Introduction of Products

Container Forklift FH120-1 Guidance and Semi-automatic Functions

Manabu Yamashiro

Kazuo Yamane

Takahiro Noyori

Yoshihiro Iwanaga

In recent years, as labor shortage has become increasingly serious in the logistics industry, securing skilled operators of forklifts and training human resources is an issue because of the increasing demand for container transportation by rail as a means of modal shift. In order to solve this issue, Japan Freight Railway Company (hereinafter referred to as "JR Freight") and Komatsu have been working to reduce the workload of operators. Based on the engine-powered forklift FH120-1, we have developed guidance and semi-automatic functions that aim to achieve "safe," "easy and reliable," and "fatigue-free" operations even for unskilled operators. This paper reports on the main features of these functions.

Key Words: *Container, Handling work, Workload, Guidance, Semi-automatic*

1. Introduction

Recent years have seen growing interest in the shift to freight transportation by railway (modal shift), which is capable of transporting large volumes of freight and excels in environmental characteristics, mainly to address labor shortages in the logistics industry and to reduce environmental impact. On the other hand, due to the decline in the working population, freight stations have faced issues of securing skilled operators and training human resources in container handling work.

For container handling work at freight stations, large forklifts are used and operators are required to have advanced operation skills and to work flexibly according to freight train schedules in order to ensure safe, high-quality transportation. Against this backdrop, newly hired operators are having a hard time learning operating techniques and performing their work-intensive duties, indicating major issues of ensuring safety and developing human resources swiftly in response to the growing labor shortage.

After being consulted by JR Freight, Komatsu began to make efforts to resolve these issues in 2019. As a result of sharing and discussing the current issues and the future ideal situation, we started research and development of an operation guidance function (**Fig. 1**) and a semi-automatic operation function **(Fig. 2**) based on the FH120-1 with the aim of reducing operators' workloads by assisting manned work to achieve remote and automated handling work in the future. Under a joint development agreement signed for the mass production of this function in 2023, we developed the FH120-1 guidance and semi-automatic functions.

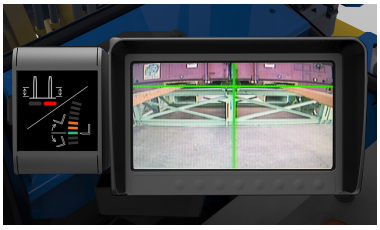


Fig. 1 Operation guidance function

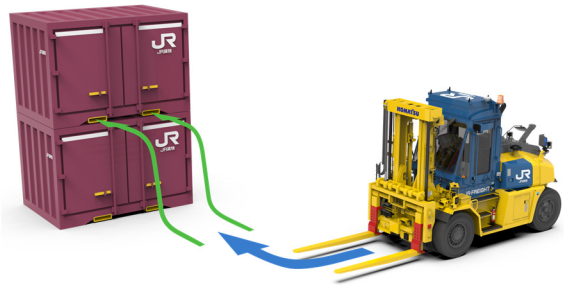


Fig. 2 Semi-automatic operation function

2. Aims of development

In examining the functions, we performed analyzes to identify works with heavy load for operators. Eye tracking and time studies were conducted at freight stations to compare the work of new operators with that of skilled operators. The results showed that new operators had difficulty in facing a forklift toward a container and confirming work equipment posture during container handling work, and the confirmation procedure for safe handling of containers, which were due to difficult operations and visibility.

Therefore, to reduce the workload of operators, we developed the following functions to enable even unskilled operators to work “safely,” “easily and reliably,” and “without fatigue” (**Fig. 3**).

(1) Operation guidance function

- With an aim to facilitate confirmation procedure during container handling work, the operation guidance function provides operation assistance by displaying guide lines and fork angles, reminds the operator to hold the container in the proper position, and improves the operators’ visibility.

(2) Semi-automatic operation function

- With an aim to facilitate operations during container handling work, the semi-automatic operation function partially automates the difficult operation of facing the forklift to freight and the adjustment of the work equipment posture when forks are inserted.

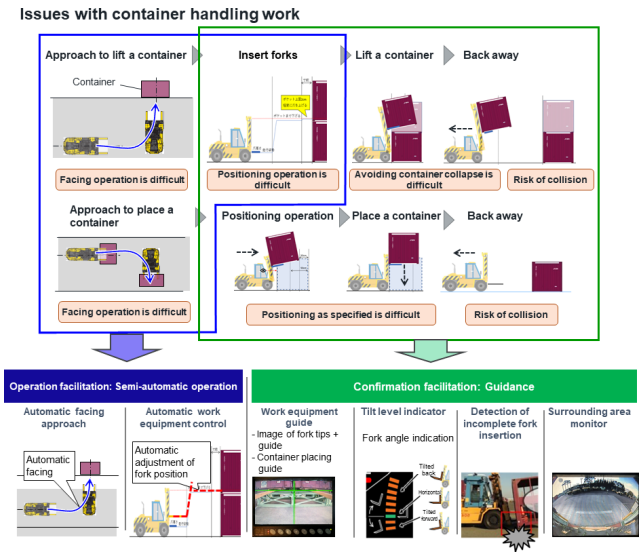


Fig. 3 Issues with container handling work and functions to be achieved

Installing these functions is expected to bring the following benefits.

- Reduced blind spots and easier confirmation lead to a reduction in the risk of accidents for both new and skilled operators.
- Simple and reliable operations lead to a reduction in the number of rework during container handling work, especially for new operators.
- Physical fatigue and mental stress of new operators will be alleviated.

3. Major features

3.1 Operation guidance function

3.1.1 Outline of the function

The operation guidance function assists the operator in confirmation procedure. The guidance monitor system assists in checking the front and rear of the vehicle, and the guidance indicator assists in checking the fork angle and fork insertion depth into the container.

3.1.2 Guidance monitor system

This system is equipped with three guidance cameras in the front and one in the rear (**Fig. 4**). The images from the cameras are displayed on a guidance monitor located at the right front of the operator’s seat. The screen display of the guidance monitor can be switched using the guidance monitor changeover switch located under the armrest (**Fig. 5**).

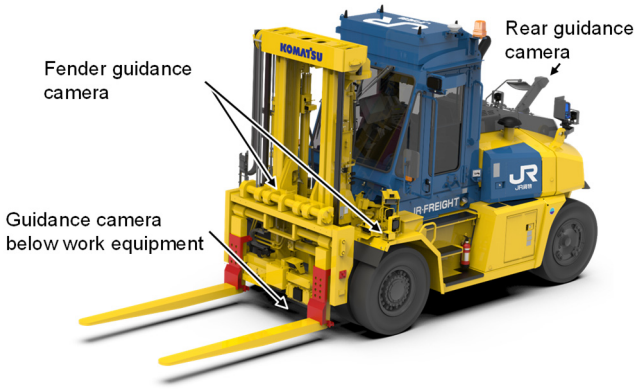


Fig. 4 Layout of the guidance cameras

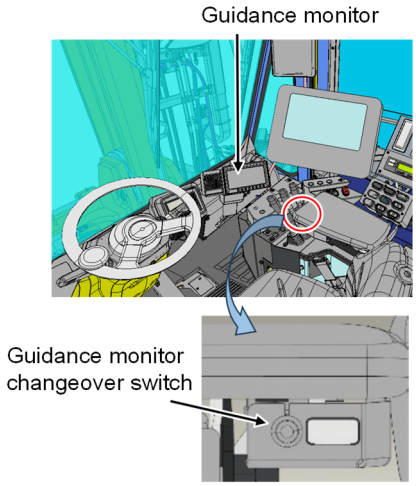


Fig. 5 Layout of equipment for the guidance function in the cab

The layout and angles of the cameras are set with the assumption that they will be used for confirmation procedure during operations to lift containers and place containers to freight cars, enhancing operator's visibility in areas with limited direct line of sight from the operator's seat.

During container handling work, particular care must be taken to securely lock and unlock a device used for tightening a container to a freight car (tightening device) as well as to avoid direct contact between adjacent containers. The screen display can be switched manually using the guidance monitor changeover switch and automatically according to the container holding status, allowing the operator to confirm them according to the situation (**Fig. 6**).

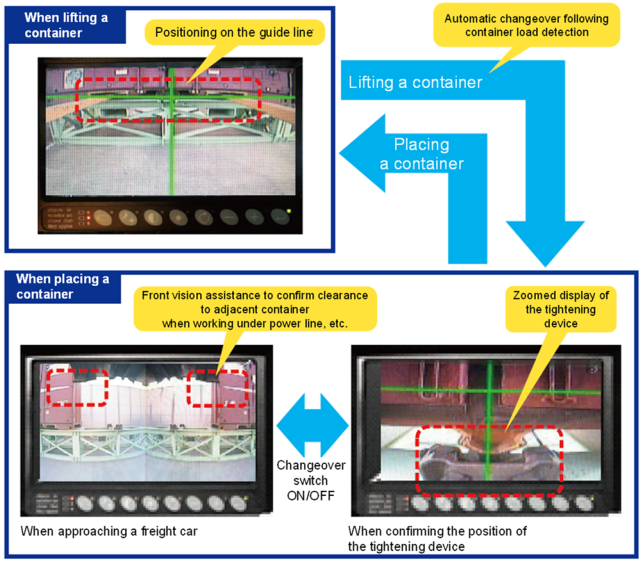


Fig. 6 Switching of guidance monitor screen (when checking the front)

When the forklift reverses, the display on the guidance monitor automatically switches to the image of the rear camera in conjunction with the operation of the forward-reverse lever. The ultra-wide-angle camera allows the driver to see a wide area in the rear of the vehicle (**Fig. 7**).

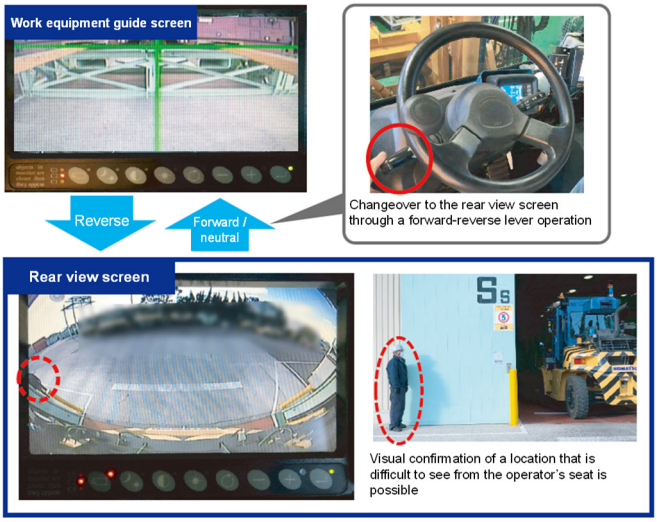


Fig. 7 Switching of guidance monitor screens (when checking the rear)

3.1.3 Guidance indicator system

The guidance indicator system includes a tilt level indicator function and an incomplete fork-insertion warning function.

The tilt level indicator function shows the angle from the fork top from the horizontal direction. New operators on large forklifts such as the FH120-1 find it difficult to adjust the fork angle to the horizontal direction and need a long training period to master it, but the tilt level indicator function allows them to check the fork angle, making it easier to adjust the forks to the horizontal direction.

A tilt sensor is mounted on the board of the work equipment, allowing the system to display the angle of the forks (container being held) with respect to the horizontal plane, even when the chassis is on a slope. The angle is displayed after the amount of deflection of the forks due to the load of the container being held is corrected (**Fig. 8**).

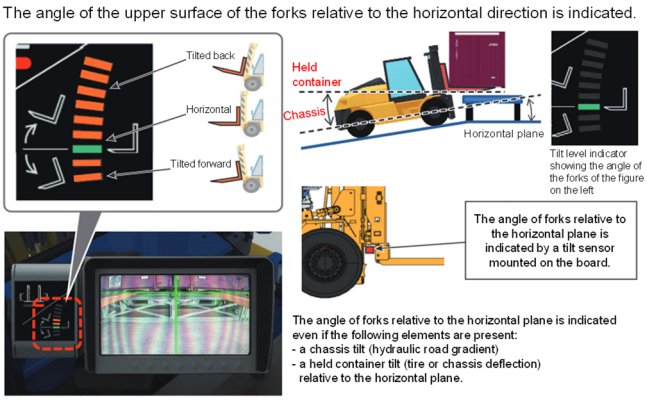


Fig. 8 Guidance indicator system (tilt level indicator function)

To reduce the risk of container dropping when a container is lifted with the forks not inserted completely, we developed an incomplete fork-insertion warning function. The indicator lamp illuminates when the forks are not completely inserted under the container. If a container is lifted with the forks not inserted completely, the lamp flashes, and a buzzer sounds to notify the operator. The incomplete fork insertion is detected and displayed for each of the left and right forks; therefore, the incomplete insertion warning is issued even if the forks are inserted under a container at an angle (**Fig. 9**).

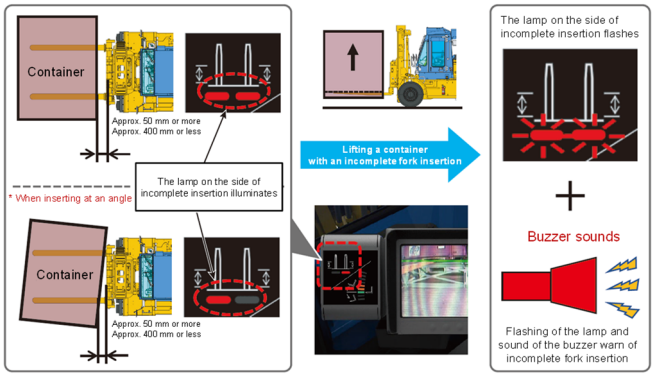


Fig. 9 Guidance indicator system (incomplete fork-insertion warning function)

3.2 Semi-automatic operation function

3.2.1 Outline of the function

The semi-automatic operation function partially automates forklift operations in handling containers and consists of automatic steering control and automatic work equipment control. The automatic steering control performs steering control to face the forklift toward an object, and the automatic work equipment control performs control to align the tips of forks of work equipment with the fork pockets of the container.

To use the semi-automatic operation function, the operator follows the steps below:

(1) Confirm that the semi-automatic monitor in the cab displays a recognition frame indicating the object to be handled (**Fig. 10**).
(2) Press the semi-automatic start switch to start the automatic steering control.
(3) When the operator depresses the accelerator pedal to start forward movement, the steering is automatically controlled to face the forklift toward the object (**Fig. 11**).
(4) After it faces toward the object, when the operator presses the semi-automatic start switch again to start automatic work equipment control, the fork tips of the work equipment are controlled to align with the center of the container pockets (**Fig. 12**).
(5) The operator depresses the accelerator pedal to move forward and inserts the forks into the container pockets.

Besides, the automatic steering control is also used for container-placing operations where a container is held and loaded onto a freight car or truck, targeting the tightening device of freight cars and the like, as well as an open space next to the container.

In this way, the operator can perform most of the container handling work with accelerator pedal operation only by using the semi-automatic operation function.

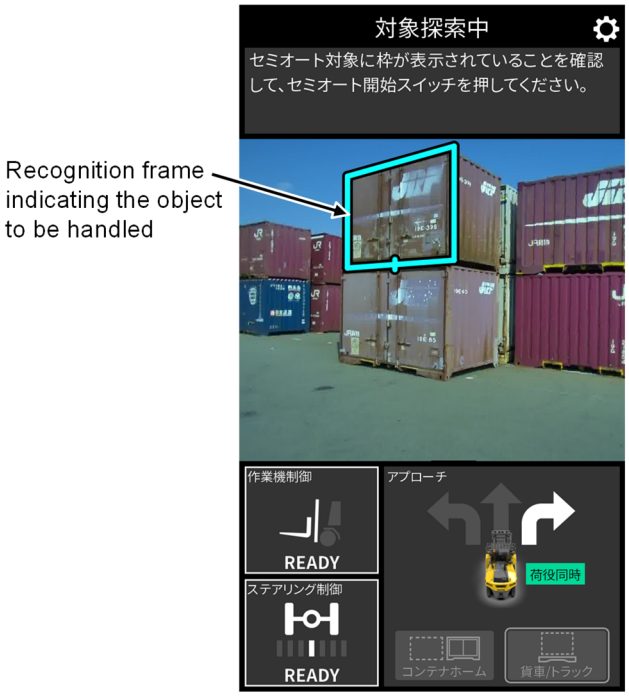


Fig. 10 Display of target object in semi-automatic monitor

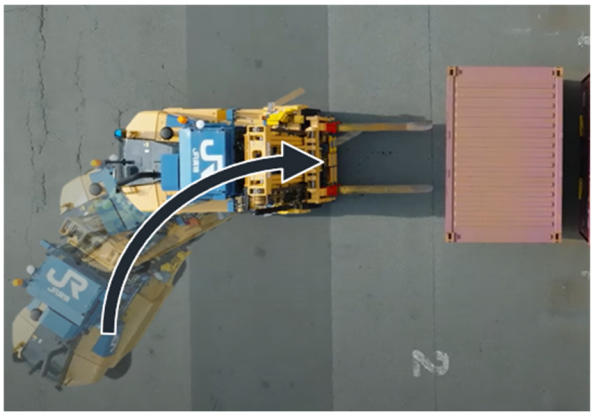


Fig. 11 Automatic steering control

Fig. 12 Automatic work equipment control

3.2.2 Installed equipment

This system is equipped with the following devices for the semi-automatic operation function. First, as external sensors, four sets of a LiDAR *1 and a camera are mounted: three sets above the tire fenders facing left, right, and forward, respectively, and one set on the work equipment. The sensor used is switched according to the direction of the object to be handled to the chassis and the presence of a load. It is also equipped with a steering electromagnetic proportional control (EPC) valve and work equipment EPC valves, enabling automatic control of steering and work equipment. A steering angle encoder and work equipment cylinder length encoders are also mounted to measure their respective positions. A semi-automatic monitor and switches are installed in the cab, allowing the operator to check the target of the semi-automatic operation and perform various operations (**Fig. 13**).

*1: Abbreviation for Light Detection and Ranging. A technology to measure the distance to an object and the shape of an object by irradiating laser beams and using the information obtained from the reflected beams.

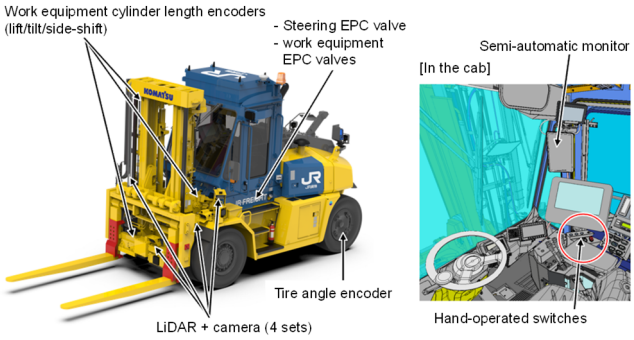


Fig. 13 Layout of equipment for the semi-automatic operation function

3.2.3 Control system

Figure 14 shows a block diagram of the control system for the semi-automatic operation function. The control system consists of five blocks: external sensors, vehicle information, recognition processing, semi-automatic control, and actuator control.

This system estimates the position and posture of the object to be handled through recognition processing based on the point cloud data and images obtained from the LiDARs and cameras, and vehicle information. The target steering angle and target work equipment position are determined by semi-automatic control based on the position and posture of the object to be handled. Based on the target steering angle and target work equipment position, the system controls the actuators for steering and work equipment, realizing the semi-automatic operation function.

The details of the recognition process and semi-automatic control are explained below.

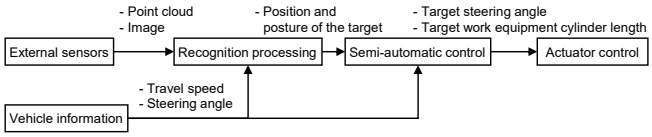


Fig. 14 Block diagram of the control system

3.2.4 Recognition processing

The purpose of the recognition process is to detect the object to be handled using the information obtained from external sensors and to accurately estimate the position

and posture. The semi-automatic operation function can recognize three types of objects: containers, tightening devices on freight cars and trucks, and open spaces (**Fig. 15**). This section outlines the recognition algorithm using container recognition as an example.

Fig. 15 Objects that can be recognized

Figure 16 shows the block diagram of the recognition processing. First, using the 3D point cloud data acquired by LiDARs, the point cloud recognition block detects the container and estimates its position and posture. This block extracts the plane of the container's front surface using the point cloud data and detects the fork pockets on that plane to estimate the three-dimensional position and posture of the container.

Then, the camera images are input to a pre-trained image classification model, which classifies whether the object detected based on the point cloud data is a container or not. The image classification model uses perspective-transformed images of the object detected based on the point cloud data as input to the model in order to achieve a more accurate image classification. Besides, some freight stations have double-stacked containers, but due to the lack of vertical field of view of LiDARs, the system cannot determine from point cloud data whether containers are double-stacked or not. Therefore, camera images with a relatively large field of view are used for the image classification model to classify whether containers are double-stacked or not.

Finally, the consistency confirmation block checks the consistency between the point cloud recognition and image classification to determine the success or failure of the recognition. This block holds past recognition results, and only when recognition is successful a certain number of consecutive times, the block performs the process to determine that the object is a container. As described above, this system is designed to perform the time-series consistency check in addition to the combined use of point cloud data and images to minimize misrecognition.

The position and posture of the object to be handled estimated by the above procedures are finally integrated using wheel odometry (a method for estimating the travel distance of a vehicle based on steering angle and travel speed) and an unscented Kalman filter, and the smoothed data is used as the input for control.

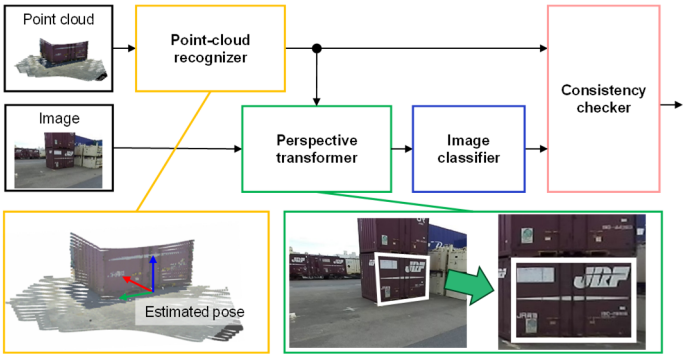


Fig. 16 Block diagram of the recognition processing

3.2.5 Semi-automatic control

The semi-automatic control uses the automatic steering control to face the vehicle toward the object to be handled based on the position and posture of the object estimated by the recognition processing, and it uses the automatic work equipment control to align the fork tips of the work equipment to the center of the fork pockets of the target container.

The automatic steering control includes two processes: path planning and path tracking.

The path planning plans the target path for the forklift to face toward the object to be handled based on the position and posture of the target. The target path consists of a combination of clothoids and arcs and is generated to smoothen vehicle behaviors (**Fig. 17, left**). Besides, the target path varies depending on the positional relationship between the vehicle and the target. When the vehicle is close to the object, a curve with a large curvature is generated; when it is far, one with a small curvature is generated, preventing unnecessary sharp steering turn. (**Fig. 17, right**).

In the path tracking, the target steering angle is determined based on the target path. The target steering angle is determined by adding the feedback component of the deviation from the path to the feed-forward component of the steering angle calculated from the curvatures of the target path, which helps the vehicle tracking the target path.

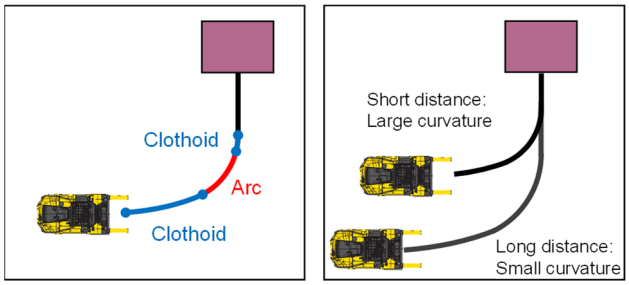


Fig. 17 Path planning

The automatic work equipment control adjusts the position of forks so that they are inserted into the fork pockets of the container. The tilt angle of the work equipment is controlled to match the pitch angle of the container to be handled. At the same time, the lift and side-shift positions are individually controlled so that the positions of the fork tips align with the fork pocket positions (**Fig. 18**).

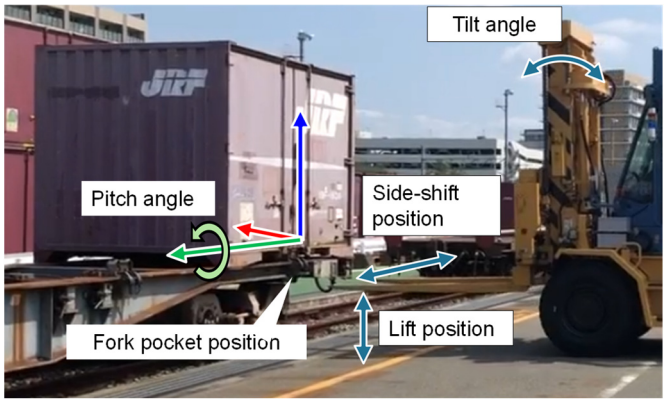


Fig. 18 Automatic work equipment control

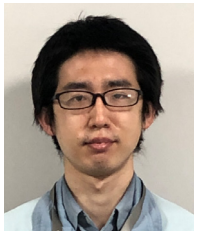
The automatic work equipment control also functions to simultaneously control steering and work equipment, and the function can be enabled and disabled by monitor operation. When it is enabled, the automatic work equipment control is started simultaneously with the start of the automatic steering control. When the work equipment control is completed during a turn and the forklift faces toward the container, the fork tips are aligned with the center of the fork pockets. This function achieves a series of seamless container handling work; therefore, it is expected to significantly save time, especially for lifting containers on freight cars or stacked containers.

4. Conclusion

We are advancing discussions with JR Freight about measures to address the growing labor shortage, and the development of this guidance and semi-automatic functions represents one step toward further labor-saving and automation of freight handling operations in the future. We plan to deploy vehicles with this function to freight stations gradually. We will investigate new issues that will arise during operations to move forward to the next step. We would like to utilize the knowledge gained from this development to shape the future logistics that JR Freight and Komatsu are both aiming for.

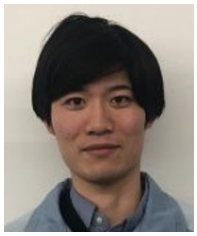
Introduction of the authors

Manabu Yamashiro
Joined Komatsu Ltd. in 2009.
Vehicle Development Center 4,
Development Division



Kazuo Yamane
Joined Komatsu Ltd. in 2013.
Vehicle Development Center 4,
Development Division

Takahiro Noyori
Joined Komatsu Ltd. in 2013.
ICT System Development Center,
Development Division



Yoshihiro Iwanaga
Joined Komatsu Ltd. in 2016.
ICT System Development Center,
Development Division

[A comment from the authors]

Through this development process, we have worked with our customers to create new value. We have faced many first experiences and difficulties, but with the cooperation of many people, we succeeded in creating a product never seen before. We would like to express our deepest gratitude to everyone who contributed to this development.