Development of New AGF Improving Warehouse Storage Efficiency and Throughput

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For expanding the application of automated guided forklifts (hereafter AGF), there are issues that need to be addressed: the processing capacity is only about half that of manned forklifts, and the aisle width for AGF operation needs to be wider than that for manned forklifts. Therefore, this time, we have developed a prototype AGF that can perform cargo handling operation equivalent to those of a manned forklift by implementing new mechanisms (e.g., 3-wheel steering and new mast mechanism) and sensor and control technologies (e.g., 2D-LiDAR/SLAM), and evaluated the performance of the new AGF, which improves the warehouse storage efficiency and throughput simultaneously. As a result of its demonstration test, we confirmed that the new AGF achieves the processing speed equivalent to that of a manned forklift and that it can be used even in narrow aisles where manned forklifts cannot be used.

1. Introduction

The introduction of automated and intelligent systems is an effective approach to address manpower shortages in production and logistics sectors and to avoid contact in the ongoing COVID-19 situation. However, the existing AGFs have issues such as the processing capacity being about half that of manned forklifts, expensive introduction costs, long payback time, and greater aisle width necessary for their operation. As a result, the use cases in which automation can be made with AGFs are limited, posing a barrier to their introduction.

We are developing a new AGF to improve the throughput (cargo processing capacity) and to reduce the necessary aisle width for an increase in storage capacity of warehouses. Based on Mitsubishi Logisnext Co., Ltd's manned forklift (Platter-Multi), we designed a compact AGF with three-wheel steering and developed control technology that enables operation even in narrow aisles, thereby achieving the prospect of operating the AGF in narrow aisles where manned forklifts cannot be operated, while maintaining the processing speed. This report describes the outline of our development.

2. Mechanism design of new automated guided forklift (new AGF)

The new AGF prototyped in this study was developed with the aims of (1) increasing the warehouse storage density by reducing the forklift size and (2) improving the throughput by increasing the forklift speed. As shown in **Figure 1**, we used Platter-Multi, which can move in all directions by human operation, as a base forklift, and utilized its drive motor, cargo handling system, and basic control equipment in order to minimize the items of new developments.

The new AGF was designed by carrying out 3D CAD modeling and mechanical analysis in parallel, and the study of size reduction of AGF shape, design of weight distribution, and simulation of movement with MBD (Multi Body Dynamics) were performed in a cycle of about one week; thereby, a practical AGF design was achieved in a short time.

Figure 2 shows the appearance of the developed AGF and the layout of its main components. First, in order to change the specifications for manned operation to those for unmanned operation, several 2D-LiDARs that implement safety detection and self-positioning were

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installed on the lower body to cover all directions, and a computer for autonomous operation was newly installed in the space for the control equipment.

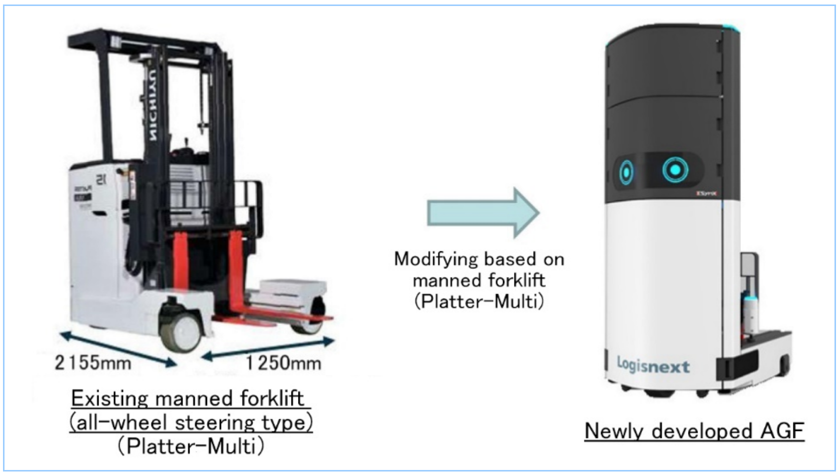

Figure 1 Base forklift and newly developed AGF

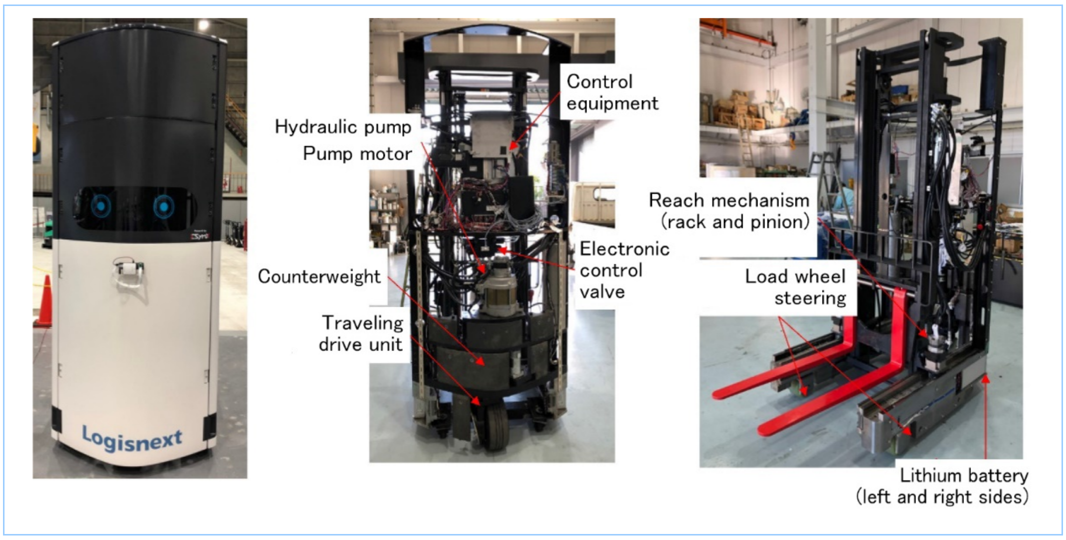

Figure 2 Appearance and main components layout

For downsizing, the traveling drive unit and hydraulic system components of the forklift were rearranged. The forklift size was reduced as shown in **Figure 3** by measures such as changing the driving battery to a small lithium battery in addition to modifying the fork reach mechanism from hydraulic-cylinder driven to rack-and-pinion driven. Compared with the existing machine, the new AGF can hold a 1,100-mm-square pallet within the forklift's own footprint, and its overall length during loading and unloading was reduced by 65%.

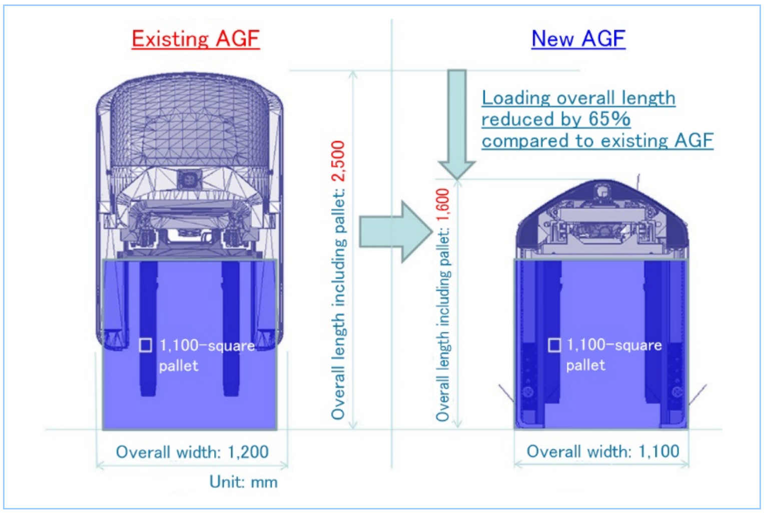

Figure 3 Comparison of AGF size (top view)

Platter-Multi is equipped with motors to control the steering angle on the two fork-side driven wheels (load wheels), and the new AGF utilizes these motors to enable three-wheel steering. In addition to reducing the size, the new AGF can perform on-the-spot turning (pivotal turning) due to three-wheel steering, which is not possible for the existing AGF, and as shown in **Figure 4**, the minimum necessary aisle width for running has been reduced to 1,900 mm.

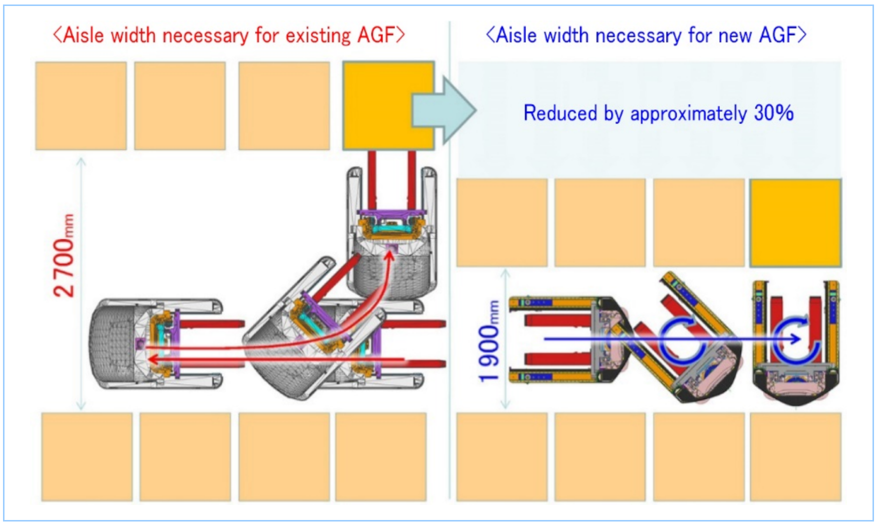

Figure 4 Comparison of minimum necessary aisle width for operation

3. Turning control technology to enable operation in narrow aisles

In order to enable operation even in aisles too narrow for existing AGFs and manned forklifts to operate (2.7 m or less), we developed a technology that enabled the AGF to turn while correcting the translational position so that a certain distance from aisle walls is maintained. As shown in **Figure 5**, when a forklift turns from an off-center position in the aisle width and the off-center amount is large, it will collide with a wall unless positional correction is made. Therefore, based on the clearance between the body and aisle walls measured during turning using the sensing data of the 2D-LiDARs installed for estimating the self-position, turning control is performed to move the AGF away from a small-clearance wall by adding a translational position correction component.

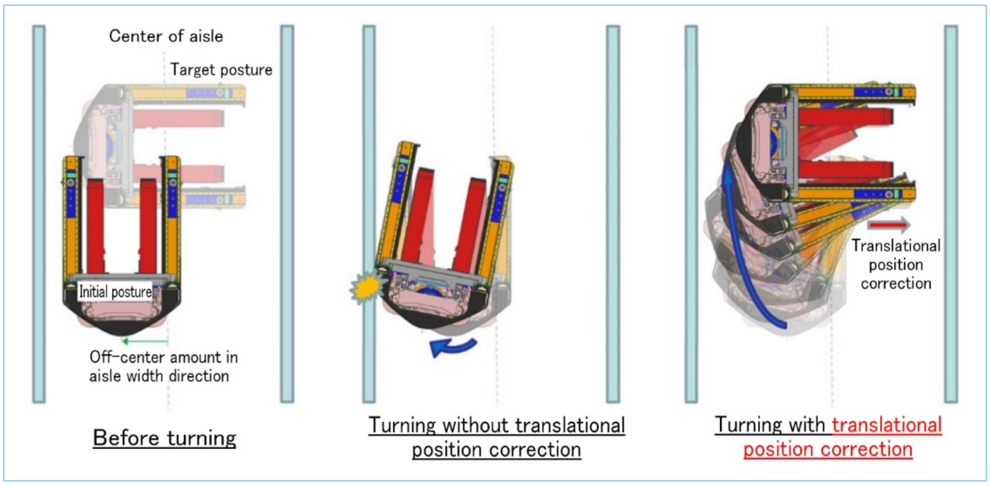

Figure 5 Turning technique with translational position correction

The clearance between the AGF and aisle walls is measured by detecting the walls on both sides by performing linear fitting with respect to the point cloud data around the AGF measured by 2D-LiDAR and measuring the minimum distance between each wall and the AGF exterior area, as shown in **Figure 6**. The direction of translational movement to move away from the wall is obtained by calculating the inclination of the wall with respect to the AGF's coordinate system.

For turning, the turning speed and steering angle are commanded with the fork-side driven wheel (load wheel) as the turning center. To do so allows the AGF to turn within a narrower-width space than pivotal turning with the center of the forklift as the pivot because each of the left and right external shapes on the drive wheel side (bumper side) is curved along a circle centered on the respective-side load wheel.

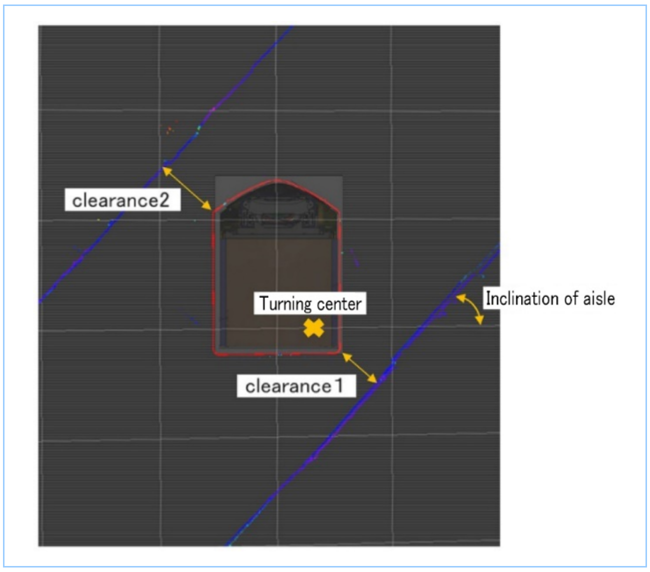

Figure 6 Example of sensing distance to aisle wall

When turning with translational position correction, the turning center load wheel is steered in the aisle width direction, as shown in **Figure 7**, based on the inclination of the wall with respect to the forklift measured above. The steering angles of the other two wheels are controlled in the direction of the resultant turning speed component vector for allowing the forklift to turn around the turning center load wheel and the translational position correction speed component vector. As a result, turning and translational position correction are performed simultaneously. Based on the clearance measurement result, which changes from time to time during turning, the turning center load wheel is always oriented in the aisle width direction. This allows for translational position correction in the aisle width direction even if the forklift attitude changes.

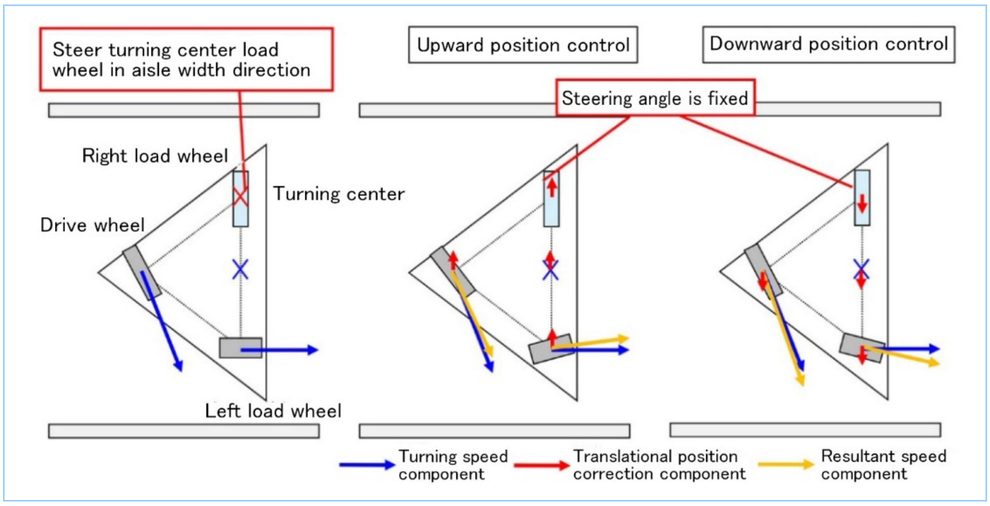

Figure 7 Calculation of speed component allowing for simultaneous turning and translational position correction

4. Verification test using actual equipment

We verified the operation of the new AGF, which implements the above-mentioned turning control technology. We conducted a narrow-aisle operation test to compare the time required to travel straight through the aisle between shelves, turn, and pick up cargo between the existing and new AGFs. In this test, the width of the aisle was changed for each AGF by placing pillars that simulate shelves, as shown in **Figure 8**.

Figure 8 Comparison of aisle widths for verification test using actual equipment

Figure 9 shows the test results. It was confirmed that the new AGF was able to turn without colliding with a shelf even when operating in the narrower aisle width than that necessary for the existing AGF and that the new AGF was able to more quickly complete cargo pick-up operations.

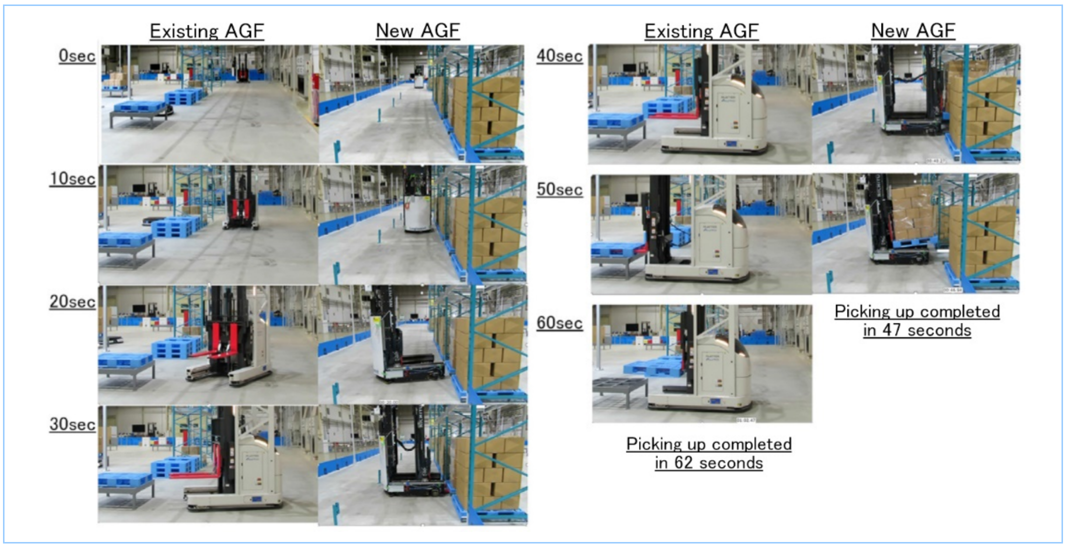

Figure 9 Comparison between existing and new AGFs of time required to travel straight through aisle between shelves, turn, and pick up cargo

In addition, we considered an operating scenario assumed in usage in a multi-tenant warehouse and evaluated the throughput by estimating the time required for the sequence of processes from picking up a cargo from a temporary storage area, placing the cargo on a shelf, and returning to the temporary storage area. The verification test was conducted according to a partial extract of the above scenario, and the total time each AGF required to execute it was evaluated. **Figure 10** shows the test result. It was confirmed that the new AGF not only operates faster than the existing AGF, but also has the potential to achieve a throughput comparable to that of human operation (experienced forklift operator).

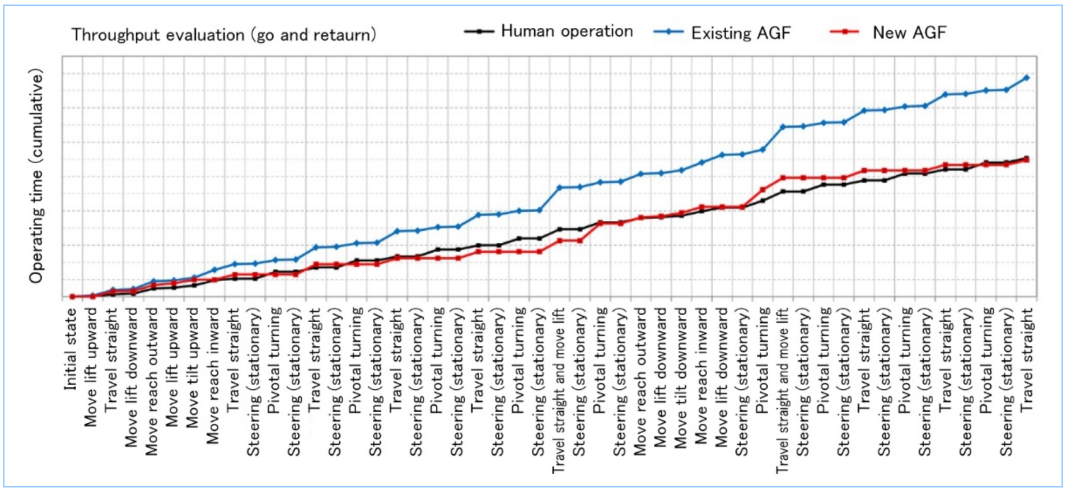

Figure 10 Throughput comparison result

5. Conclusion

In this study, we developed a new AGF that can perform cargo handling work comparable to that of a manned forklift by implementing new mechanisms (e.g., 3-wheel steering, and new mast mechanism, etc.), sensors (e.g., 2D-LiDAR, etc.), and automated traveling technology, using a manned forklift as a base. To enable operation in narrow aisles, we developed a travel control technology that simultaneously corrects translational position displacement and performs turning movements using three-wheel steering.

Based on data obtained from actual operation and loading/unloading using a prototype, the throughput (number of pallets processed per unit of time), which is an indicator of warehouse loading/unloading processing speed, was estimated, and it was confirmed that the processing speed comparable to that of a manned forklift was achieved in the assumed model case. In this model case course, it was also demonstrated that the new AGF can operate in narrow aisles of 2.7 m or less (1.9 m), in which a manned forklift cannot operate, while maintaining the processing speed.

Moving forward, we plan to make the new AGF more practical by conducting repeated operation tests in operating environments closer to the application site and improving the running and steering controls in consideration of the throughput.