple ray tracing method. Therefore, we used two methods: (1) Calculate received power (P_r) as the composite wave of reflections from the entire human model, and (2) Assign a representative RCS of the human body as a point target.

Method (1) makes it possible to calculate the radar's received power (P_r) according to the posture and size of the human model, but it increases the computational load accordingly. As a method for calculating received power (P_r) obtained from the human body, there is also a method that combines ray tracing and physical optics approximation; however, as a simpler calculation method used for this development, we adopted a method where virtual scattering point(s) are placed on the human body surface, the received power (P_r) at the radar is obtained according to the radar equation from the path loss to those points and their scattering characteristics, and then those contributions are combined.

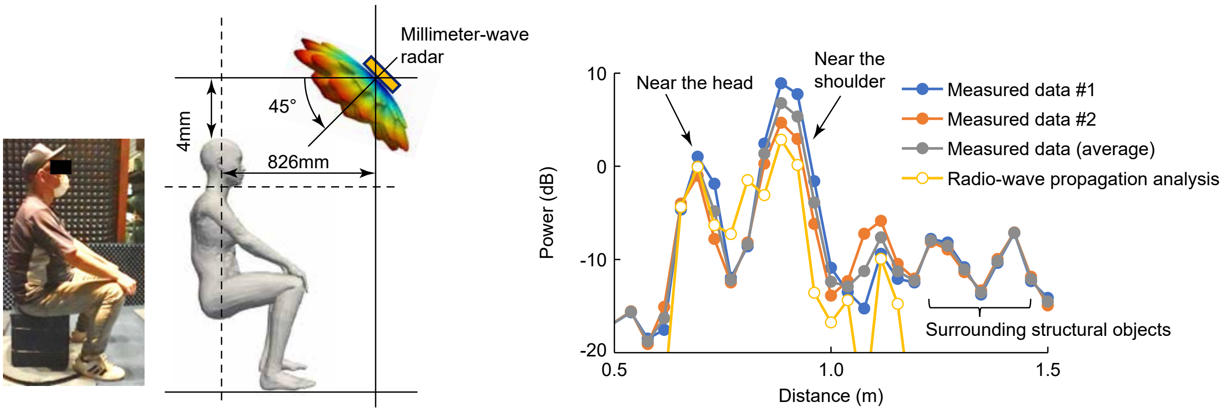
Method (2) fixes the human body's RCS to the set RCS; however, because it becomes a point target, it can be calculated with a simple ray tracing method, and it is suitable for comprehensively evaluating whether sufficient power reaches each area inside the cabin.

3. Evaluation Using Radio-wave Propagation Analysis for the In-cabin Radar

This chapter outlines the evaluation results obtained by applying Mitsubishi Electric Corporation's radio-wave visualization technology to an in-cabin radar and verifies its effectiveness.

3.1 Experimental verification using human-body scattering data

We verify the validity of the developed radio-wave propagation analysis for in-cabin radar using comparison with human-body scattering data measured in an electromagnetic anechoic chamber. Figure 4 shows an example comparison between the radio-wave propagation analysis results and the measured results for the relationship between received power (P_r) and distance when applying the human modeling method (1) outlined in Section 2.2 (method that calculates received power (P_r) as the composite wave of reflections from the entire human model). The human model was generated by capturing an actual human body with a 3D scanner so that the posture and shape would be equivalent. In the simulation, 28,796 virtual scattering points were placed on the human body surface, and the received power (P_r) at the radar was calculated according to the radar equation from the path loss to those points and their scattering characteristics. Note that the power on the vertical axis is normalized with the received power (P_r) near the head set to 0dB, and the measured data uses the average of two measurements set to 0dB. From Fig. 4, while the measured and analyzed results do not match completely, both show a tendency for higher power near the head and shoulders; thus, we confirmed that radio-wave propagation analysis can yield received power (P_r) trends similar to those of the measured results. Possible causes of the error include that the human model and the measurements do not match completely, and that the human body during measurement has some degree of sway even while the data is being acquired. Going forward, we will conduct verification with various postures and verification with occupants in the cabin, and confirm effectiveness in an environment closer to real-world conditions.



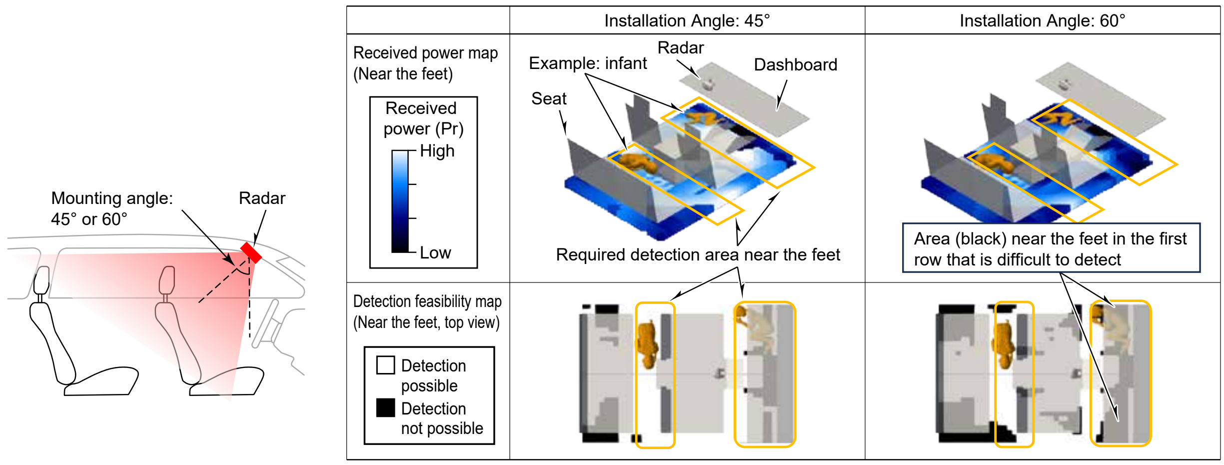
(a) Condition (b) Results

Fig. 4 Comparison between radio-wave propagation analysis and measured results for received power observed from the human body

3.2 Study of mounting conditions by creating a detection feasibility map

The following is an example where radio-wave propagation analysis is performed while changing the mounting angle to assess whether an in-cabin child can be detected. The radar is mounted near the overhead console above the rearview mirror, and the mounting position corresponds to Fig. 2 outlined in Section 2.1. In this simulation, we used human-body modeling method (2) (method that assigns a representative RCS of the human body as a point target).

Figure 5(a) shows the mounting position and angle conditions, and Fig. 5(b) shows the received power map and the radar detection feasibility map in the vicinity of the feet for mounting angles of 45° and 60°. The received power map represents with color shading the strength of received power (P_r) when a child-representative reflector is present at each point in the cabin, and is used to identify how many radio waves reach each region in the cabin. The radar detection feasibility map, which takes into account the radar hardware and signal processing performance, visualizes in white the range where the received power (Pr) is at or above the signal-to-noise ratio (SNR) required to detect a child, and in black otherwise—this is used to intuitively identify whether the desired detection range is covered. For reference, the figure also overlays child-representative objects at the feet of the first- and second-row seats; moreover, to make the cabin easier to see, the vehicle body is not drawn in the figure.



(a) Mounting position and angle (b) Radio-wave propagation analysis results (received power map / detection feasibility map)

Fig. 5 Example of mounting (installation) conditions and radio-wave propagation analysis results

From Fig.5(a), it can be seen that received power (P_r) decreases due to the effects of shielding objects such as seats and attenuation with distance. From Fig. 5(b), it can also be seen that for both mounting angles of 45° and 60°, even in the radio attenuation region in Fig. 5(a), it is generally possible to detect a child. However, for a mounting angle of 60°, we also confirmed that there are areas where it is difficult to detect some children in the first-row footwell; under these conditions, it can be said that a mounting angle of 45° is more appropriate. As outlined above, by leveraging radio-wave propagation analysis, it is possible to confirm the appropriateness of design parameters such as “radar unit specifications” and “radar mounting position and angle” at the pre-prototype stage. This makes it possible to optimize the design at an early stage, and is expected to improve development efficiency.

4. Conclusion

Mitsubishi Electric Corporation’s radio-wave visualization technology was applied to in-cabin radar, and its effectiveness was demonstrated.

Going forward, we will evaluate the validity of analysis results in an actual vehicle and establish radio-wave propagation analysis technology for in-cabin radar; moreover, by leveraging not only radio-wave propagation analysis technology but also a variety of Mitsubishi Electric’s radar technologies, we will contribute to developing a CPD system capable of more reliably detecting infants left behind in the cabin.

References

(1) Euro NCAP: Child Presence Detection Test and Assessment Protocol Ver.1.3(2024)
https://www.euroncap.com/media/83740/euro-ncap-cpd-test-and-assessment-protocol-v13.pdf
(2) Mitsubishi Electric Corporation: Development of “Radio-wave Visualization Technology” that Supports IoT by Assisting Optimal Placement of Wireless Equipment (2017)
http://www.mitsubishielectric.co.jp/news/2017/pdf/0524-c.pdf
(3) In-cabin Occupant Detection Technology Using Camera and Millimeter Wave Radar, Mitsubishi Denki Giho, 97, No. 1, 71 (2023)

SoC Control Technology to Reduce Separate Microcontrollers for DMS/HDL

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Abstract

Mitsubishi Electric Mobility Corporation contributes to creating a safe and secure mobility society by providing ADAS (Advanced Driver-Assistance Systems) products such as ADAS Electronic Control Units (ADAS-ECUs), Driver Monitoring Systems (DMS), and High-Definition Locators (HDL). DMS and HDL in particular require both computationally intensive tasks and real-time tasks, and in conventional Mitsubishi Electric Mobility Corporation systems, functions were divided between a system on chip (SoC) and a microcontroller to meet system requirements. However, recent advances in SoC capabilities have enabled a single SoC to execute both real-time and non-real-time tasks by selectively utilizing multiple cores. Accordingly, we integrated the microcontroller functions of the conventional system into the SoC and evaluated functionality, performance and cost.

1. Introduction

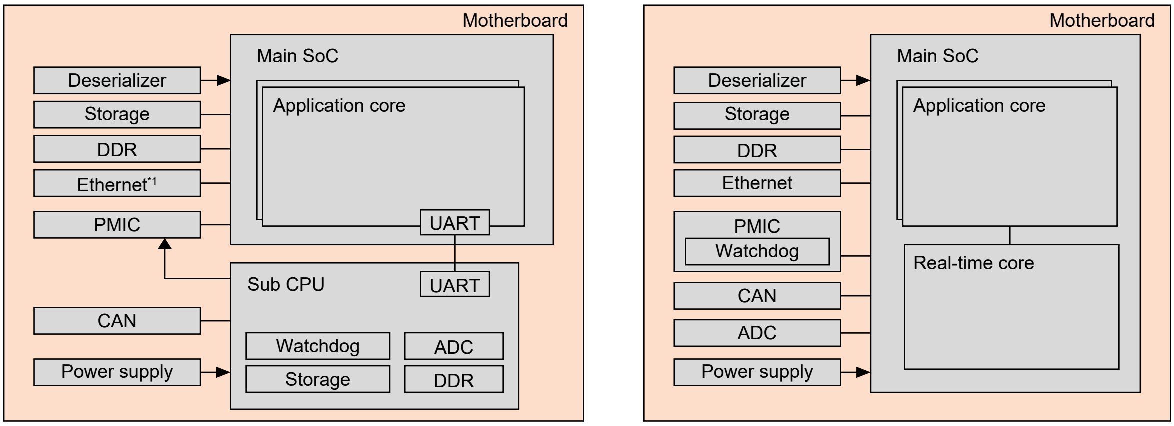
Mitsubishi Electric Mobility Corporation is working toward achieving an accident-free society in which people can move with peace of mind and safety, and is developing ADAS to support safe driving for drivers, such as ADAS-ECUs that apply information processing technologies for inside and outside the vehicle, DMS that applies image recognition technologies, HDL that applies high-precision positioning technologies, and Vehicle-to-Everything (V2X) based on external communication technologies.

While strict real-time performance is required for control-related ECUs such as electric power steering, ADAS-related ECUs such as DMS and HDL require both computationally intensive tasks such as image processing and real-time tasks.

In Mitsubishi Electric Mobility Corporation's conventional ADAS-related ECUs, a dual-processor architecture consisting of an SoC and a separate microcontroller was used to satisfy various performance requirements of in-vehicle devices. The SoC handled applications that define the system, such as image recognition and high-precision positioning, while the microcontroller handled functions that require real-time performance, such as in-vehicle network communication control. However, this dual-processor architecture increased the number of on-board components and board area, making cost reduction challenging and also complicating hardware design.

To address these issues, we developed a system (hereinafter referred to as the "developed system") using a heterogeneous-core SoC with a real-time core, thereby enabling both real-time and computationally intensive processing on a single SoC. As shown in Fig. 1, we integrated the microcontroller functions of the conventional system into the SoC to evaluate functionality, performance, and cost. This enabled unified storage, resource sharing, inter-core communication, and simplified system control, achieving a 30% reduction in component cost while maintaining the existing functionality and improving performance.

In this paper, we outline the features of the developed system in Chapter 2, present the evaluation results in Chapter 3, and conclude with Chapter 4.



(a) Conventional system (b) Developed system

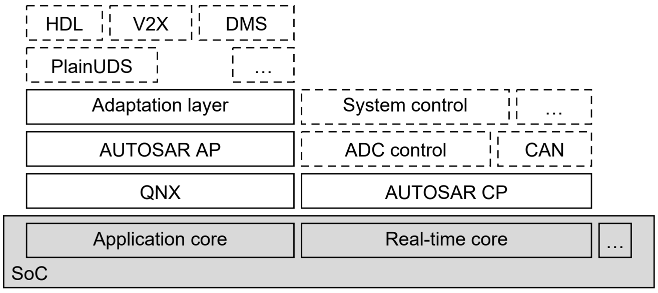
DDR: Double Data Rate, PMIC: Power Management IC, CAN: Controller Area Network, ADC: Analog-to-Digital Converter, UART: Universal Asynchronous Receiver Transmitter

*1 Ethernet is a registered trademark of FUJIFILM Business Innovation Corp.

Fig. 1 System block diagrams: conventional vs. developed

2. Features of the Developed System

As shown in Fig. 2, the developed system runs a real-time OS (QNX*2) and AUTOSAR*3 Adaptive Platform (AP) for computationally intensive tasks on the SoC application cores, while AUTOSAR Classic Platform (CP) for power control and in-vehicle communication runs on the real-time core, thereby achieving microcontroller integration.



UDS: Unified Diagnostic Services

Fig. 2 Software block diagram of the developed system

2.1 Configuration of the developed system

Details of the developed system configuration described above are provided below.

2.1.1 AUTOSAR CP

AUTOSAR CP is a platform for embedded systems defined by AUTOSAR, the automotive standardization organization, and it emphasizes real-time performance and stability. When deployed on the SoC's real-time core, it abstracts hardware details and improves software reusability and interchangeability.

2.1.2 AUTOSAR AP

AUTOSAR AP is a platform defined by AUTOSAR for advanced and computationally intensive applications. AUTOSAR AP is deployed on the SoC's application cores to enhance software reusability and interchangeability, as well as development efficiency and quality. As a defining feature of AUTOSAR AP, service-oriented communication between Adaptive Applications enables applications to be developed independently of specific communication counterparts, while facilitating switching between configurations with and without AUTOSAR AP.

*2 QNX is a registered trademark of BlackBerry Limited.
*3 AUTOSAR is a registered trademark of AUTOSAR GbR.

2.1.3 QNX

QNX is a real-time operating system (RTOS) developed by QNX Software Systems, a Canadian company. It employs a microkernel architecture and thus achieves high stability and real-time performance. QNX, which ensures high reliability and responsiveness while readily incorporating new technologies, is deployed on the application core. Because QNX can be deployed across various SoCs and hardware platforms without being tied to specific hardware, it is also well-suited for the development of various types of ECUs.

2.2 Single storage system

Automotive ECUs are equipped with storage, either within or outside the microcontroller, for storing and updating data such as control programs, configuration information, and logs. In the conventional system, dedicated storage was provided to ensure that both the SoC and the microcontroller could independently access their respective storage. The system was first booted from the bootloader stored in the microcontroller, and then the bootloader stored in the SoC was executed to complete the boot process.

In the developed system, all data, including the bootloader, is stored in a single storage device, enabling the system to boot from a single bootloader. This reduced the number of components and the board area required for the microcontroller and its peripheral circuits compared to the conventional system (Table 1). However, to implement the power-supply voltage and temperature monitoring functions previously performed by the microcontroller in the conventional system, an external ADC IC and a thermistor were added.

Table 1 Component configurations: conventional vs. developed

	Conventional System	Developed System
Storage	Two components	One component
Memory	Two components	One component
Separate microcontroller	✓	
X’tal, LDO, peripheral components	✓	
ADC IC		✓
Thermistor		✓

X’tal: Crystal Oscillator; LDO: Low Drop Out

2.3 Inter-function resource sharing (or single-memory system)

In the developed system, in addition to the storage described in Section 3.1, memory, timers, and sensors were implemented with higher performance by sharing the SoC’s high-performance hardware resources among the cores, while maintaining the same functionality as the conventional system.

As shown in Table 1, in the conventional system, each microcontroller had dedicated memory, enabling its respective functions to be achieved without interference from other microcontrollers. However, when multiple cores access the same memory, as in the developed system, memory access violations can become a critical issue. Therefore, memory isolation is achieved for the shared memory by utilizing both the SoC’s and the OS’s memory access protection capabilities. This enables a reduction in the number of components while ensuring safe resource sharing.

2.4 Inter-core communication function

In the conventional system, the SoC and the microcontroller were connected via physical lines such as UART for control, whereas in the developed system, inter-core communication using shared memory and an interrupt register was implemented. In addition, UART communication in the conventional system used a half-duplex protocol, which limited communication efficiency; in the developed system, this protocol was changed to a full-duplex protocol, thereby enabling high-speed communication. Furthermore, in the conventional system, strict synchronization of operating times was difficult, and in the event of a failure, analysis required cross-referencing the operation logs of each microcontroller. In the developed system, time synchronization is facilitated by having each core refer to the same clock. Furthermore, since information on the real-time core can be obtained from the application core via shared memory, it is also straightforward to consolidate the log output mechanism on the application core.

2.5 System control function

In the conventional system, the microcontroller that first received vehicle information via communications such as CAN was responsible for startup and shutdown control and power management. For system control, multiple GPIOs (General Purpose Input/Output) were used to control the microcontrollers and the multi-function power-supply ICs before the inter-microcontroller communication described in Section 2.4 was established and after it had ended.

In the developed system, the real-time core performs system control. The number of GPIOs managed is reduced, and the startup/shutdown sequence is simplified by following the SoC boot sequence. In addition, reducing error sources and system state transitions is expected to improve system reliability and reduce development and verification costs.

Regarding software updates, complex state management and longer update times were also issues in the conventional system because software on multiple CPUs was updated sequentially. Furthermore, because the microcontroller had limited storage capacity, it was often difficult to support dual-bank redundancy. In the developed system, software updates can be simplified through a dual-bank configuration.

In the conventional system, system startup/shutdown and control such as system health monitoring were achieved not only via inter-microcontroller communication over UART but also with ON/OFF control (GPIO control) using hard wiring. In the developed system, these processes were replaced with shared memory and CPU register access, thereby reducing GPIO-based control and simplifying system control. This helps prevent increased system complexity caused by a shortage of GPIO pins, which was a critical issue in the conventional system.

The developed system also simplifies the software update function. In the conventional system, the following issues existed:

(1) Sequential processing was required: data in the SoC's storage must be updated first, followed by data in the microcontroller's storage.
(2) If an update failed on either the SoC or the microcontroller, the other node had to be rolled back to maintain system-wide consistency.
(3) Because the microcontroller had limited storage capacity, dual-image redundancy was not feasible, which necessitates complex update control.

In the developed system, consolidating storage into a single large-capacity SoC storage device addressed the issues of the conventional system, thereby simplifying the software update function and reducing the update time by 45% (equivalent to a 180% increase in update throughput).

3. Evaluation

This section evaluates the changes in the system resulting from the removal of the microcontroller described in Chapter 2.

3.1 Startup performance

With the removal of the microcontroller, boot time becomes a key challenge in realizing a large-scale system that supports multiple operating systems across multiple cores within a single SoC. As the system scale increases, the software image size also increases, lengthening the time required to load the image from non-volatile memory and start execution. Fast booting is essential for automotive ECUs; for instance, ADAS-related ECUs are required to respond on the CAN bus within approximately 200 ms after power-on.

In the conventional system, the microcontroller loaded only the minimum necessary data from internal flash memory in order to achieve rapid startup response. In the developed system, programs for the real-time core and the application core are managed separately, and rapid startup response is achieved by first loading only the programs that require fast response at startup. As shown in Fig. 3, we achieved startup response performance equivalent to that of the conventional system by first starting the minimum required programs for communication response and then starting the remaining programs in parallel. Furthermore, by separating the timing and regions of storage access, it became possible to save error logs through single-core processing when a system abnormality occurs, as in the conventional system.

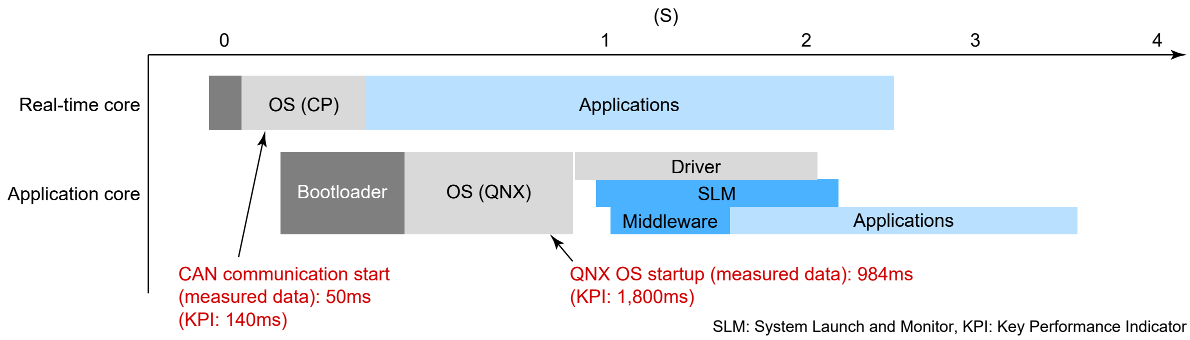


Fig. 3 Startup timing chart of the developed system

3.2 Inter-core communication performance

In the conventional system, because communication was performed over physical lines, it was relatively susceptible to noise and interference, and it was difficult to increase the amount of data transferred per communication. In contrast, in the developed system, inter-core communication using shared memory instead of physical lines became possible, and communication speeds several tens of times higher were achieved as the transfer size increased, as shown in Fig. 4.

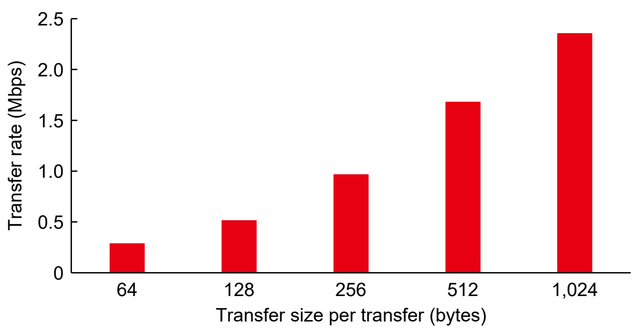


Fig. 4 Inter-core communication throughput of the developed system

4. Conclusion

Conventional systems with a dual-processor architecture faced challenges in reducing costs due to increases in both the number of on-board components and board area, which also complicated hardware design.

Therefore, we developed a single-SoC system using an SoC with a heterogeneous-core architecture that includes a real-time core capable of real-time processing. In this system, a real-time OS (QNX) and AUTOSAR AP for computationally intensive tasks run on the SoC application cores, while AUTOSAR CP for power control and in-vehicle communication runs on the real-time core, thereby integrating the microcontroller functions of the conventional system. We then evaluated its functionality, performance, and cost. The developed system enabled unified storage, resource sharing, inter-core communication and simplified system control, achieving a 30% reduction in component cost while maintaining the existing functionality and improving performance.

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