Quick-adapting and Flexible Autonomous Robot System

● Yukio Ozaki ● Taizan Kobayashi ● Junji Tomita

Fujitsu is working on developing an autonomous robot system in order to realize Monozukuri (Japanese way of manufacturing) that can adapt itself quickly and flexibly to changes in manufacturing products and in production requirements, such as variation of parts and aged deterioration of equipment. The deployment of robots on production lines requires programming by expert engineers, and the robots need to be taught the supply position and assembly position of parts beforehand. However, such a development process necessitates a significant amount of work. Meanwhile in mass production, certain changes in the production environment, such as variation of parts, often cause robots to stop. Therefore, we have developed technology that is capable of automatically generating programs that control robot motions. The technology also makes it easier to automatically convert the programs into applicable data formats, and transmit them to the robots. We are further working to develop technologies that allow robots to "sense," "think," and "act" so that we can achieve autonomous and cooperative control. By enabling flexible response to the above mentioned changes and fluctuations with these technologies, the changeovers and rearrangements of production can be minimized, thereby eliminating the barriers to robot introduction in production lines. This paper describes this autonomous robot system development, which can be applied to variable product and variable volume production for enhanced production efficiency.

1. Introduction

The Fujitsu Group manufactures and sells information and communications equipment such as servers, notebook PCs, smartphones, and wireless base station equipment, and the use of industrial robots is promoted at the manufacturing plants of Fujitsu Group companies to enhance production efficiency. However, the electronic devices used in products require cables to electrically connect the various parts and units, making assembly work too difficult for robots to accomplish.

Even though testing and application of assembly of electronic devices by robots is beginning at other companies as well, the introduction of robots for such work is slowed down by the need for specialized engineers for robot operation. Moreover, as preparations for the application of robots for new products and process changes according to production volume take time, it is currently difficult to apply robots to variable product and variable volume production that produces products in demand in a timely manner. Furthermore, the specifications of the control program languages differ for each robot manufacturer and they are not intercompatible, which is another obstacle to introduction. Common software such as RT-middleware (RTM) and Robot Operating System (ROS) has been proposed, but its use is still too limited for such software to be regarded as a de facto standard. This is due to the fact that, until now, robot manufacturers and major companies with specialist production engineers have been leading the robot industry. Thus the creation of a general-purpose system that is independent from specific robot models is eagerly awaited by users such as small- and medium-sized enterprises (SMEs) that lack robot experts. Fujitsu is working on developing an autonomous robot system in order to realize Monozukuri (Japanese way of manufacturing) that can adapt itself quickly and flexibly to changes in manufacturing products and fluctuations in production quantity or capacity, such as variation of parts and aged deterioration of equipment.

This paper describes the development by Fujitsu of an autonomous robot system designed to improve productivity through the application of robots to variable product and variable volume production.

2. Adaptation to variable product and variable volume production

Coping with the changes that arise in variable product and variable volume production requires a large number of workers and involves challenges such as downtime during regular work hours and hefty amounts of overtime (**Figure 1**). This is compounded by the fact that product life cycles are growing increasingly short, making it necessary to launch new products at shorter intervals.

Fujitsu has been promoting productivity improvement through the minimization of production fluctuations via leveling as well as through autonomous improvement activities. In addition, we are beginning to aim at absorbing fluctuations through *jidoka* (automation with a human touch). Further, we are expanding the scope of application of robots by devising work methods for different types of work.

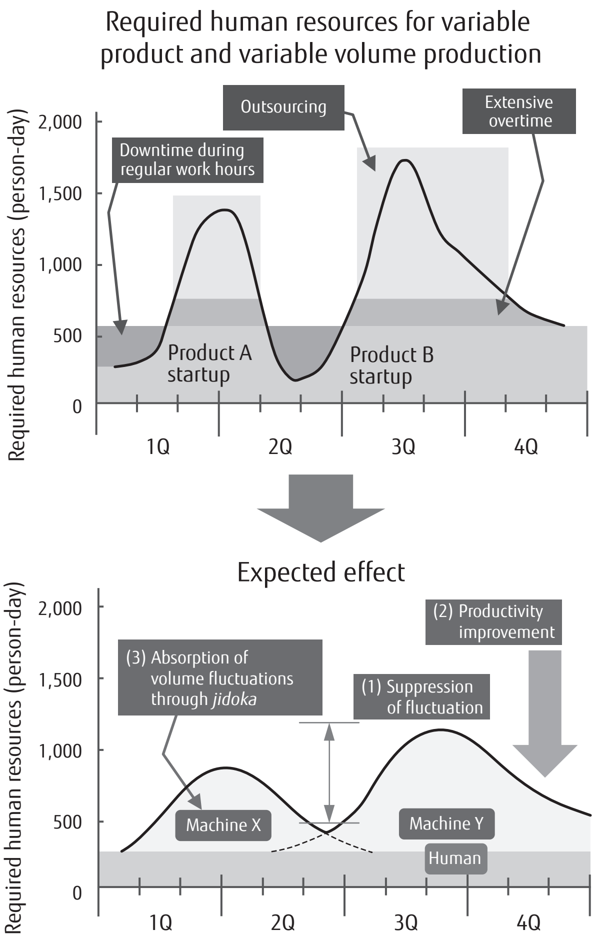

Figure 1
Current status of and approach to response to variable product and variable volume production.

Handling variable product and variable volume production through *jidoka* requires the construction of human-machine harmonization lines, and expansion of scope in which humans and machines can share work with a high degree of freedom. To this end, machines are required to have low cost versatility and high retoolability (product changeover).

3. Overview of Fujitsu's autonomous robot system

The configuration of the autonomous robot system that Fujitsu is developing is shown in **Figure 2**. The autonomous robot system is composed of an autonomous control unit that deals with variation of parts and aged deterioration of equipment and a robot controller that can operate independently of the model of the robot used. This system allows robots to act autonomously and controls peripheral equipment.

Based on the design data, the system can automatically generate the motion program of a robot after simulating the robot motions such as the motion algorithm and trajectory (automation of the motion plan) with a simple operation and confirming the validity of the simulation results. The generated motion program is automatically converted into a data format suitable for the robot to be used when the data is transferred to the robot.

Through such automatic program generation and model-independent robot control, the user does not have to be conscious of the model of the robot. This frees up the user for complex programming and debugging tasks, making it easier to apply robots to more complex tasks. Moreover, by making it easier to use robots for other processes and work, it is possible to shorten the time required for setups and to speed up the launch of production of new products.

In order to make robots able to cope with manufacturing environment changes such as variation of parts during mass production, Fujitsu is developing autonomous and cooperative control technology for robots that allows them to sense (measurement/

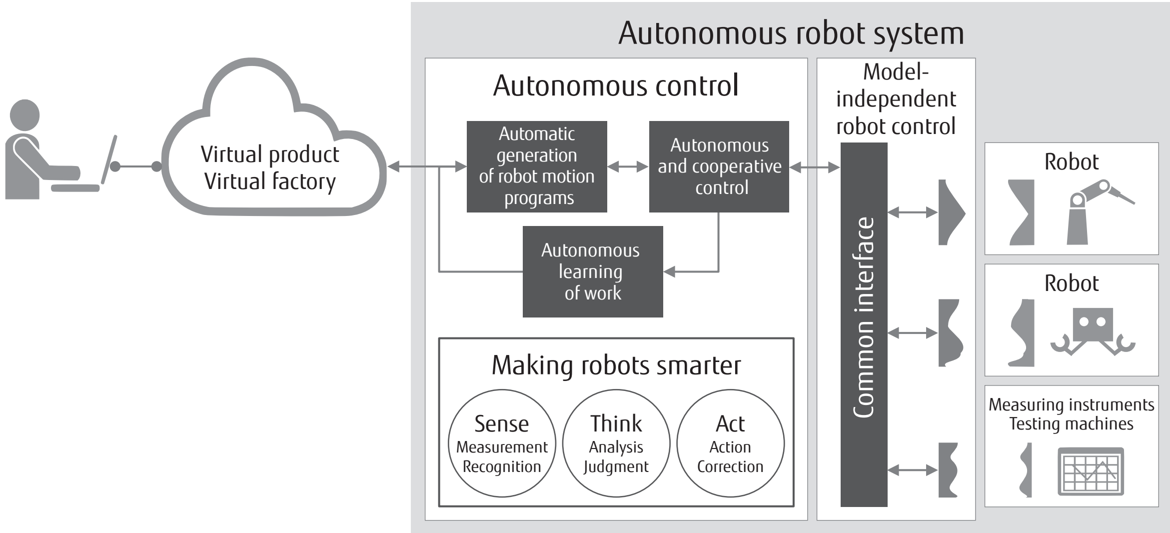

Figure 2
Configuration of autonomous robot system.

recognition), think (analysis/judgment), and act (action/correction) autonomously. The aim of this technology is to make robots able to decide whether or not to suspend or continue work when they recognize an erroneous operation, and to select the appropriate operation.

Through autonomous operation, robots automatically correct component lot variations and mechanical deterioration of the robot system. As a result, it is possible to maintain manufacturing quality, free up operators from daily tuning work, and lengthen the maintenance cycle. As described above, the autonomous robot system can realize Monozukuri that respond quickly and flexibly to changes and fluctuations. The following sections describe the various technologies employed in the system.

4. Automatic generation of robot motion program

In order to automatically generate the robot motion program, design requirements, such as 3D models of the products, and the manufacturing requirements of work plan/procedures are input to the system. At this time, it is possible to easily input data through coordination with a 3D computer-aided design (CAD) system or a manufacturing simulator. The 3D models of the robots provided by the robot manufacturers are loaded and the robot model setups, including the tool positions and the coordinate system, are carried out (**Figure 3**).

The operations settings are made by selecting the work elements required for the assembly work plan/procedures and selecting the operation mode of the robot for each work element. Making use of the already acquired 3D model data of the robot and simply choosing parts, teaching points can be set by which to easily configure the supply position and assembly position of parts.

In order to avoid singular points of the robot (postures in which control is not possible) and interference with the product being assembled or nearby equipment, it is necessary to manually create the motion trajectory with the robot simulator provided by the robot manufacturer. In this system, it is possible to automatically generate an appropriate motion trajectory by setting analysis conditions and simulating motion. Workers can confirm the validity of the motion by using animations and graphs. After verification that the desired robot motions can be performed, the motion trajectory data of the robot is output.

Fujitsu plans to increase the automatability range from 70% to 80% in order to realize human-machine harmonization lines. In the assembly of electronic devices, tasks dealing with flexible objects such as cables account for 30% or more of all the work, and such tasks are highly difficult because they require coordination

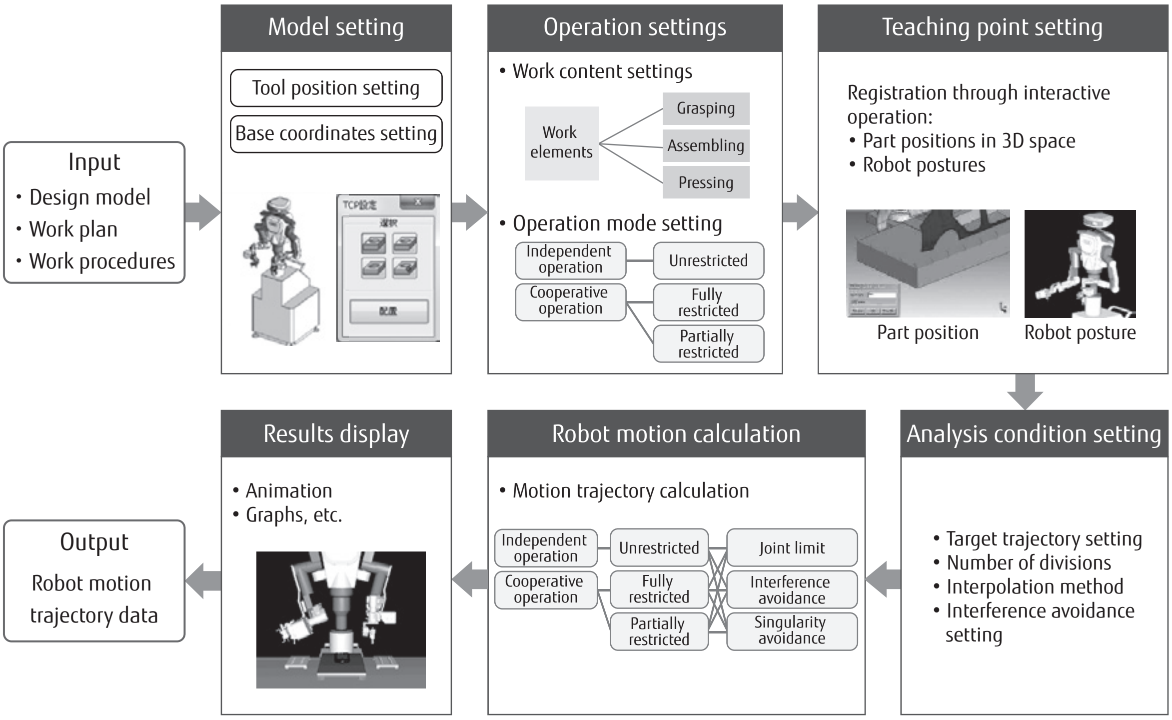

Figure 3
Flow of automatic generation of robot motion program.

of two robot arms or auxiliary operation of one robot arm. In particular, forming of cables, which are flexible objects, requires planning that takes into consideration the sagging and bending of the cable over the entire forming route, and appropriate grasping positions and postures, pressing positions and postures, and forming trajectory considering interference with surrounding objects.

In this system, automatic generation of robot motion with two coordinated arms has become available for practical use for the assembly of rigid parts, and we are now aiming for the automatic and continuous generation of motion programs for flexible object assembly work.

Currently, we are working on research and development of technology to predict the behavior of the cable in conjunction with the motion of the robot in advance, and to automatically generate the robot motion program for cable forming work, and we are aiming for practical application of this technology in fiscal 2017.

5. Model-independent robot control

Actually operation of a robot with the motion trajectory generated through simulation requires the development of a control program. However, robot control programming languages (robot languages) differ among the various robot manufacturers. Therefore, Fujitsu has developed a technology to automatically generate robot motion programs and automatically convert them to a data format suitable for the robot to be used, and transfer the data to the robot (**Figure 4**).

The robot motion trajectory data output from the simulator is generated as a standard motion program using a common language (SLIM). As information about the robot manufacturer and the language to use are already stored in the simulator, the standard motion program can be converted automatically to each manufacturer's motion program by using the translator developed through syntactic analysis of each manufacturer's language. We are promoting the development of the translator in cooperation with each robot manufacturer.

As it is no longer necessary for users to be aware of the differences among robot manufacturers and

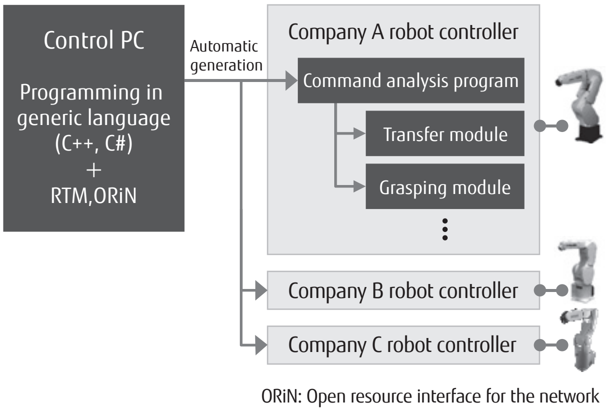

Figure 4
Automatic generation of robot programs for robots of each robot manufacturer.

robot models, they can easily select an appropriate model for the work to be done and change the robot model as needed according to the production situation.

6. Autonomous and cooperative control

When production shifts to mass production, robots frequently stop working. This is so-called short stoppage. Such stoppages are caused by changes in the manufacturing requirements such as variation of parts. This is because robots move as taught based on teaching/playback, so they cannot keep up with such change.

Until now, to avoid short stoppages, users had to estimate the cause of various error stoppages and try to improve the operational availability by taking error prevention measures separately, but it is impossible to prevent all errors with this approach. Moreover, expert production engineers having to spend a lot of time dealing with short stoppage is a disincentive factor to the introduction and application of robots.

By contrast, autonomous robot systems enable autonomous and cooperative control to flexibly respond to changes and fluctuations. Our system uses force sensors, tactile sensors, and cameras to measure and recognize the "work state" of the robot. Here, "work state" refers to the state and behavior of the parts rather than the control state of the robot itself. The features of the methods adopted in this system to recognize the work state are described below.

The data from the various sensors (force sensors, tactile sensors, etc.) are identified to be in steady state or transient state. In transient state, the robot performs some assembling operation, and the data fluctuates markedly over time. On the other hand, in steady state, the robot does not perform assembly operations. That is, the robot in steady state is either stopped or in transfer, and there is no data fluctuation like in the transient state.

In order to identify the state of robots during operation, anomaly detection is important in the transient state. For transient state, a judgment method using a support vector machine (SVM) classifier that discriminates based on the feature quantities of data waveforms has been adopted, making it possible to reliably detect anomalies even from large variance data. In steady state, a method to determine the allowable range from the variation in the data is used, and anomalies are detected as a deviation amount of the operation result, thereby realizing anomalies detection[1] suitable for each state.

Further, for the video data from the cameras, a method that uses cubic higher-order local autocorrelations (CHLAC) features was selected as it is considered to be effective for anomaly detection based on the features of motions. In this method, since the features of the obtained video data is extracted from the movement of each pixel, this method is less affected by the shapes of parts and allows detection of even slight anomalies in assembly operation.

The existence of anomalies is judged in real time through integration and analysis based on the data from the various sensors, including video data, taking into account the sensitivity of each sensor and correlations among the data from the various sensors.[2), 3)] When it is determined that the work state is anomaly, the robot operation is immediately stopped, the cause of the anomaly is analyzed, and the robot motion is autonomously changed so as to work normally.

In actual operation, the system learns during prototyping and at the start of mass production (initial learning) and evolves into a smart system just like humans become expert in their work through additional learning and relearning during mass-production.

As described above, by predicting and detecting anomalies before the robot stops due to an error, and by analyzing the anomaly condition and changing the operation accordingly, it is possible to achieve zero failures in Monozukuri. As a result, it is possible to realize Monozukuri that can quickly and flexibly adapt to changes and fluctuations in production lines.

7. Automation of process planning and work planning

As mentioned above, an autonomous robot system can reduce time for machine startup and improve work quality and production efficiency in mass production.

Further expanding our aim from individual machines to the whole production line, we began to work on optimizing process planning, work planning, and motion planning for the entire assembly process, based on consideration of the operation of robots. These initiative aims to optimize work allocation and work sequence for humans and robots based on consideration of product characteristics and manufacturing characteristics on lines where humans and robots cooperate.

Currently, the work assigned to robots is fixed, but by expanding the application scope of robots and promoting their autonomy, it will become possible to flexibly change the work given to robots. However, as the characteristics of work differ between humans and robots, new process design and line design methods are required. Fujitsu aims to establish technology to solve this problem by combining the industrial engineering (IE) technology and simulation technology that we have cultivated in the field so far.

Also, with the aim to further expand the use of robots, we are planning to develop human-robot communication technology, technology for self-development based on its own experience, and environment recognition technology that will make robots more intelligent and useful.

8. Conclusion

In this paper, we described the development of an autonomous robot system that realizes Monozukuri that can respond quickly and flexibly to changes and fluctuations in production lines. Going forward, we will establish automatic robot program generation technology, model-independent robot control technology, and autonomous and cooperative control technology, and combine them with our various existing technologies to construct a practical system. We will also continue to provide customers with technologies that have reached the practical implementation stage.

Our development project of automation technology for process planning and work planning is subsidized by the New Energy and Industrial Technology Development Organization (NEDO).

References

1) S. Amemiya et al.: Anomaly judgment method in automation of assembling process. The Japan Society for Precision Engineering, Proceedings of 2015 JSPE Spring Meeting, pp. 953–954 (2015) (in Japanese).
2) T. Fuse et al.: Development of anomaly judgement system using machine learning techniques for factory automation. The Japan Society for Precision Engineering, Workshop on dynamic image processing for real application (DIA2015) papers, OS1-1 (2015) (in Japanese).
3) T. Fuse et al.: Development of anomaly judgement system using machine learning techniques for factory automation. Japan Industrial Publishing, Image Laboratory, Vol. 26, No. 9, pp. 74–79 (2015) (in Japanese).

Yukio Ozaki
Fujitsu Ltd.
Mr. Ozaki is currently engaged in manufacturing technology planning and development and robot-related technology development.

Taizan Kobayashi
Fujitsu Ltd.
Mr. Kobayashi is currently engaged in the development of ICT technology for Monozukuri and the promotion of its application.

Junji Tomita
Fujitsu Laboratories Ltd.
Mr. Tomita is currently engaged in research on Monozukuri.