The e-RT3 Plus Real-time-OS-based Controller with Excellent Usability

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The e-RT3 Plus released in December 2015 is the latest model of the e-RT3 series with Linux installed. By integrating customers’ applications, open architecture, and Yokogawa’s technologies, the e-RT3 comes with many useful functions for controlling devices while featuring robustness, real-time performance, and stability. In the e-RT3 Plus, usability has been improved in terms of accessibility, visibility, and applicability, in order to expand application areas from device control to factories and infrastructure, offering an environment in which anyone can develop applications on Linux. This paper describes how the e-RT3 Plus delivers excellent usability, and its scalability.

INTRODUCTION

With the intensifying global competition in the manufacturing industry, conventional programmable logic controllers (PLC) can no longer satisfy customers’ requirements. In addition to satisfying product specifications such as high functionality and performance and developing control logics, controllers must offer various functions and improve the efficiency of development, which means making the development environment convenient and assets reusable. In addition, customers’ development style is shifting from “producing” to “using and combining.” To respond to these requirements, Yokogawa released the e-RT3 Plus, the latest model of the e-RT3 series, in December 2015 (Figure 1). The e-RT3 Plus can not only create conventional control logics but also support various applications by using open source software (OSS) that streamlines system development. Moreover, the e-RT3 Plus offers various tools for assisting development and engineering. This paper introduces various features of the e-RT3 Plus.

OVERVIEW OF THE e-RT3 SERIES

The e-RT3 series released in 2004 are controllers with controlling and computing functions. This series was named differently from the FA-M3 range-free controller to emphasize that the e-RT3 goes beyond the conventional PLC. The e-RT3 series are intended not for developing control logics in a ladder language but for creating applications in C/C++ in cooperation with digital and analog input/output (DIO/AIO) accesses and peripheral I/Fs (Ethernet, serial interfaces, storages, and others), in an environment with a real-time operating system (OS) installed.

The e-RT3 is intended to be used in mission-critical areas of device control, and the product concept is expressed

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by five key terms: deterministic real-time property, data processability, network connectivity, reliability, and expandability. The main targets are semiconductor manufacturing equipment, electronic device manufacturing equipment, processing machines, and molding machines, which have a driving system. The e-RT3 delivers excellent control performance under tight time constraints, and has gained a high reputation in the market. The e-RT3 is robust, maintenance-free, stable, and long-lasting.

The e-RT3 Plus, the third generation of this series, comes with an additional product concept of “usability.” This means that the e-RT3 Plus has a wide range of functions from improving the efficiency of developing applications to maintenance after delivery, and aims to reduce the total cost of ownership (TCO) for our customers and their customers (end users). With Linux OS installed, the e-RT3 Plus supports various applications by using OSS while minimizing costs.

The e-RT3 has been used by major customers as a device controller and its application area is now expanding from controlling devices to replacing PCs for production. One of the reasons for this is that customers are not satisfied with the performance of PCs. In a general production control process, a line computer manages the production process and a controller supervises the production line. PCs are used since conventional PLCs cannot perform advanced data processing and control simultaneously. However, PCs are not ideal in FA systems in terms of stability, continuous operation, quick recovery from failures, and security. The e-RT3 overcomes these issues because it has controlling and computing functions. In particular, the e-RT3 Plus released in December 2015 has computing power comparable to that of PCs, thanks to a high-speed processor (ARM Cortex-A9 MPCore 866 MHz (Dual Core)), Gigabit Ethernet, and large memory (DDR3 SDRAM 1 GB). Moreover, since the e-RT3 Plus can use various OSS and run stably and continuously, this controller is useful in various situations. Figure 2 shows the evolution of FA systems.

FEATURES

The three features added to the e-RT3 Plus (accessible, visible, and applicable) are explained below.

Accessible (Application development by anyone)
The e-RT3 Plus ships with a Linux kernel and OSS pre-installed, enabling anyone to start development immediately (Figure 3). In addition to the Linux host environment, the e-RT3 Plus can use the Microsoft Windows environment.

Visible (Easy maintenance at any time)
By using the web maintenance tool for web browsers, users can monitor the e-RT3 Plus and set various items. There is no need to install any dedicated tool on the PC (Figure 4).

Applicable (Controller that can be used anywhere)
The e-RT3 Plus supports various applications thanks to the external I/Fs and abundant I/O modules and OSS (about 90 programs) (Figure 5).

SPECIFICATIONS

Table 1 shows the major specifications of the e-RT3 Plus.
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Table 1 Major specifications of the e-RT3 Plus

<table>
<thead>
<tr>
<th>Series</th>
<th>e-RT3 Plus</th>
<th>e-RT3 2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>F3RP71-2L/F3RP71-2R</td>
<td>F3RP61-2L/F3RP61-2R</td>
</tr>
<tr>
<td>CPU</td>
<td>ARM Cortex-A9</td>
<td>PowerPC MPC8347E</td>
</tr>
<tr>
<td>Core</td>
<td>MPCore (dual) 866 MHz</td>
<td>533 MHz</td>
</tr>
<tr>
<td>L1 cache</td>
<td>32 KB/32 KB (I/D)</td>
<td>22 KB/32 KB (I/D)</td>
</tr>
<tr>
<td>L2 cache</td>
<td>512 KB shared by both cores</td>
<td>Not applicable</td>
</tr>
<tr>
<td>OS</td>
<td>Linux 3.18.16 + patch-3.18.16-rt1</td>
<td>Linux 2.6.26.8 + patch-2.6.26.8-rt1</td>
</tr>
<tr>
<td>Memory</td>
<td>256 MB/128 MB</td>
<td>64 MB</td>
</tr>
<tr>
<td>SDRAM</td>
<td>1 GB/256 MB (DDR3 533 MHz)</td>
<td>128 MB (DDR2 266 MHz)</td>
</tr>
<tr>
<td>SRAM</td>
<td>8 MB</td>
<td>4 MB/Not applicable</td>
</tr>
<tr>
<td>I/F Ethernet</td>
<td>100BASE-T, 100BASE-TX, 10BASE-T (2 ports)</td>
<td>100BASE-TX, 10BASE-T (2 ports)</td>
</tr>
<tr>
<td>RS-232C</td>
<td>9.6 to 115.2 kbps (1 port)</td>
<td></td>
</tr>
<tr>
<td>Storage</td>
<td>SDHC card (2 slots)</td>
<td>CF card (1 slot)</td>
</tr>
<tr>
<td>PCI</td>
<td>For utility modules (32 bit)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6 Basic hardware configuration of the e-RT3 Plus

The CPU of the e-RT3 Plus has been upgraded from that of the previous e-RT3 2.0, with a higher clock speed and dual cores for more powerful processing capability (Table 1). The Linux OS processes multiple tasks efficiently by operating the two cores in parallel. The OS fixes multiple processes allocated to each core in order to avoid overload on one core. The large-capacity L2 cache improves the cache hit ratio and enables high-speed processing.

The memories are in the same configuration as in the e-RT3 2.0 but have larger capacities for the convenience of customers. The main memory, SDRAM, is upgraded from DDR2 to DDR3 to improve the processing speed.

The interface was improved substantially from that of the e-RT3 2.0. The data transfer rate of Ethernet was improved from 100 Mbps to 1 Gbps to allow for heavier traffic. The storage was switched from CF cards to SD cards for more convenience. The number of card slots was doubled; one can be used for removable data storage while the other is secured for system start-up. The RS-232C communication port and the PCI port are the same as in the previous model.

An important feature of the e-RT3 Plus is that it uses ZYNQ\(^2\), an FPGA from Xilinx, which has a built-in processor (Figure 7).

In the e-RT3 Plus, the processor communicates with the FPGA circuit via an on-chip bus (AXI), which ensures high-speed, high-reliability communication. The CPU module accesses the I/O modules through the FPGA circuit, which reduces the delay in data transfer and speeds up access to the I/O modules. Since the communication between the processor and the FPGA circuit is bi-directional, the FPGA circuit can access peripherals (via interconnect). By undertaking some processes (self-diagnosis and I/O operations), the FPGA circuit can lessen the load on the processor. Moreover, additional IP cores (hardware circuit information) can be added to the FPGA. Thus, the e-RT3 Plus is expected to become a highly expandable platform.

Figure 7 FPGA in the e-RT3 Plus

PURSUING USABILITY

Development Environment

The Linux installed in the e-RT3 Plus is Xilinx’s Zynq-7000 All Programmable SoC Linux. This solution offers not only software components for developing applications but also an environment useful for customizing Linux, such as support for the Xilinx Software Development Kit (SDK: application development tool) and Yocto Project (http://www.yoctoproject.org). This makes the development environment independent of the type of host system and removes the restriction on the development environment, which had been a problem of the previous e-RT3 2.0. In other words, users can develop applications in the Microsoft Windows host environment as well as in the Linux host environment.

User Land

In the e-RT3 Plus, user lands can be created by using the build tool (Poky) provided by Yocto Project for importing OSS into a customized Linux.
Yokogawa provides a mechanism to boot the image of a Linux web in accordance with the GNU general public license (GPL). This facilitates the interdependence of OSS easily by themselves. To offer an environment in which users can install intricately, users can customize this if they have the same type and number of OSS installed, and have no difference in the functions.

The e-RT3 Plus offers two types of user land. Both have the same type and number of OSS installed, and have no difference in the functions.

- User land
  User land is a group of files composed of OSS and provides user interfaces and basic functions. Applications are arranged on a user land.

  The e-RT3 Plus offers two types of user land. Both have the same type and number of OSS installed, and have no difference in the functions.

- Pre-installed user land
  This user land is pre-installed in the factory and is suitable for customers who want to focus on developing applications. This user land uses the initial RAM disk (initrd) technology, and returns to the initial state every time the e-RT3 Plus is started. This technology makes Linux resistant to unexpected power failure when using a PLC.

- Custom user land
  This user land is suited for customers who want to develop their own user lands.

  These two user lands have a common operating environment. Therefore, customers are not aware of the difference between them when developing applications.

  The e-RT3 Plus also offers functions to install applications in other equipment and facilities in times of mass-produced. With this function, users can download data to SD memory cards and upload them to other equipment and facilities with switching operations, requiring no knowledge of Linux.

**Customizing Linux**

Since the custom user land is provided as an archived file (assembly of files), users can customize this if they have a cross-development environment for Linux. Users can also install their own OSS by using SDK. Yokogawa is planning to offer an environment in which users can install intricately interdependent OSS easily by themselves.

All source codes of the Linux kernel are disclosed on the web in accordance with the GNU general public license (GPL). Yokogawa provides a mechanism to boot the image of a Linux kernel reconstructed by users although this is not covered by Yokogawa’s support package.

**Linux Operating Environment**

Users can determine whether they need real-time performance or not and select the number of cores for operating programs, according to the characteristics of applications.

Applications are executed according to the priority set for each process. Real-time performance matters here. Real-time performance does not simply mean processing speed but also ensuring the process response time. With simple prioritization, a high-priority process may be kept waiting when the execution of a low-priority process has been started. In contrast, a system with real-time performance can execute processes in the order of actual priority, and improve the precision of control by predicting the maximum delay time (latency) of processing. Thus, real-time performance can finish tasks within the maximum delay time and stabilize control equipment that requires precision.

Meanwhile, efficiency (throughput) is more important than responsivity in human machine interface (HMI) or computing systems, and pursuing real-time performance is not necessarily beneficial. It is more important to improve the throughput of processing unit than real-time performance.

To switch real-time performance, the Linux kernel needs to be reconfigured by using the build function. This operation requires advanced knowledge of Linux and the number of engineers with such knowledge is limited. This condition makes Linux products difficult to handle.

The e-RT3 Plus comes with two Linux kernels pre-installed: one with real-time performance and the other without. Customers can select either according to the characteristics of applications. To improve real-time performance, the RT-Preempt patch has been applied to the kernel.

Symmetric multiprocessing (SMP) is a technology that makes hardware with dual core processors work efficiently on Linux, and helps improve both real-time performance and throughput.

In SMP, applications are processed by two cores. Some applications designed to operate on a single core cannot use the schemes of exclusion and synchronization efficiently. Therefore, users must carefully port applications from a non-SMP environment including the previous products into an SMP environment. The e-RT3 Plus allows users to select a non-SMP environment if necessary.

Table 2 shows the four operating environments with the combination of real-time performance and SMP; users can select one among them. In the factory setting, real-time performance and SMP are enabled, which is the recommended environment for the e-RT3 Plus. When real-time performance is disabled, the operating environment becomes similar to a Linux PC with multicores. Similarly, selecting the non-SMP environment enables the execution of applications that are not made for multicores.
Web Maintenance Tool

The web maintenance tool enables users to ease CPU setting, set parameters for start-up, and monitor I/O modules.

In the previous products, such settings and monitoring required a dedicated development environment and advanced skills. Therefore, these operations were difficult for customers who only needed to maintain equipment and facilities.

To solve this problem, the e-RT3 Plus comes with the Apache web server software pre-installed, with which users can access the e-RT3 Plus via a web browser. This function is called the web maintenance tool and is a standard feature for all models of the e-RT3 Plus. Users can set parameters and monitor devices immediately after starting up the e-RT3 Plus.

Functions offered by the web maintenance tool are introduced below.

- Login function (Figure 9)
  This function ensures secured login, and prevents unauthorized access.

- Monitoring function for CPU internal devices and I/O devices (Figure 10)
  This function supports monitoring CPU internal devices and I/O devices, and changing their current values. It is possible to monitor and set various values without writing a program.

- CPU setting function (Figure 11)
  This function sets Linux system parameters and CPU configuration. This function can also set the operating environment and network addresses.

### Table 2 Linux operating environment

<table>
<thead>
<tr>
<th></th>
<th>SMP</th>
<th>Single core</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real-time</td>
<td>Recommended environment</td>
<td>For compatibility</td>
</tr>
<tr>
<td>performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not real-time</td>
<td>PC desktop environment</td>
<td>For compatibility</td>
</tr>
<tr>
<td>performance</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 9 Login function

Figure 10 Monitoring function

Figure 11 CPU setting function

Figure 12 Web maintenance tool

In the server-side service, the file system on Linux and the local devices and I/O modules in the controller are accessed. The files on Linux can be accessed by using Linux standard commands or m3io-monitor (dedicated API for accessing the local devices of the CPU module and I/O modules). In either way, processes are executed via the command line. The PHP library issues commands and receives the results of the commands.

The client-side service is the user interface part that users can handle directly, and is written in HTML5/JavaScript. The web maintenance tool uses HTML5 to dynamically change the display according to user operations and controller conditions and adjust the layout design for the web browser being used (responsive web design). As JavaScript, Ajax is used to communicate with PHP and obtain information from the server. Since Ajax does not need to reload web pages, it can drive the server side (PHP) as requested by the client side (JavaScript) and receive the results. Thus, the information on the web browser is renewed dynamically.

HTML5/JavaScript used for the web maintenance tool has been developed for standard web contents. Therefore, the web maintenance tool can use universal web browsers and flexibly respond to customers’ operating environment on any platform.

Users can expand the contents on the web servers as much as they like. Moreover, users can create their own web-based...
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GUIs by using the access library in PHP (Figure 13).

Figure 13 Dedicated contents

CONCLUSION

Controllers need sophisticated functions to handle various data in the field. Since its release, the e-RT3 has been improved continually while maintaining its computing capability, and is good at creating complex, highly-functional applications. The addition of the usability concept has made it much easier for many customers to handle the e-RT3.

Since a single e-RT3 Plus can control equipment, replace PCs, control I/O, and perform advanced calculations, this controller is expected to become a de-facto standard in the age of the Internet of Things (IoT).

REFERENCES


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