E series evolutionary robot controller

Recently, further productivity improvements, quality improvements in each specific application, and improved maintainability have been required of the industrial robots. Among such conditions, the E Controller was developed with the latest electronic and information technology so as to offer easier operation and maintenance, higher basic performance and enhanced safety features. This paper provides an overview of the E Controller.

Preface

It has now been 44 years since Kawasaki commenced production in 1969 of the first industrial robots in Japan. Industrial robots introduced a level of flexibility not seen in earlier automation equipment, reducing labor requirements in spot welding, arc welding, painting, handling, semiconductor and liquid crystal substrate transport, and other fields of application, and improving productivity at manufacturing sites in Japan and overseas. However, the role played by industrial robots at manufacturing sites has continued to increase in importance, and further improvements in productivity, quality in the respective application, and maintainability are demanded.

Meanwhile, there has been remarkable technological progress in the electronic and information sectors, and early incorporation of that progress into robot technology has been the determining factor in the evolution of industrial robots. With this background, it is essential that the latest hardware and software be incorporated into robot controllers to improve basic performance and functionality, together with timely provision of added values that respond to diverse user needs.

To meet these demands, we have developed the E series controller as a new offering in our line of robot controllers. In addition to improved operation performance, this controller delivers greater operability and maintainability as well as enhanced safety functions.

1 Development concepts

In developing the E controller, we placed particular emphasis on the following items based on demands from users regarding existing controllers.

(i) Smaller size

Make the controller more compact to reduce the footprint for a leaner production line.

(ii) Improved basic performance

Use a powerful CPU to achieve more accurate trajectory control, faster program execution, and more convenient saving and loading, etc.

(iii) Improved maintainability

To reduce the maintenance time during operation and reduce the system setup time before operation, improve the replaceability of parts that require periodic replacement, and strengthen various monitoring functions.

(iv) State-of-the-art safety functions

Make full use of functional safety technologies to realize state-of-the-art safety functions such as software control of the robot's operating space.

2 Specifications

The specifications of the E controller are shown in Table 1. The enclosure consists of five types, including the newly developed E9X compact enclosure (for an arm with a payload capacity of up to 20 kg), as well as the E2X standard specification model, E3X/4X standard specification model, E2X/3X/4X explosion-proof specification model, and E7X compact enclosure (for an arm with a payload capacity of up to 10 kg). The enclosure to be used is determined according to the application, arm size, and applicable standard (UL certification/European standards compliance). The enclosure features a smaller footprint than the existing types and components that are organized into units by function for improved maintainability and reduced wiring.

Table 1 Specifications of controller

Item		Specifications
Enclosure structure		E2X/3X/4X Std/Ext, E7X: Enclosed structure E9X: Open structure
Size		E3X/4X Std: W550×D550×H1200 E2X Std: W450×D550×H950 E2X/3X/4X Ext: W500×D550×H1400 E7X: W500×D420×H259 E9X: W500×D580×H270
No. of control axes	Standard	6 axes
	Enclosure internal extension	E2X Std, E7X: (2 axes added) E3X/4X Std, E2X/3X/4X Ext: (3 axes added)
Drive system		Full digital servo system
Operation method		Coordinate systems: Joint, base, tool Types of motion control: Joint, Linear, Circular interpolated motion
Programming		Point to point teaching or language based programming
Memory capacity		8 MB/Approx. 80,000 steps equivalent
I/O signal	External operation signal	Emergency stop, external hold signal, etc.
	Universal I/O	E2X/3X/4X Std/Ext: 32, (64, 96, 128) points E7X, E9X: 32, (64, 96) points
Auxiliary storage device		(USB memory)
Communication function	PC, network communication	Ethernet 100BASE-TX, RS-232C
	Fieldbus	(CC-Link, DeviceNet, PROFIBUS, Ethernet/IP, CANopen, etc.)
Cable length	Teaching pendant	5 m, (10 m, 15 m)
	Robot/controller	5 m, (10 m, 15 m)
Power specifications		E2X Std/Ext: AC200-220V 3 ϕ, 50/60 Hz E3X Std/Ext: AC440-480V 3 ϕ, 50/60 Hz E4X Std/Ext: AC380-415V 3 ϕ, 50/60 Hz E7X: AC200-240V 1 ϕ, 50/60 Hz E9X: AC200-230V 1 ϕ, 50/60 Hz
Environmental condition		Ambient temperature: 0-45℃, for E7X standing installation only, 0-40℃ Relative humidity: 35-85%, no condensation

Figures in parentheses show options.
Std: standard specifications
Ext: explosion-proof specifications

In particular, the E2X standard and explosion-proof specification enclosure enables the replacement of all components including the fan from the front, eliminating the need for maintenance space in the back and side areas. Also, the E7X and E9X use a compact enclosure and single-phase 200V power source, enabling installation in any environment.

The interior of the controller is divided largely into a card rack unit, a servo amplifier unit, and an MC unit (Fig. 1). The features of each unit are described below.

(1) Card rack unit

The card rack unit consists of ① a DC power source for supplying control power, ② a main CPU board for managing the execution of the operating system and user programs and generating position commands, ③ a power sequence board for monitoring and controlling safety circuit conditions, and ④ an I/O fieldbus board for sending and receiving signals with external equipment. In addition, use of a PC-based architecture forms a configuration for flexible functionality expansion.

(2) Servo amplifier unit

The servo amplifier unit consists of ① an amplifier for controlling the motor current driving the robot, and ② a servo CPU board for performing the servo control to track the encoder values with the position commands sent from the main CPU board. In the amplifier, we used the latest power device (power conversion element) and a current sensor for detecting the motor current, to achieve downsizing and improved reliability.

(3) Magnetic contactor (MC) unit

The MC unit consists of ① a magnetic contactor for shutting off power supplied to the robot during an emergency stop, etc., ② a converter for converting AC voltage to DC voltage, and ③ a bleed circuit for limiting the rise in voltage during power regeneration. We placed the converter and bleed circuit on a printed circuit board, for downsizing and reduced wiring.

3 Performance improvement

(1) Faster robot operation—improved vibration control

In the E controller, we enhanced the robot model for vibration control computed internally by the software, making it closer to the operating conditions of the actual robot and improving vibration control performance. This enabled minimizing delays in robot operations and increasing operating speed. As a result, we reduced the average cycle time for a typical operation by about 10% compared with existing models.

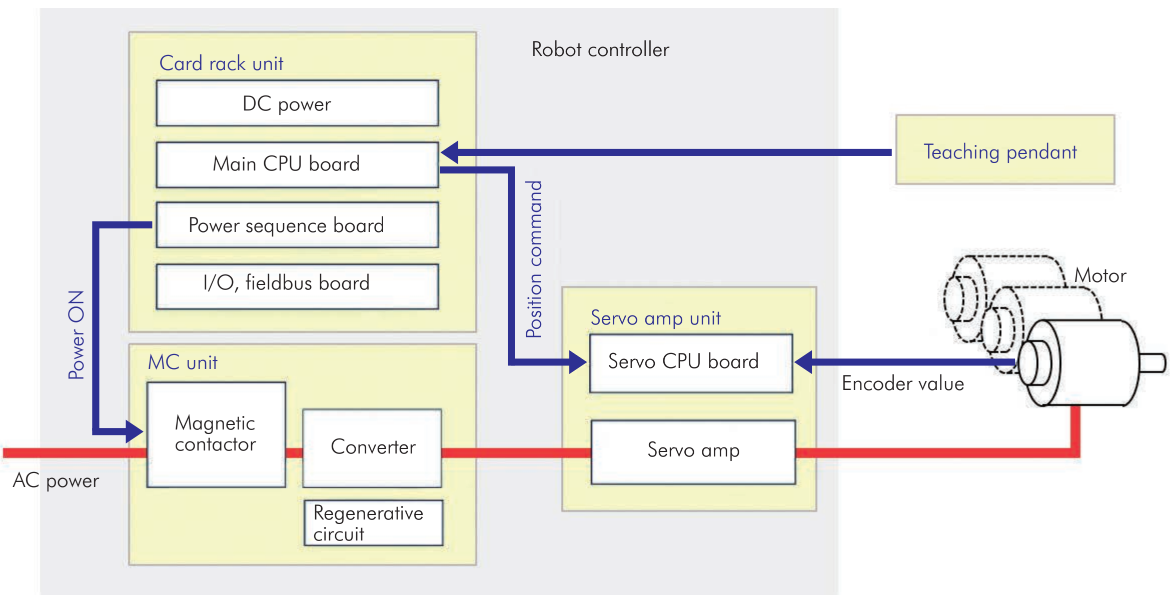

Fig. 1 Configuration diagram of controller

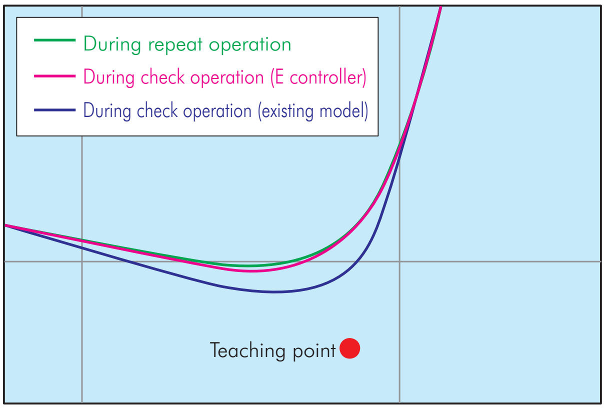

Fig. 2 Examples of trajectory error reduction

(2) Reduced check/repeat trajectory errors

In the past, there were large trajectory errors between check operations and repeat operations, and in some cases teaching correction was performed while monitoring the trajectory in repeat operations. In the E controller, this was improved by separating the trajectory errors into command values, delay elements, and dynamics. As a result, we were able to reduce the average trajectory errors for a typical operation to about 1/7 of existing models. Since only check operations are required to check the interference between the robot and tool in spot applications and the sealing position in sealing applications, the teaching time can be greatly reduced. Examples of robot trajectories before and after the improvements are shown in Fig. 2.

(3) Faster software processing speed

We used the latest high-performance CPU and also modified the software process to achieve a processing speed for KLogic (programmable logic controller [PLC] composed of software only) and the PC program (numerical operation program executed separately from robot operation) double that of existing models, and a signal input-output response speed four times faster than existing models.

4 Features

(1) Easier to use—user I/F, operability

The E controller comes equipped with two USB interfaces for users. This enables the teaching programs and the various setting parameters to be saved and loaded to USB memory in a short time at high speed. In addition, the teaching pendant screens can be saved (captured) to USB memory with a simple operation, greatly facilitating setting value checks or on-site creation of operation guides, etc. Users can also connect a USB keyboard for input via the keyboard, facilitating programming changes on-site.

We have also improved operability of the teaching pendant by moving the switches and lamps (motor power-on switch, error lamp, etc.) from the front of the controller to the top of the teaching pendant, eliminating the need to return to the controller to switch on the motor power, etc., during teaching operations. In addition, for the screen display we have enlarged the status display and other often-used monitor displays to make them easier to read, and made modifications to enable simultaneous checking of two items such as position information and signal information, to improve operability.

(2) Easier maintenance—maintainability

We added a self-diagnostic function that would be useful while the system is up or for daily maintenance. The display of safety circuit conditions, fan speed, and CPU temperature, etc. is useful for pinpointing breakdown locations. Examples of the safety circuit monitor are shown in Fig. 3. This improvement makes it easier to confirm the problem location when the motor power source fails to switch on.

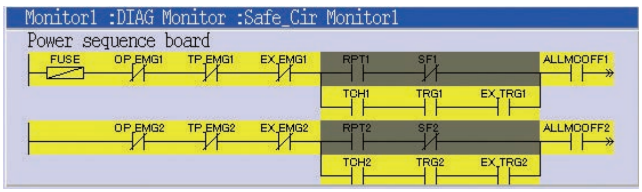

Fig. 3 Examples of safety circuit monitor

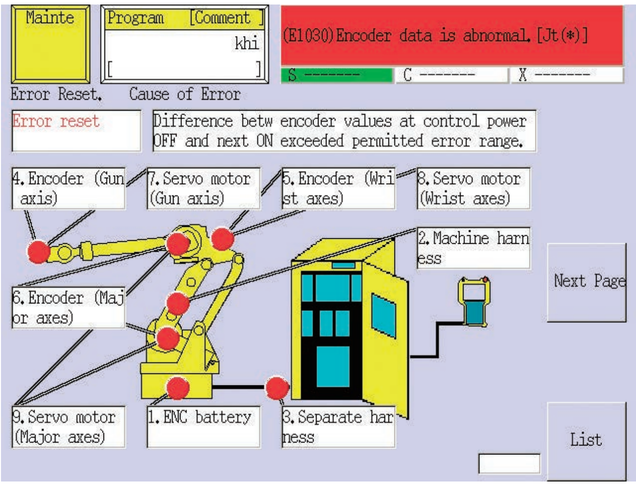

Fig. 4 Display example of maintenance support function

In addition, we have added a maintenance support function that displays on the teaching pendant information useful for resolving errors. A display example of the maintenance support function is shown in Fig. 4. When an error occurs, possible causes are displayed, together with their respective probabilities, investigation methods, procedures, time required, and necessary tools, etc., to help shorten the system recovery time.

(3) Easy information handling—network functionality

The E controller is equipped with two Ethernet connectors. Data that can be used to trace products inside the controller, robot error information useful for maintenance planning, etc. can be retrieved via the network. This can be done using such methods as a library function compiling functions for accessing the controller from the computer to retrieve information, and a web server function for displaying information in the controller on the browser software of a remote computer, etc.

Furthermore, Ethernet connection between controllers can enable connection to our vision device K-HIPE-R-PC, collaborative operation between multiple robots for handling heavy objects that cannot be handled by a single robot, and other high-performance system configurations.

We also support numerous fieldbuses that help to reduce wiring costs and increase system expandability (Table 1).

5 Expansion of safety functions

(1) Advanced safety functions

As an option for further expansion of safety functions, the E controller can be fitted with the robot motion monitoring safety function Cubic-S. Cubic-S takes its name from the three S's of "Supervise/Safety/Smart." It uses software to provide advanced safety functions that could not previously be achieved, enabling flexible, low-cost construction of production lines. Cubic-S offers eight safety functions: motion area monitoring, joint monitoring, speed monitoring, stop monitoring, tool orientation monitoring, protective stop, emergency stop, and safety state output.

These safety functions are given redundancy through the use of two CPUs, achieving the functional safety standard IEC61508 "SIL2" and ISO13849-1 "PLd/Category 3" safety performance, and obtaining certification from third-party certification authorities TÜV SÜD and UL.

(2) Application example

(i) Motion area monitoring function

In the past, a safety fence needed to be installed around the outside of the mechanically limited robot motion range. As shown in Fig. 5, application of Cubic-S enables installation of the safety fence around a smaller area, thus reducing the robot installation space.

(ii) Function for selecting motion range to limit space

An example of selectable limitation on operating range is

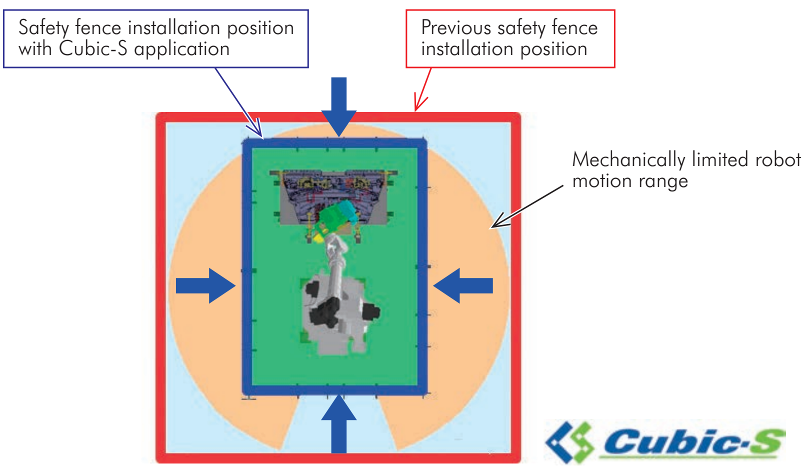

Fig. 5 Operating range limited by Cubic-S

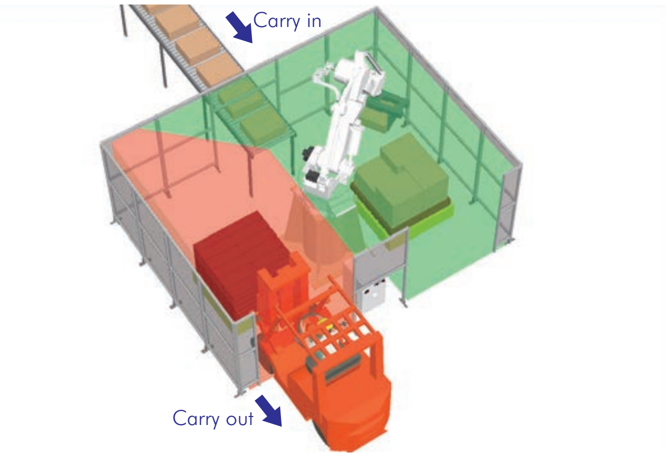

Fig. 6 Selectable limitation on operating range

shown in Fig. 6. In this example, two robot operating areas exist, with the robot piling up on one side of the operating area workpieces brought in on a conveyor, while a completed pile of workpieces is carried out by forklift in the other operating area. In this case, the robot's motion range needs to be limited when the forklift is carrying out the workpieces so that the robot does not intrude into the forklift area. Previously, multiple light curtains for detecting forklift and robot intrusion and a safety PLC for their control were required. With the application of Cubic-S, however, the motion range of the robot can be limited by detecting forklift intrusion, eliminating the need for light curtains and the safety PLC to limit the robot's motion range.

Closing remarks

The E controller is already adopted by many users and contributes to their daily production. We intend to strive for further functional expansion and performance improvement, in order to address user needs on a finer level and to expand the application range of robots.

Hiroaki Kitatsuji
Technology Planning Department,
Robot Division,
Precision Machinery Company

Koji Muneto
Research and Development Department,
Robot Division,
Precision Machinery Company

Hirofumi Yamamori
Research and Development Department,
Robot Division,
Precision Machinery Company

Tsuyoshi Tagashira
Research and Development Department,
Robot Division,
Precision Machinery Company

Professional Engineer (Electrical & Electronics Engineering)
Hideki Tanaka
Research and Development Department,
Robot Division,
Precision Machinery Company

Atsushi Kameyama
Research and Development Department,
Robot Division,
Precision Machinery Company

Takashi Takatori
System Integration Technology Department,
System Technology Development Center,
Corporate Technology Division

Takahiro Ueno
Control System Department 1,
System Development Division,
Kawasaki Technology Co., Ltd.