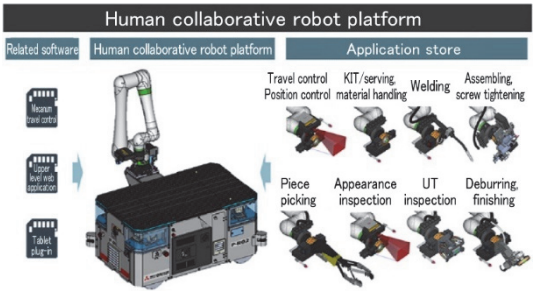
Autonomous Mobile Robot System to Meet Needs for Human Resource Minimization and Factory Automation “Collaborative Robot Platform”



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As the working population declines due to the aging of society and the declining birthrate and a trend toward reducing labor costs in response to intensifying global competition, the need for human resource minimization and factory automation in manufacturing sites is growing. On the other hand, in high-mix low-volume production sites, where it is difficult to introduce large-scale manufacturing automation systems, the introduction of human collaborative robots that can work together with workers can be expected to improve production efficiency. Research & Innovation Center of Mitsubishi Heavy Industries, Ltd. has developed an autonomous mobile human collaborative robot platform. This system is characterized by the robot's self-traveling to the work site and its ability to handle a variety of tasks by attaching and detaching the necessary tip tools for each task, and is being introduced to various manufacturing sites in Mitsubishi Heavy Industries, Ltd. Group. This paper reports on the outline and features of this system.

1. Features of collaborative robot platform

The developed autonomous mobile human collaborative robot platform, FCR-PF (Flexible Collaborative Robot-PlatForm) is a robot system consisting of an automated guided vehicle (AGV) and a FANUC CRX collaborative robot thereon (**Figure 1**). The hand/tool at the tip of the robot can be automatically attached and detached. After arriving at the worksite, the appropriate hand is attached to the robot so it can carry out the work. The robot can travel without any problem over uneven parts of the factory floor, and has a system that automatically performs relative position calibration between the robot and the workpiece after stopping. The relative position calibration is performed without the need for target markers, etc., and is calculated by directly acquiring the shape data of the workpiece with a 3D sensor. This calibration function allows the robot to always work correctly even when the robot position is misaligned due to uneven floor surfaces or when the workpiece is positioned in an out-of-place location.

Figure 1 FCR-PF external view

1.1 AGV traveling function

The AGV can move forward/backward and leftward/rightward, and turn in place, enabling accurate traveling even in narrow factory spaces. The AGV's traveling speed ranges from 0 to 250 mm/sec. The AGV's traveling control is characteristically performed by the robot controller, rather than by the AGV itself, which contributes to lower overall system cost and improved operability. The position and posture control of the AGV when traveling is performed by utilizing the vision sensor installed on the robot. This enables, for example, understanding its own position by reading QR codes, fine-tuning of the stopping position, and guided traveling using lines on the factory floor (**Figure 2**).

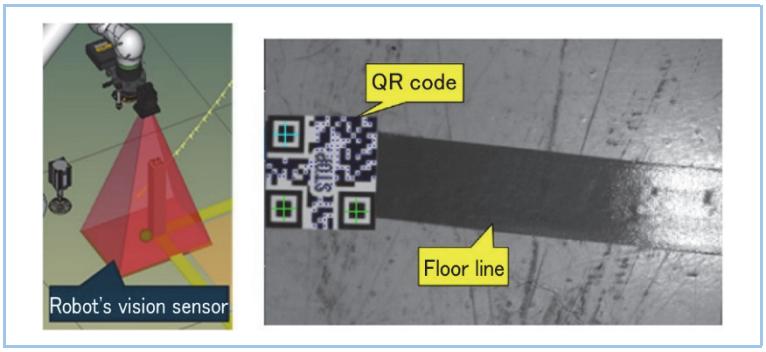

Figure 2 AGV travel utilizing robot's sensor

1.2 Automatic hand changing function

The robot hand can be automatically detached and attached. The robot is equipped with an automatic tool changer on its wrist (**Figure 3**). By attaching an automatic tool changer to the hand as well, automatic hand change by using a robot program is made possible (**Figure 4**).

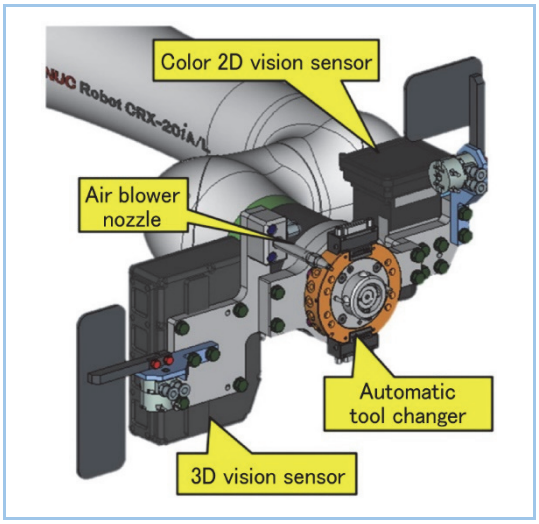

Figure 3 Automatic hand detaching and attaching mechanism

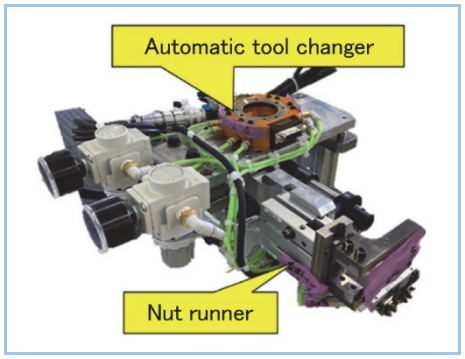

Figure 4 Example of robot hand

1.3 Power and air supply functions

While the AGV is traveling, the system is powered by the built-in battery, and the continuous operation time without a power supply is about 4 hours. In addition, air is supplied by the built-in compressor. However, to enable the system to use tools that require a large amount of air, a power and air supply plug in the form of a robot hand that allows for automatic supply of power and air after arrival at the home position or work area was developed. This power and air supply plug can be automatically attached and detached by the robot.

1.4 Safety devices and safety category

The system was developed so that it has the specifications complying with Category 3 defined in ISO 13849-1.

- System architecture

A safety PLC is installed in the AGV as an architecture specified in ISO 10218-2.

- Sensor for automatic switching between collaborative and high speed mode

  The robot is equipped with a sensor that detects workers within its operating range and automatically switches between collaborative and high speed mode (**Figure 5**). This enables the robot to automatically change its operating speed to achieve both safety and productivity.

- Area sensor for AGV traveling

  The system is equipped with a sensor that detects obstacles and persons while the AGV is traveling (**Figure 6**). Areas are set up around the AGV, and if an obstacle or person enters the yellow area, the system decelerates its operation, and if an obstacle or person enters the red area, the system stops.

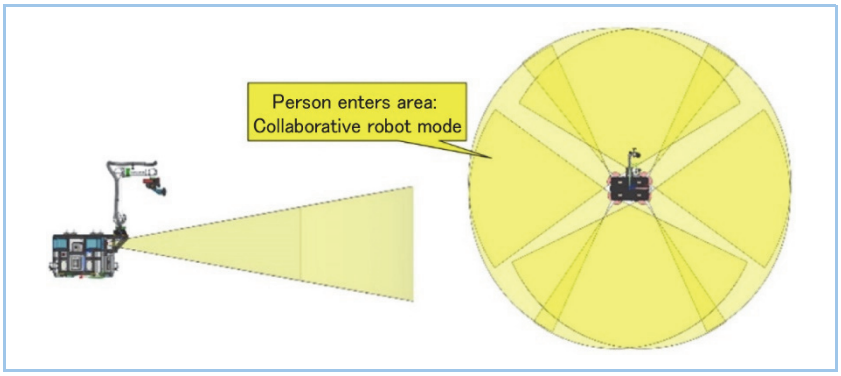

Figure 5 Sensor for mode switching

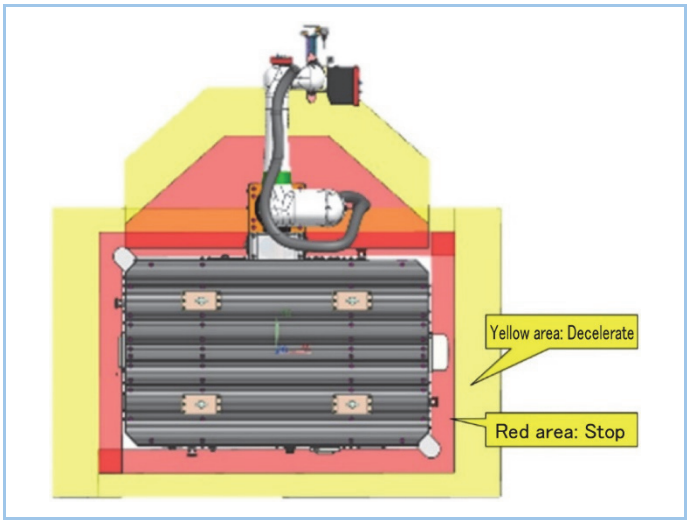

Figure 6 Area sensor for AGV traveling

1.5 Other functions

- Wireless communication function

  The AGV is equipped with a wireless communication device (industrial WiFi). Communication between robots, with upper system control panels, and with web applications is performed via WiFi.

- Battery temperature monitoring function

  The AGV contains various devices, and the temperature around the battery rises due to their heat release. Monitoring the temperature while the battery is charging minimizes the risk of abnormal charging or ignition.

- Waterproof function

  For waterproof and dustproof functions, the robot and vision sensor are IP67 rated, the robot controller is IP54 rated, and the AGV body is IP24 rated.

2. Application store

The hand (tool) and robot controls that have already been applied onsite have been compiled into a library in the application store to promote their application at other manufacturing sites, thereby establishing a system that enables downloading of (1) hand 3D CAD data and (2) robot control programs, etc., from the web page. (*Currently, the system is under construction and is being tested within Mitsubishi Heavy Industries, Ltd. (hereinafter referred to as MHI) Group.)

Table 1 Currently available applications

Application name	Operation
Relative position calibration after AGV stop	Automatic correction of relative position between robot and workpiece
Fillet welding	Automatic fillet welding without teaching
Appearance inspection (inspection for wrong or missing parts)	Automatic inspection for wrong or missing parts
Deburring ver. 1	Automatic deburring without teaching
Deburring ver. 2	Deburring with self-judgment using AI
Material handling	Automatic transfer of workpieces and tools

3. Various software to facilitate onsite operation

Related types of software that simplifies the operation of the robot system and facilitates onsite operation are also developed in-house. Software that can be easily operated by operators onsite is available.

3.1 Plug-in software for collaborative robot tablet TP (Teaching Pendant)

This plug-in software was developed to operate the traveling program and the original functions of this system on the collaborative robot tablet TP. By installing this plug-in on the robot, icons to operate this system, such as the Mecanum travel icon and the QR code shift icon are displayed on the tablet TP (**Figure 7**). By dragging and dropping these icons on the sequence panel, the user can visually create a traveling sequence. As mentioned above, since the AGV traveling program runs on the robot controller, users who are not familiar with the robot controller have a high hurdle to overcome in introducing this system. However, making it possible to perform teaching using the tablet TP enables even operators who have never handled robots before to easily create traveling programs. Along with the future expansion of the robot functions, it is planned to increase the number of icons supported by the tablet TP.

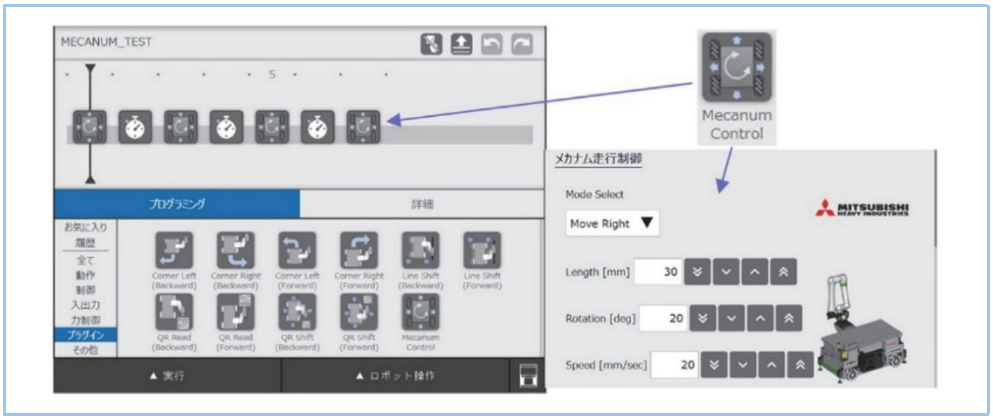

Figure 7 Plug-in software for collaborative robot tablet TP and realization of Mecanum travel program icon

3.2 FCR-PF operation management web application

A web application to visualize the robot operation status and work progress was also developed (**Figure 8**). Even in cases where it is undesirable to place onsite a permanently installed (fixed) system control panel for the autonomous mobile collaborative robot system, it is possible to monitor operation status and work progress visually via a web browser by installing a server for this Web application on the same network as the robot to transmit AGV status information, robot controller status, and images acquired by visual inspection applications, etc. It is also possible to start a

program, etc., enabling operation management that is different from conventional robot systems. The web application component design is based on open source JavaScript, and the GUI (graphical user interface) components can be reassembled according to the application to improve reusability. As the number of applicable applications increases in the future, the GUI components developed will be expanded, and therefore the reuse of GUI components is expected to reduce the development cost of web applications.

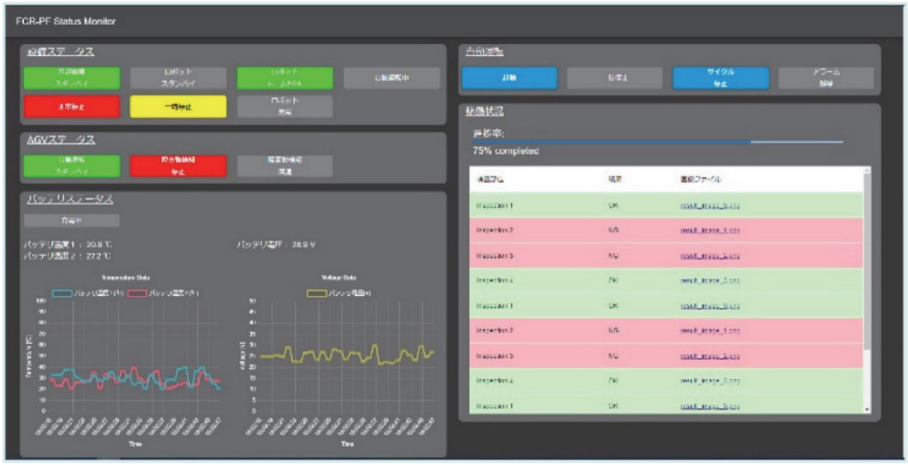

Figure 8 FCR-PF operation management web application (this screen is for reference only)

3.3 Mecanum travel software

The AGV traveling mechanism uses Mecanum wheels, which characteristically enable travel control such as forward-backward and left-right traveling and in-place turning. Control commands to each wheel for traveling forward, backward, leftward, and rightward are generated by a separate device from the robot controller based on the travel direction and amount commands from the robot controller. Since the Mecanum controller is implemented on a terminal running a real-time OS, vehicle deceleration and stop controls can be carried out immediately when, for example, Light Detection And Ranging (LiDAR) mounted around the vehicle detects an obstacle. It is also possible to perform an automatic restart after the obstacle is removed.

4. Scalability to create high added value

The FCR-PF has a scalability to easily link with other automation devices, and there are already case examples of linkage with other robot systems (**Figure 9**). It is also possible to link with other logistics equipment currently under development by MHI Group, making this platform compatible with a variety of automation solutions (**Figure 10**).

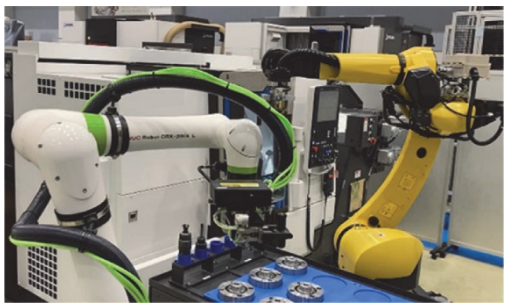

Figure 9 Case example of linkage with other robot system

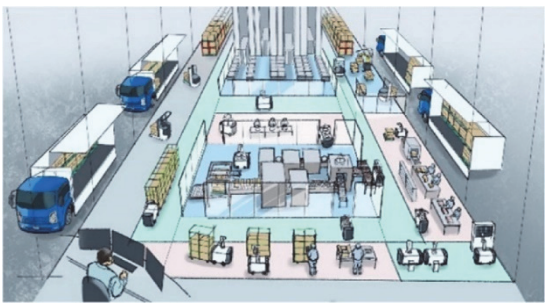

Figure 10 Schematic illustration of linkage with logistics equipment

5. Future prospect

As described above, the FCR-PF has a number of features not found in conventional human collaborative robot systems and meets the need for human resource minimization and factory automation in manufacturing sites of MHI Group. In the future, by further expanding the application of the FCR-PF, we will contribute to solving various problems that manufacturing sites face.