

Development of General Purpose Drive Module and Drive Platform

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ABSTRACT

A general purpose drive module that consolidates the functions needed for driving, such as drive, steering, and impact absorption, and a drive platform equipped with a cooperative control function that governs the driving functions and is easily connectable to an autonomous drive function were developed. This paper describes the configuration of the drive module, the system configuration of a drive platform consisting of four drive modules, and the steerability achieved by cooperative control. An autonomous delivery robot based on this drive platform was developed with Rakuten Group, Inc. and the effectiveness of the drive platform was confirmed in driving demonstration tests conducted on the University of Tsukuba campus with the support of the New Energy and Industrial Technology Development Organization. Use of this general purpose drive module and cooperative control technology enables the efficient creation of various forms of electric mobility.

1. Introduction

Labor shortages due to a declining birthrate and aging population and response to the COVID-19 pandemic are increasingly becoming social issues. As a result and against the backdrop of technological progress, society is starting to see the implementation of autonomous electric mobility that provides services and performs work in place of people, such as delivery, guidance, cleaning, and security, and the field of electric mobility is experiencing remarkable changes.

Honda has developed various electric mobility products that are useful in daily life, such as the four wheel scooter Monpal⁽¹⁾ and the robotic lawnmower Miimo⁽²⁾. Various initiatives have also been pursued with the aim of further enhancing customer lifestyles, such as development of the new four wheel scooter WANDER WALKER CONCEPT⁽³⁾ and an airport guide robot that drives autonomously⁽⁴⁾. However, the timely development of diverse electric mobility is considered necessary in order to support these remarkable changes.

Therefore, this paper introduces a general purpose drive module that consolidates the functions necessary for mobility driving into a single package (Fig. 1), control technology, and a drive platform that is extendable into diverse formats (Fig. 2).

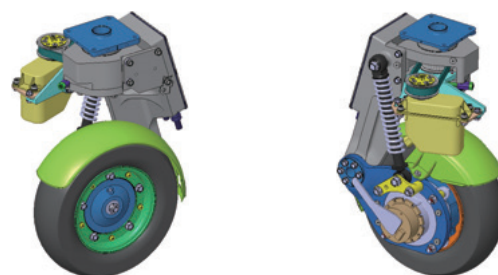


Fig. 1 General purpose drive module

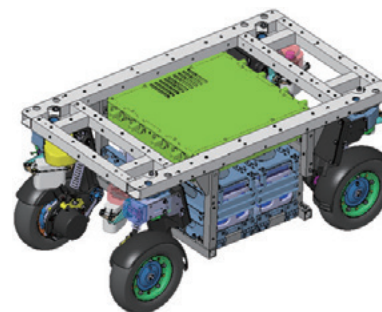


Fig. 2 Drive platform

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2. Concept and Configuration

2.1. Concept

An example of autonomous electric mobility is an autonomous delivery robot. When designing such a robot, first the requirements are defined such as the driving environment and the amount and size of the load. However, the requirements are often undetermined in the initial stage of development, and it is conceivable to go through a process of reconsidering the requirements and reviewing the basic design of the robot. For example, an increase from the initially required load capacity may result in insufficient load capacity, and a change in the robot size can be expected to result in a change in specifications such as wheelbase and tread. The driving environment requirements may also change, resulting in demands for greater driving force or small turn performance than expected, and it may be necessary to respond to new needs not anticipated in the initial stage, such as the addition of monitoring functions.

For these reasons, it is considered important that development of new types of mobility be able to respond immediately to specification changes and extension of functions. In particular, specification changes have a large impact on the drive and steering parts, and it is anticipated that separate design for each application would call for many development resources.

These circumstances led to the concept of a general purpose drive module that consolidates the driving functions such as drive and steering into a single package and a drive platform that performs integrated control of the drive modules. Modularization of the driving functions increases the wheelbase and tread setting flexibility, and different numbers of modules can be used to vary the driving performance. In addition, the drive platform has extendability, which enables the addition of various work and autonomous drive functions. This drive module and drive platform will form a base for various forms of autonomous electric mobility.

2.2. Configuration of General Purpose Drive Module

The general purpose drive module consolidates the functional parts (tires, drive motor, steering motor, etc.) needed for driving, and is operated by providing a power source and input signals. The operating angle of the steering motor is set to $\pm 180^\circ$ in order to obtain any steering angle. The combination of at least a single drive module with driven wheels enables the creation of mobility that can move in any direction, and functionality can be enhanced by increasing the number of drive modules.

For example, mobility that can move freely including turn on a spot and horizontal move is achieved by placing two drive modules between four free driven wheels such as swivel casters or omni wheels [Fig. 3(a)]. In addition, use of four drive modules achieves mobility with both rough

road driving performance and maneuverability [Fig. 3(b)].

2.3. Drive Platform Configuration

The drive platform configuration is explained here using the example of the contents investigated for the autonomous delivery robot described hereinafter. In order to complete the work tasks, autonomous mobility should have a wide drivable range and should be able to climb over steps and drive even on narrow and rough roads, etc. Therefore, the configuration has four drive modules located on the vehicle body, and uses four wheel independent drive and four wheel independent steering.

Four wheel independent drive is effective for driving on slopes and uneven ground and for climbing up steps, and four wheel independent steering enables turning on a spot and horizontal movement, and provides the ability to pass through narrow roads, avoid obstacles, and store the vehicle in the manner of parallel parking.

In this research, the size was set to a width of 700 mm, length of 1200 mm or less, and weight of 200 kg or less, which is equivalent to a four wheel scooter such as Monpal. It is thought that an autonomous delivery robot with these dimensions will be able to drive without greatly obstructing the passage of people even in walking spaces, and move indoors, including elevators.

The drive modules are placed in the four corners of the main frame to take advantage of packaging merits. The power source system and electrical components are consolidated between the drive modules, and all functional parts needed for driving are housed below the main frame. The sensors for autonomous drive and a delivery box are mounted above the main frame.

The main frame has a structure that enables easy replacement according to the application, so changes in the mobility size and format can be supported. For example, extension to security robots with monitor functions equipped on top of the main frame and autonomous work robots with working parts such as cleaning brushes or lawnmower cutter decks installed on the front or rear of the vehicle body can be expected (Fig. 4).

The drive platform system consists of a drive function and a cooperative control function and safety function that govern the drive function. Commands are given to the drive platform system from a separately configured autonomous drive system (Fig. 5).

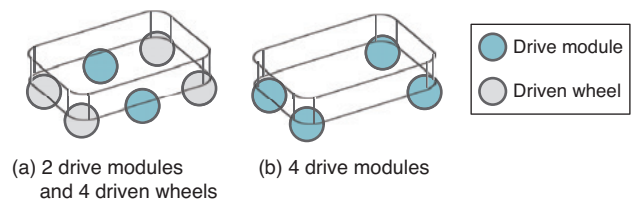


Fig. 3 Example of module layout variations

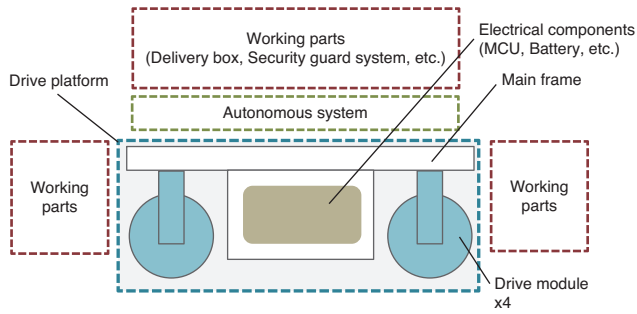


Fig. 4 Layout concept of drive platform

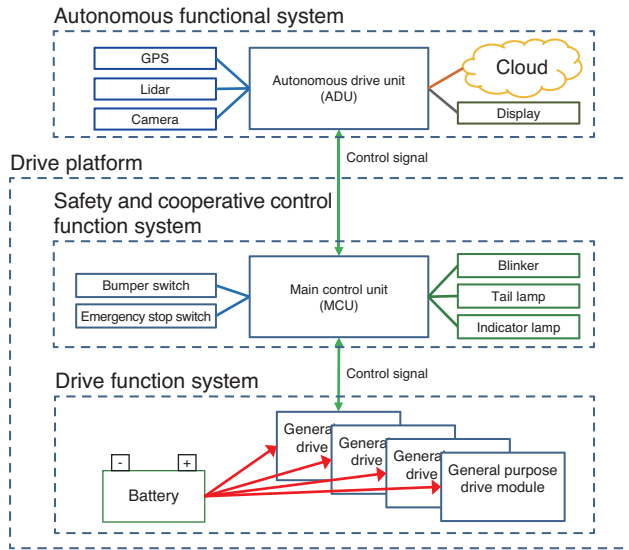


Fig. 5 Control outline diagram

3. Design and Features

3.1. General Purpose Drive Module

Table 1 shows the specifications and Fig. 6 shows the parts layout of the general purpose drive module used to realize the above-mentioned concept.

The general purpose drive module consists of a (e) tire,

Table 1 Specifications of drive module

Drive motor rated output	150 W
Steering motor maximum torque	38 N·m
Tire (Diameter x Width)	280 x 80 mm
Suspension	Bottom link
Wheel stroke	50 mm
Parking brake	Power off brake

a (f) drive motor, a (m) power off brake for stop holding, a (l) swing arm that fixes those parts, a (k) shock absorber for impact absorption and enhancement of tire contact patch characteristics, a (j) steering motor, a (h) belt and (i) pulley for power transmission, a (b) spindle with fixing flange for fixing the module to the vehicle body, and a (c) frame that supports all of the aforementioned parts.

The (e) tire is a urethane-filled airless tire with an outer diameter of 280 mm and a width of 80 mm in consideration of rough road driving performance and maintainability. The (f) drive motor is an in-wheel type three-phase brushless motor with a built-in reduction gear and rated output of 150 W. A (m) power off brake with a release lever is installed to the motor axis as a parking brake.

The (e) tire, (f) drive motor, and (m) power off brake are fixed to the (l) swing arm and installed together with the (k) shock absorber to the (c) frame. The wheel stroke is set to 50 mm. The suspension format is a bottom link type suspension, and the (k) shock absorber expands and contracts according to the drive and braking reaction force. The objective as described hereinafter was to use this mechanism to suppress changes in vehicle body attitude when accelerating and decelerating.

In order to simplify installation to the vehicle body, the mechanical connection to the vehicle body uses a structure that can fix the (b) spindle with fixing flange provided at the top of the module using only bolts. The (o) driven pulley is fixed to this (b) spindle with fixing flange, which serves as the (a) steering axis (Fig. 7). The (i) drive pulley is installed to the (j) steering motor fixed to the (c) frame side, and the motor torque is transmitted to the (o) driven

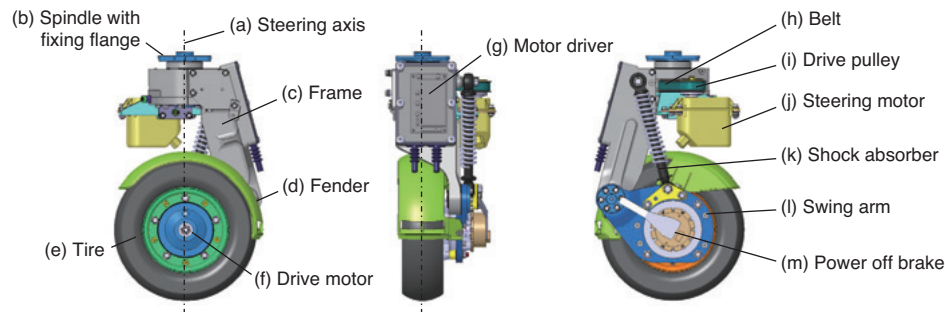


Fig. 6 Design of general purpose drive module

pulley by the (h) belt. As a result, the entire module rotates around this (a) steering axis.

In order to realize compact packaging, the (a) steering axis passes through the longitudinal and lateral center of the (e) tire to reduce the rotation path. This eliminates the caster trail and does not generate self-aligning torque, enabling suppression of the steering force.

The (a) steering axis is hollow and the wire harness of the motor is led through it to the vehicle body. The motor driver for the (g) drive motor is installed to the (c) frame and is operated by providing a power source and signals.

As for the layout of each component, in order to realize compactness and ease of installation, the steering motor mounting structure and the layout of the suspension pivot axis were arranged so that all the components are contained in a cylinder with a diameter of approximately 300 mm, which is nearly equivalent to the tire outer diameter. The drive, steering, impact absorption, and stop holding functions are consolidated in the cylinders as shown in Fig. 8, providing good space efficiency. Furthermore, when developing mobility using this module, designers can basically arrange the frame and other items while leaving this cylindrical space, which enables efficient design promotion.

In order to adjust the toe angle of the tire after the module is installed to the vehicle body, electrical adjustment by steering motor position control is used and a (p) link that enables mechanical adjustment is also provided in the steering motor fixing part in consideration of maintainability.

3.2. Drive Platform

3.2.1. Configuration

Table 2 shows the main specifications and Fig. 9 shows the appearance of the drive platform. The size corresponds to a four wheel scooter such as Monpal, which assumes use in human walking spaces.

As the drive platform combines rough road driving performance and maneuverability, four general purpose drive modules are mounted and four wheel independent drive and four wheel independent steering are used. The maximum speed is 6 km/h in consideration of movement

Table 2 Specifications of drive platform

Length x Width x Height	1180 x 620 x 530 mm
Rated output	600 W
Maximum speed	6 km/h
Minimum turning radius	700 mm
Step height which can be climbed over	90 mm

in walking spaces, and the drive platform can climb up steps as high as 90 mm without a run-up. Each drive module can steer independently in an area of $\pm 180^\circ$, which

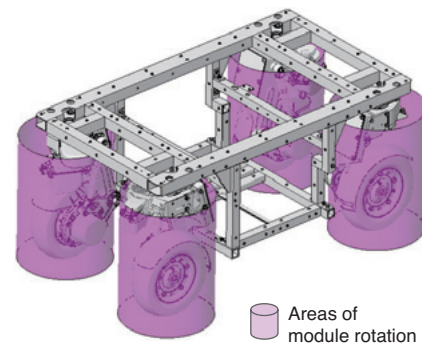


Fig. 8 Areas of module rotation

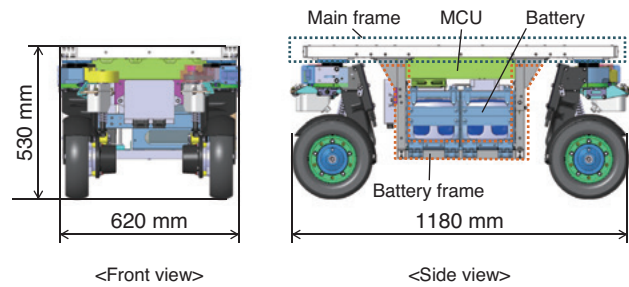


Fig. 9 Layout of drive platform

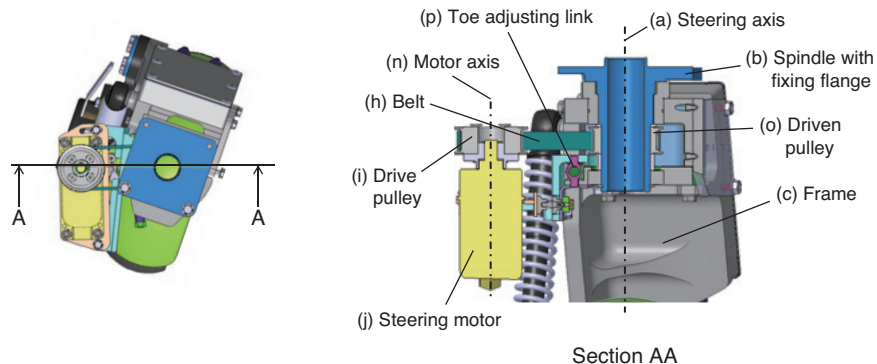


Fig. 7 Cross section of steering axis

enables turning on a spot with a turning radius of 700 mm [Fig. 10(a)] and parallel move including directly sideways [Fig. 10(b)] using the cooperative control function described hereinafter.

Drive modules were placed in the four corners of the main frame to make efficient use of space. In addition, the pivot axis of the swing arm is positioned toward the vehicle body center for the anti dive mechanism described hereinafter. The functional parts needed for driving are consolidated in the drive module, which enables securing a wide space for the batteries, MCU, sensors, etc. Two main batteries are placed sideways below the vehicle body center to secure separate power sources for driving and the autonomous drive function. This consolidated the power source system components including the sub battery below the vehicle body, which lowered the center of gravity.

The power source system components are housed in a box-shaped battery frame and fixed to the main frame. This box-shaped frame forms an independent power source module that can also be placed above the main frame, making it easy to change the drive platform format. The driving system MCU is positioned in the space between the power source system and the main frame. No parts protrude above the main frame and the upper surface of the vehicle body is flat. This provides extendability with a structure that enables easy installation of sensors for autonomous drive and working parts such as a cargo compartment. The main frame also has a replaceable unit structure, so expansion of the wheelbase and tread can be supported.

3.2.2. Anti dive mechanism

In a bottom link type suspension, the shock absorber expands and contracts according to the drive and braking reaction force from the road surface. This mechanism was used with the objective of suppressing longitudinal vehicle body inclination when accelerating and decelerating. Figure 11 shows a schematic of the forces acting on the vehicle body when braking. When the drive motors generate braking torque, the tires receive the braking reaction force from the road surface. This braking reaction force slows down the vehicle body and at the same time tries to rotate

the swing arm around the pivot axis. In the drive modules on the front side, this becomes a force that presses the tires against the road surface, and that reaction force extends the shock absorbers, becoming a force that pushes up the front of the vehicle body. In the drive modules on the rear side, the braking reaction force contracts the shock absorbers such that the rear of the vehicle body sinks. This movement mitigates nose dive due to inertial force, which helps to stabilize the vehicle body attitude. The opposite movement results during acceleration, which likewise helps to stabilize the vehicle body attitude.

The spring rate and pivot axis position of the drive module, the mounting interval of each module, and other parameters were set while confirming how the attitude changes using multibody dynamics simulation software (Adams). Figure 12 shows the analysis models. Model (A) is a bottom link type suspension, and Model (B) is a model without links in which it is imagined that the shock absorbers are installed directly to the tires. The two models differ only in the suspension format, and the wheel rate, weight, center of gravity position, and other parameters are the same.

Figure 13 shows the analysis result of the vehicle body pitch angle when braking force is applied while driving at constant speed on flat land. The horizontal axis plots the time and the vertical axis plots the pitch angle with the nose dive direction as negative. Model (A) exhibits a smaller pitch angle than Model (B), which shows that the desired effect is demonstrated.

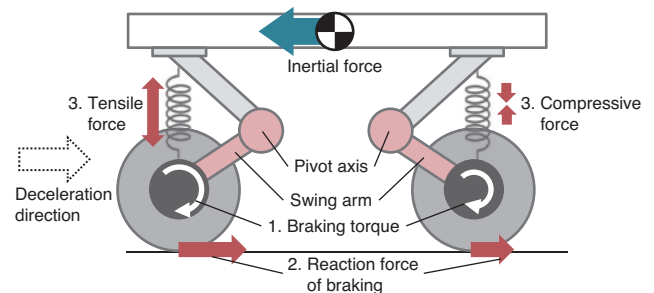


Fig. 11 Force acting on vehicle during deceleration

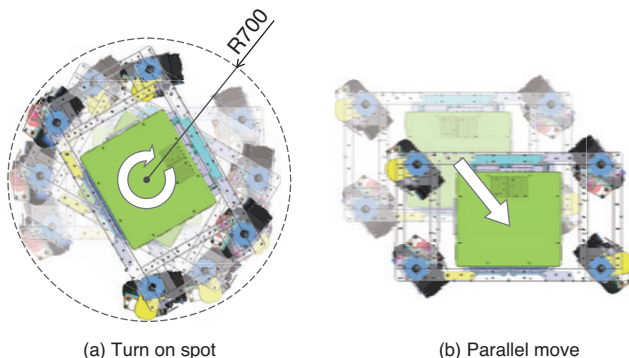


Fig. 10 Maneuverability of drive platform

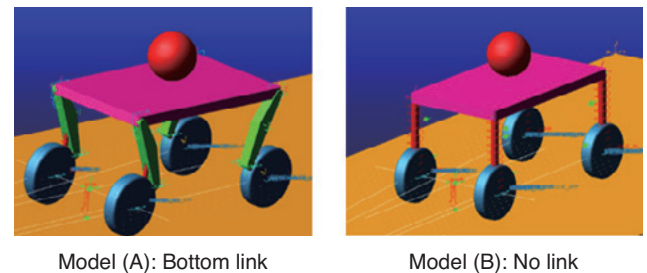


Fig. 12 Simulation models of Adams

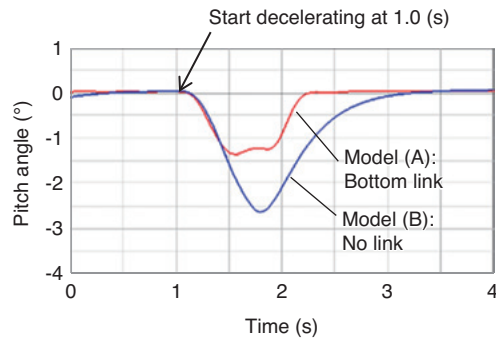


Fig. 13 Simulation result of pitch angle during braking

4. System Configuration and Features

Figure 14 shows the block diagram of the general purpose drive module.

The drive module is equipped with only the drive function and steering function and does not handle complex control, so it has only the necessary functions. The drive function and steering function are independent, and each can be operated separately by supplying power and providing commands.

Figure 15 shows the system block diagram of the

drive platform using this drive module. The drive platform consists of drive modules, an MCU that governs the drive modules, and a power source. Mobility capable of autonomous drive can be configured by providing commands from the ADU with autonomous drive function to the drive platform.

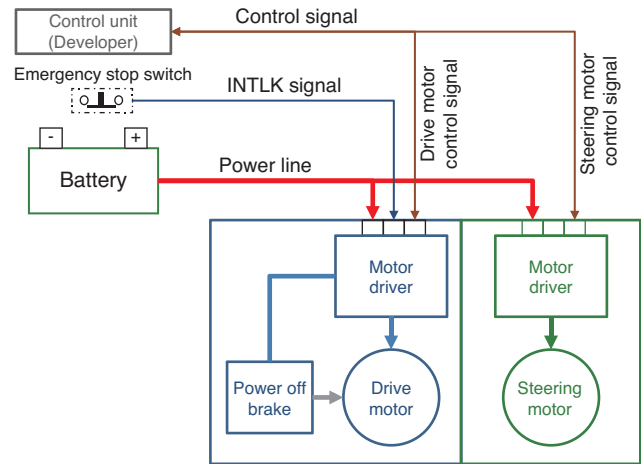


Fig. 14 Block diagram of general purpose drive module

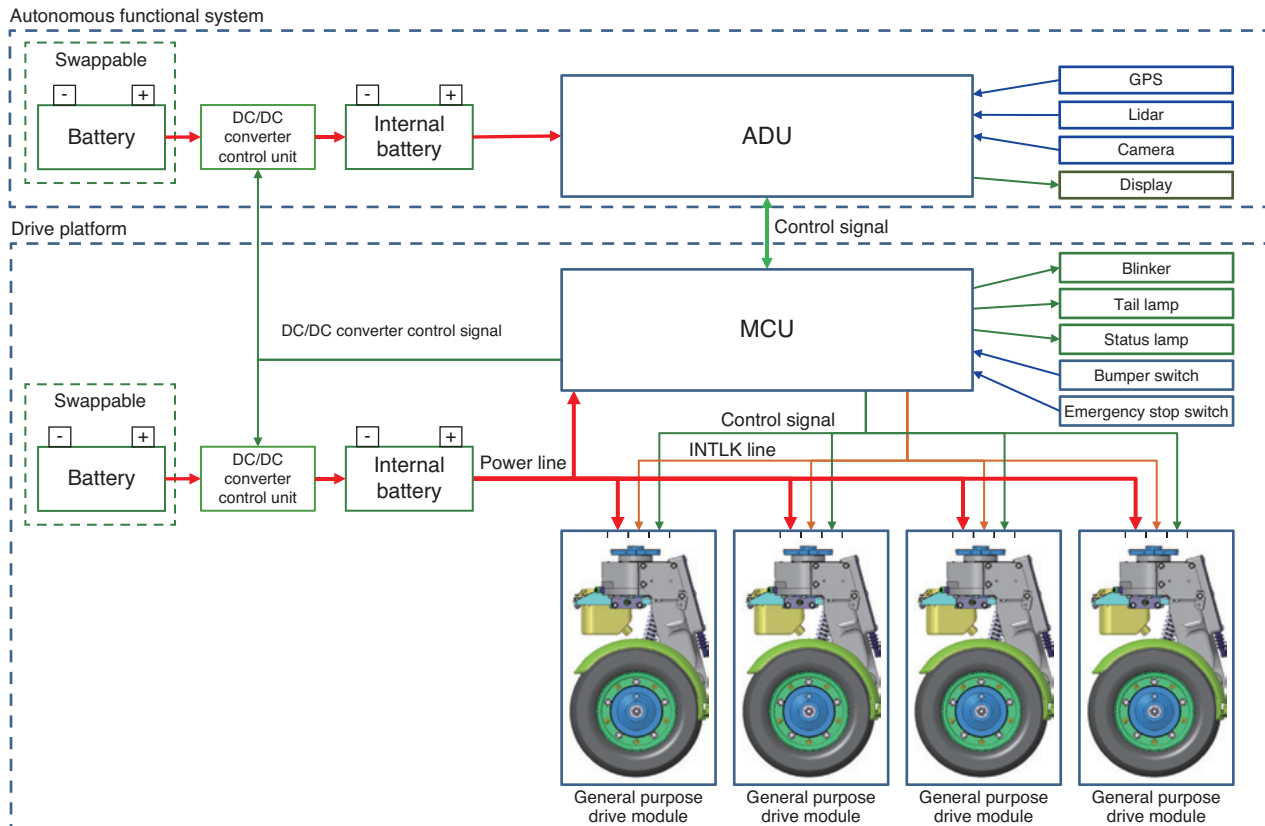


Fig. 15 Block diagram of drive platform

4.1. General Purpose Drive Module

4.1.1. Drive function

The drive function consists of the three blocks of the motor used for drive, the motor driver, and the power off brake. The power source is connected to the motor driver, and the motor speed is controlled simply by indicating the rotation speed via signal communication from the control unit. The motor driver autonomously turns the power off brake ON and OFF. The drive status is fed back to the control unit side via signal communication.

Apart from drive commands by signal communication, there is also an interlock function that stops the drive function, and the drive motor can be stopped by activating that interlock function. Table 3 shows the specifications of the drive function.

Table 3 Specifications of drive function

Rated output	150 W
Maximum continuous speed	182 rpm
Interface	CAN
Control method	Rotation speed control

Table 4 Specifications of steering function

Steering angle	$\pm 180^\circ$
Steering speed	$90^\circ/\text{s}$
Interface	PPM/CAN

4.1.2. Steering function

The steering function consists of a motor that provides steering force and a motor driver, and the steering function of the drive module can be operated by connecting a power source and providing steering commands. The area of the steering angle is set to $\pm 180^\circ$. The unit structure enables rotation in excess of 180° , but the wire harness of the power source and signals is connected through the hollow shaft of the steering axis, so the steering angle is limited to protect the wire harness.

The steering status is fed back to the controller side via signal communication in the same manner as the drive function. Table 4 shows the specifications of the steering function.

4.2. Drive Platform

The system configuration of the drive platform consists of the drive modules described above, the MCU, and a power source.

The MCU can configure mobility capable of autonomous drive by receiving commands from the ADU with autonomous drive function, converting those commands into commands to the drive modules, and providing the commands to each drive module.

4.2.1. MCU monitor function

The MCU monitors the drive platform status and the operating status of each drive module. It also handles operations such as the boot sequence after power on, and monitors the power source status.

The MCU also performs signal communication with the ADU, sends the monitored contents to the ADU, and receives commands to the drive platform from the ADU. The MCU constantly monitors the contents and transmission cycle of this signal communication, and stops the drive platform when an irregularity occurs.

The drive platform is equipped with an emergency stop switch for stopping safely and bumper switches around the entire circumference of the vehicle body for stopping the vehicle when physical contact occurs. The MCU monitors

these switches and stops the vehicle in the event of switch activation.

4.2.2. MCU cooperative control function

The MCU converts driving commands sent from the ADU to the drive platform into commands for arbitrarily placed drive modules based on the Ackermann-Jeantaud theory. Figure 16 shows schematic charts related to this conversion for the case with four drive modules located on the vehicle body.

The charts show top view images of the drive platform. The X-axis and Y-axis are respectively the longitudinal and lateral directions of the drive platform and the XY intersection is the center of the drive platform. The imaginary control criteria A is an image of an imaginary tire on the X coordinates, and B, C, D, and E are images of the drive module tires.

Figure 16(a) shows the steering image of each tire for a normal turn. The ADU sends the steering angle of the imaginary tire at A to the MCU as a steering command. The MCU calculates the turning center point shown in the figure based on the steering command at A from the ADU, and then calculates the steering angle and the indicated rotational speed to the drive motor, which is proportional to the distance from the turning center, for each drive module. By indicating these calculated values to each drive module, the drive platform turns.

Figure 16(b) shows the image for turn on a spot. By steering A by 90° relative to the X-axis, the turning center becomes the drive platform center.

Figure 16(c) shows the image for parallel move. Parallel move is performed by facing each drive module in the same direction.

These operations can also be combined to steer during parallel move, and the drive platform can be operated freely by having the MCU perform the calculations at that time.

By having the MCU handle the commands to each drive module in this manner, the ADU can freely operate the drive platform without the need to take into account the number and placement of drive modules.

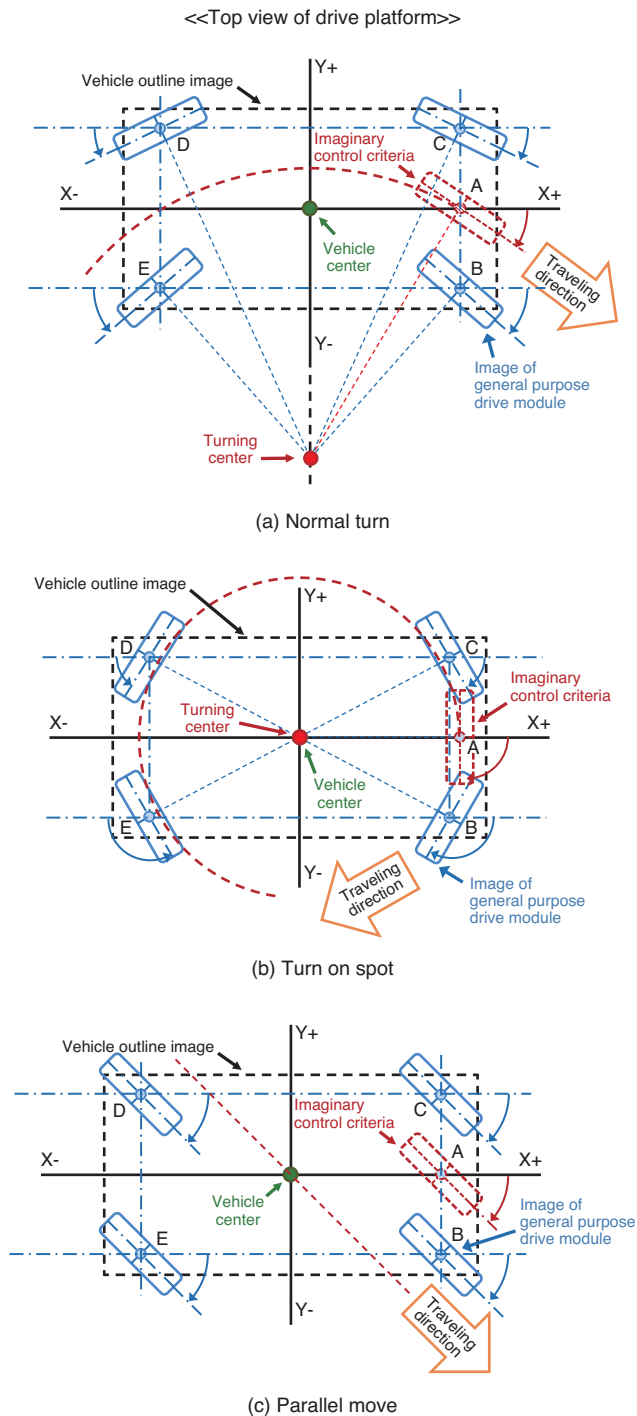


Fig. 16 Schematic chart of cooperative control

5. Confirmation of Effects in Driving Demonstration Tests

5.1. Autonomous Delivery Robot

Figure 17 shows the autonomous delivery robot developed with Rakuten Group, Inc. Honda is in charge of developing the vehicle body portion with autonomous drive

function, which is based on the above-mentioned drive platform, other than the delivery box portion of the robot.

Cameras, ranging sensors, monitors, and other devices for autonomous drive are installed on the front and rear of the drive platform. An emergency stop switch is located on top of the vehicle body, bumper switches are installed around the entire circumference of the vehicle body, and the robot stops when any of these switches is activated.

The exterior is box-shaped with rounded corners, and items such as tail lamps, blinkers, status lamps, and battery indicators are arranged in consideration of visibility and balance. In addition, the areas around the two front cameras were made into circles and ring-shaped reflective material was attached to provide a friendlier expression. The objective here was to not present an intimidating feeling when driving in a walking space with people, and to make it easy to understand the front and back of the robot.

A delivery box developed by Rakuten was fixed to the flat surface on top of the main frame of the drive platform. As stated in the above-mentioned design concept, there was no need for large-scale modification or complex coordination with Rakuten in order to mount the delivery box, and the autonomous delivery robot could be created within a short time.

5.2. Confirmation of Effects in an Actual Driving Environment

Honda and Rakuten, with the support of New Energy and Industrial Technology Development Organization (NEDO), conducted driving demonstration tests of the above-mentioned jointly developed autonomous delivery robot on the University of Tsukuba campus and some public roads from July 19 to August 31, 2021.

The driving route on the university campus included locations with braille blocks and rough pavement, but the rough road driving ability provided by four wheel drive and the suspension enabled stable driving (Fig. 18). In the course of the tests it was also necessary to climb over curbs approximately 40 mm in height between paved and unpaved road, but the robot did not become stuck there.

It was necessary to emergency stop the robot a number of times while driving during the tests in order to secure safety. However, the anti dive mechanism enabled stopping in a stable manner without disrupting the attitude.

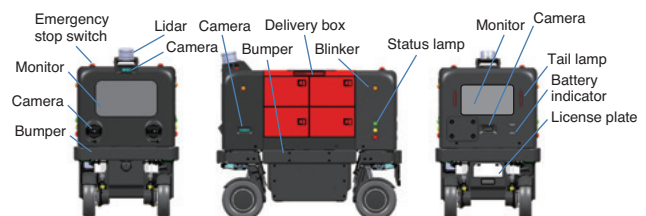


Fig. 17 Autonomous delivery robot developed with Rakuten Group, Inc.

As the robot was able to turn on a spot (turning radius approximately 700 mm), advanced control to turn back was not needed. When changing direction on a road approximately 2.6 m wide (Fig. 19), bicycles parked on the edge of the road and pedestrians coming and going limited the space actually available for turning to only about 2 m, so turning on a spot was effective. There were also an elevator and narrow corners on the path to the indoor robot storage location, but the size equivalent to a four wheel scooter and four wheel independent steering provided good small turnability, which enabled putting the robot in and out smoothly.

In this manner, the autonomous delivery robot could be efficiently operated in an actual driving environment that included uneven and narrow roads, which confirmed the effectiveness of the drive platform.



Fig. 18 Driving environment on University of Tsukuba campus



Fig. 19 Turning on spot on narrow road (Minimum turning radius: approximately 700 mm)

6. Conclusion

A general purpose drive module that consolidates the functions needed for driving, such as drive, steering, and impact absorption, and a drive platform equipped with a cooperative control function that governs the driving

functions and is easily connectable to an autonomous drive function were developed.

This development of autonomous delivery robot used four drive modules to configure a drive platform that combines rough road driving performance and maneuverability. The drive platform has space for adding functionality on the top surface and the front and rear, and has the extendability to create various forms of electric mobility.

An autonomous delivery robot based on this drive platform was developed with Rakuten, and driving demonstration tests were conducted at the University of Tsukuba with the support of NEDO. These tests confirmed the effectiveness of the extendability of the drive platform, the connectivity with the autonomous drive function, and the rough road driving performance and maneuverability.

It is thought that use of the newly developed general purpose drive module and cooperative control technology will enable the efficient creation of various forms of electric mobility, including not just autonomous delivery robots but also autonomous lawnmower robots and autonomous cleaning robots. It is hoped that the timely development of diverse and practical autonomous products will be useful and expand joy in people's lives.

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