Industrial Robot FR Series "MELFA Smart Plus"

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Diversifying customer needs and globalization have brought the manufacturing industry to a period of major reform. Industrial robots must deliver higher performance and flexibility in order to perform more complex operations in addition to conventional simple tasks.

In response to this market environment, Mitsubishi Electric has added the MELFA Smart Plus option to the industrial robot MELFA FR series lineup.

The MELFA Smart Plus option provides functions to facilitate the introduction and support the automation of high-level operations.

The main functions of MELFA Smart Plus are described below.

(1) Robot mechanism temperature compensation function

This function corrects positional errors caused by thermal expansion in the robot arm to stabilize precision operations.

(2) Calibration assistance function

This function automates the calibration between the robot and the vision sensor, between the robot and the workpiece, and between robots.

(3) Coordinated control for additional axes

This function improves productivity and increases the types of processible workpieces through coordinated control of additional axes and robots.

1. Introduction

Industrial robots are increasingly being used at manufacturing sites for next-generation production systems to keep up with the global competition. The background to this environment includes the following four factors: (1) Promotion of automation to secure stable factory workforce; (2) transition to cell production systems suitable for multi-type variable-quantity production due to diversifying customer preferences; (3) demand for designable production systems that can be implemented quickly and at a low cost; and (4) need for automation of high-level operations such as precision assembly, transfer of soft goods, and high-speed handling.

To meet such needs, Mitsubishi Electric has developed the industrial robot MELFA FR series with improved intelligent functions.[1] [2] This series now offers the new MELFA Smart Plus option that makes it possible to automate high-level operations, in addition to intelligent technologies that use conventional force sensors and 3D vision sensors. The new functions have enhanced the ability to solve various issues that hinder automation.

This paper describes the main functions of MELFA Smart Plus and examples of application.

2. MELFA Smart Plus Functions

The MELFA Smart Plus option provides advanced functions for all operating phases, from design and startup to operation and maintenance. Examples of such functions are linkage with various types of sensors and autonomous adjustment of startup. The various functions of MELFA Smart Plus are enabled by inserting the MELFA Smart Plus card into the robot controller CR800, as shown in Fig. 1.

The following section describes the robot mechanism temperature compensation function, calibration assistance function, and function for coordinated control for additional axes among the functions of MELFA Smart Plus.

2. 1 Robot mechanism temperature compensation function

The robot mechanism temperature compensation function estimates the temperature of the robot arm in real time and automatically corrects positional errors due to thermal expansion in the arm.

When robots are performing high-level operations such as precision assembly and processing, positional errors due to thermal expansion of the arm may hinder stable operation. Previously, to reduce the influence of thermal expansion, pre-production warmup was recommended. However, the MELFA Smart Plus temperature compensation function can reduce positional errors due to thermal expansion to

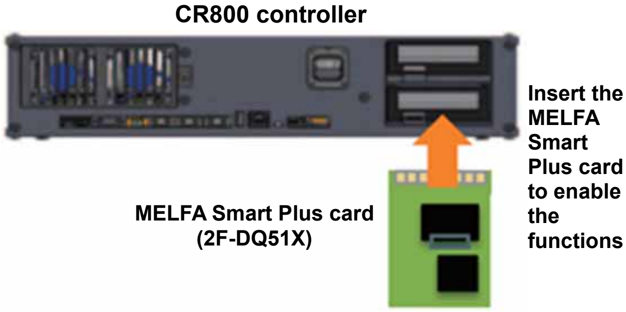

Fig. 1 Enabling the MELFA Smart Plus functions

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approximately one-fifth compared to the previous level (Fig. 2). Therefore, this function enables precision operations without the need for warmup or correction of taught positions.

The displacement of an arm due to thermal expansion is approximated by a polynomial expression using data from the temperature sensor installed at the motor (encoder) on each axis. The magnitude of displacement of the arm end position is calculated using this expression whenever necessary and a compensation command that offsets such influence is added to the position command for the motor of each axis.

This method can automatically eliminate the influence of thermal expansion of the arm without the need to revise the positioning data.

2. 2 Calibration assistance function

The calibration assistance function consists of automatic calibration, workpiece coordinate calibration, and inter-robot relational calibration.

2. 2. 1 Automatic calibration

The automatic calibration handles troublesome and time-consuming calibration (positioning) of the coordinates of the vision sensor image and the robot (Fig. 3).

Previously, such calibration operations were manually performed, which required time to start and reposition the systems. In addition, it was difficult to maintain the accuracy of calibration due to the variation of operations.

With the automatic calibration function, users only need to enter the items specified on the calibration screen of the engineering tool RT ToolBox3 (Fig. 4). In addition, calibration operations can be saved as a robot program for repeated use with the same degree of accuracy.

When multiple systems with the same model are started up and recalibration is required due to a problem, reusing programs makes it easy to perform calibration with high reproducibility.

2. 2. 2 Workpiece coordinate calibration function

The workpiece coordinate calibration function adjusts the position of the robot according to the location of the target workpiece (aligns the robot coordinates and workpiece coordinates) based on the information from the 2D vision sensor installed at the end of the robot hand. Installing this function can establish a system that autonomously corrects positional errors between the robot and the target workpiece.

To perform workpiece coordinate calibration, a calibration sheet as shown in Fig. 5 is installed in the operation area. The positional relationship between the reference marks on the calibration sheet and the origin of the workpiece coordinate system is known. Once a special program is executed, three-dimensional inclination of the calibration sheet and the position of the origin of the workpiece coordinate system are automatically measured based on multi-viewpoint imaging data and robot position

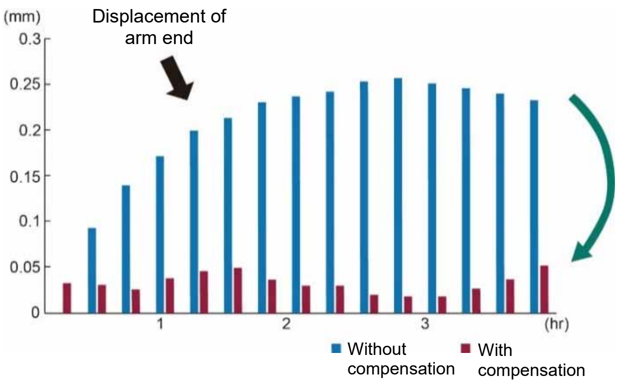

Fig. 2 Displacement of arm end locations by operation time

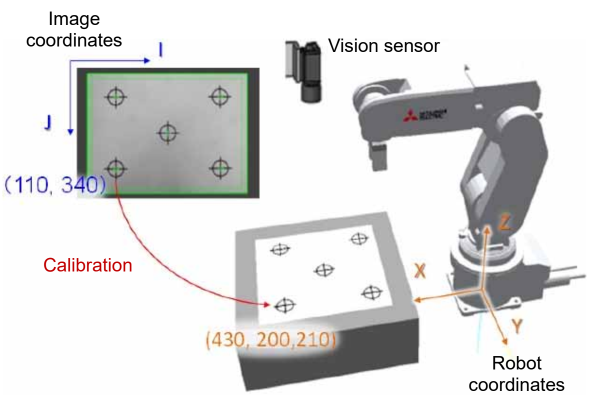

Fig. 3 Calibration of vision sensor and robot

Fig. 4 Screen for automatic calibration

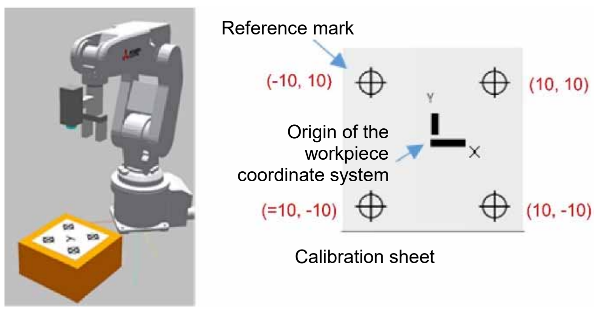

Fig. 5 Workpiece coordinate calibration

data and the workpiece coordinates viewed from the robot coordinates are calculated.

2. 2. 3 Inter-robot relational calibration function

The inter-robot relational calibration function corrects installation errors between robots in a system where multiple robots work in cooperation with each other.

As shown in Fig. 6, the calibration of robot 1 and the workpiece coordinates and the calibration of robot 2 and the workpiece coordinates are performed to calculate the relative positional relationship between the two robots.

2. 3 Function for coordinated control for additional axes

The function for coordinated control for additional axes allows synchronous operation of the robot and direct-acting axis. Included are a control function for base coordinate systems and an additional axis tracking function.

2. 3. 1 Base coordinate cooperative control function

This function expands the motion range where continuous processing is possible by using travel axes (direct-acting axes).

For operations that previously required a large-scale robot due to the limited motion range of a small robot, installing this function enables such operations by a small robot by combining it with a travel axis, thus reducing the work space and system cost.

As shown in Fig. 7, when a robot processes the circumference of a large workpiece, continuous operation is made possible by changing the base coordinates of the robot (position of the robot coordinates viewed from the world coordinates) while the coordinates are linked with the behavior of the direct-acting axis in real time.

2. 3. 2 Additional axis tracking function

The additional axis tracking function enables assembly, processing, and other operations using an additional axis while following a moving workpiece.

As shown in Fig. 8, the robot keeps up with the moving workpiece by using the additional axis (direct-acting axis) and is able to perform an operation on the moving workpiece similar to that with a static workpiece, thanks to the real-time control that ensures a relative speed of zero between the workpiece and the robot tool end.

Previously, a workpiece needed to be stopped before assembly, processing, and other operations. However, the additional axis tracking function eliminates this requirement and enables simultaneous processing and transfer operations, thus significantly reducing the takt time.

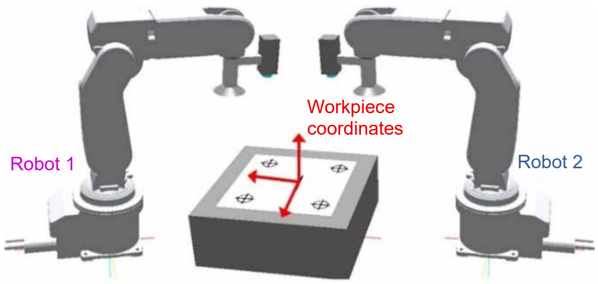

Fig. 6 Inter-robot relational calibration

3. Applications

Example applications using the MELFA Smart Plus functions are described below.

3. 1 Application to copying cells*1

When copying a cell identical to the master cell for which the startup adjustment has been completed as shown in Fig. 9, calibration and teaching operations were

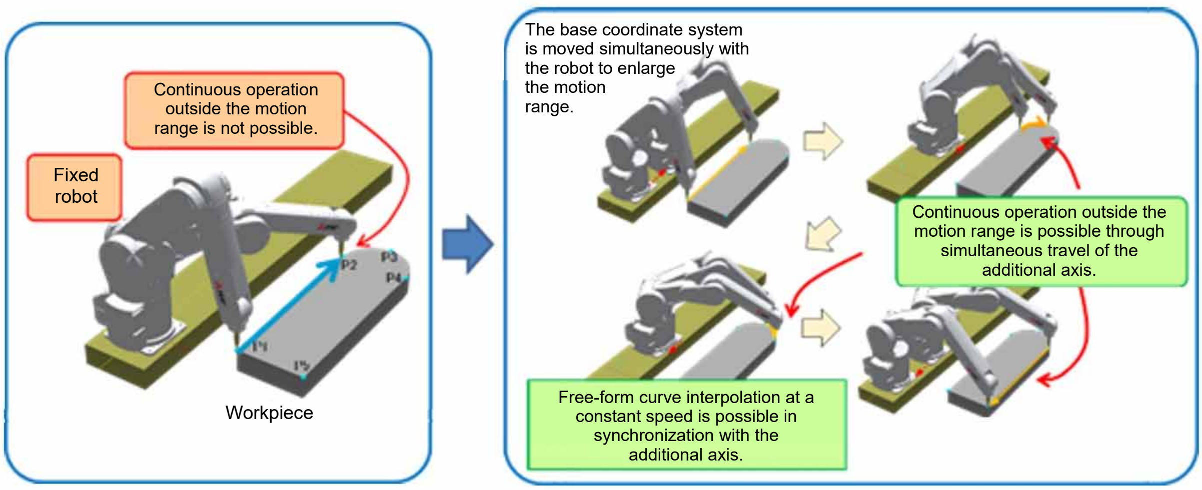

Fig. 7 Base coordinate cooperative control

1 Refers to copying a cell in the same manufacturing process in cell production.

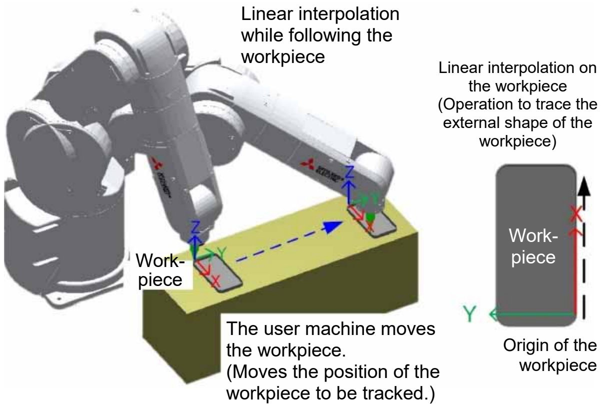

Fig. 8 Additional axis tracking

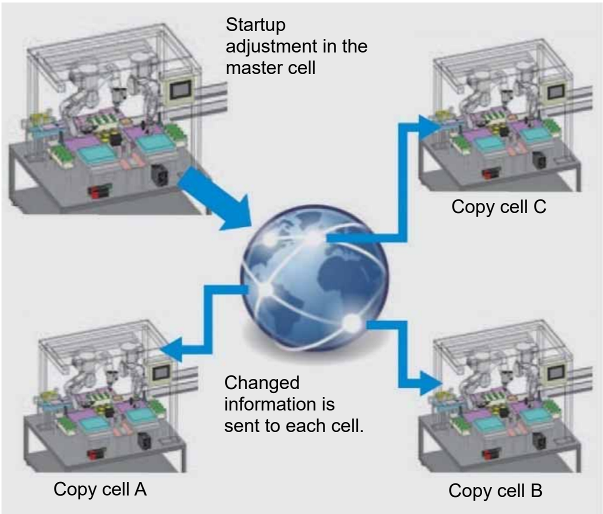

Fig. 9 Application example of copying cells

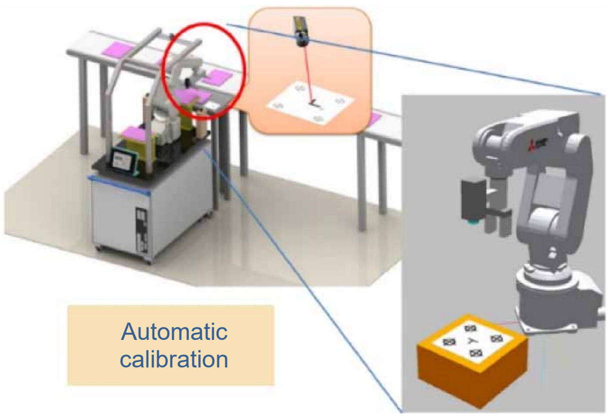

Fig. 10 Application example for a robot on a mobile cart

previously required for each cell. The robot mechanism temperature compensation and automatic calibration functions provided by MELFA Smart Plus can automatically correct machine differences between cells. With these functions, changes to information of the master cell can be similarly applied to separate cells, enabling linked operation between the master cell and other cells.

3. 2 Application to mobile robots

For systems in which robots are installed on automated guided vehicles (AGVs) and mobile carts to transfer them between machines, the operation accuracy deteriorates due to errors in the stopped positions of the AGVs or carts at the destination. The calibration assistance function of MELFA Smart Plus effectively solves this problem.

The workpiece coordinate calibration function can automatically correct the three-dimensional displacement between a robot and the surrounding equipment, making it possible to operate the robot without changing the robot program and taught position for each AGV (Fig. 10).

4. Conclusion

This paper described the main functions and example applications of the new MELFA Smart Plus option for the MELFA FR series. These functions include automatic correction of positional errors due to thermal expansion, automatic calibration, and automatic coordinated control of additional axes.

We plan to incorporate sensing and AI technologies in MELFA Smart Plus in the future to provide functions that overcome problems with automation in all phases from design and startup to operation and maintenance.

5. References

(1) Miyamoto M.: Industrial Robots “MELFA FR Series”, Mitsubishi Denki Giho, 90, No. 4, 243–246 (2016)

(2) Miyamoto M.: Industrial Robots “MELFA FR Series”, Mitsubishi Denki Giho, 91, No. 4, 217–220 (2017)