APPLICATION OF EMBEDDED LINUX BOARDS IN SSRF AND SXFEL CONTROL SYSTEM*

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Abstract

The embedded Linux boards, such as Raspberry Pi B+ and BeagleBone Black, are credit-card-sized single-board computer. They are low-cost and equipped with a huge array of GPIO (General Purpose Input Output), which can be used to take readings from sensors and control external devices. The active development community and open-source nature also make them ideal choices for many applications. They can be integrated with the accelerator control system and make more devices 'intelligent' via an economical way. It will be helpful to improve the efficiency of the accelerator. The details of the applications in SSRF and SXFEL control system will be reported in this paper.

OVERVIEW

Shanghai Synchrotron Radiation Facility (SSRF) is one of the advanced third generation light sources in the world, and it supports and pushes the cutting-edge scientific research and the innovation in China. It is composed of a 150 MeV linear accelerator, a 3.5 GeV booster, a 3.5 GeV storage ring, more than ten beamlines and experimental stations.

Shanghai Soft X-Ray Free Electron Laser Test Facility (SXFEL) is under construction neighbouring the SSRF. It is based on an 840MeV linear accelerator, and aims at generating 8.8nm FEL radiation with two-stage cascaded HGHG scheme. It will be upgraded to user facility in the near future.

The control system is designed to convey all monitor, control, model-based and computed data for the systems including vacuum, power supply, undulator, diagnostics, and operations subsystems to accomplish supervisory control, automation, and operational analysis. It must be robust and reliable in order to ensure long periods of operation without failures and malfunctions. For the future upgrades, the control system must be flexible with scalable and extensible features.

The embedded Linux boards, such as Raspberry Pi B+ and BeagleBone Black, are credit-card-sized single-board computer. They are low-cost and equipped with a huge array of GPIO. The active development community and open-source nature also make them ideal choices for many applications. They can be integrated with the control system and make more devices 'intelligent'.

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RASPBERRY PI

The Raspberry Pi is a series of credit-card-sized single-board computers developed in the United Kingdom by the Raspberry Pi Foundation with the intent to promote the teaching of basic computer science in schools and developing countries [1]. Since the February of 2012, over eight million units have been sold, which make it the best selling UK personal computer. The main features of latest product Raspberry Pi 3 are listed below, as shown in Figure 1.

- Broadcom BCM2837 64Bit Quad Core Processor (~10x the performance of Raspberry Pi 1)
- Integrated 802.11n wireless LAN and Bluetooth 4.1
- Complete compatibility with Raspberry Pi 1 and 2.

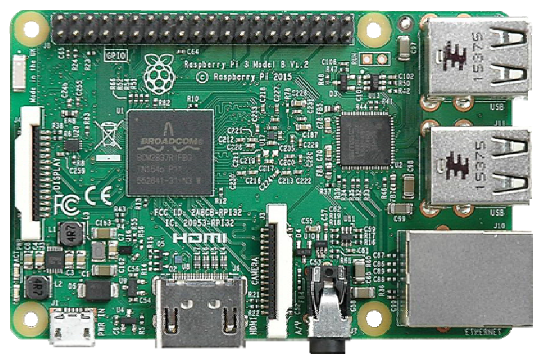

Figure 1: Raspberry Pi 3 Model B.

The Raspberry Pi GPIO (General Purpose Input Output) pins allow interface with and control of LEDs, switches, relays, sensors and so on. It also supports common protocols like I^2C, which can be used to connect more peripheral devices.

The Raspberry Pi primarily uses Linux kernel based operating systems, such as Raspbian, Ubuntu MATE, Arch Linux ARM, etc. Benefited from the work by the community [2], the EPICS (Experimental Physics and Industrial Control System) environment is easy to build. The Wheezy Raspbian distribution already has all the tools necessary to build the base. All that is necessary is only to define the host architecture and then build it.

It promotes Python as the main programming language. PyEpics [3] is an interface for the CA (Channel Access) library of the EPICS to the Python. It provides a base epics module to python, with methods for reading from and writing to PVs (Process Variables) via the CA protocol. To simplify installation, the easy_install (from setuptools) can be used. The GPIO can also be accessed and controlled via Python.

BEAGLEBONE BLACK

The BeagleBone Black [4] is another low-cost, community-supported development platform. The Rev C, as shown in Figure 2, utilizes the low cost Sitara ARM Cortex-A8 processor from Texas Instruments and runs a variety of operating system including Debian, Angstrom, Ubuntu and Android. The main features are listed below.

- AM3358 1GHz ARM Cortex-A8 Processor
- 4GB 8-bit Embedded MMC Onboard Flash
- 3D Graphics Accelerator
- NEON Floating-Point Accelerator
- 2x PRU 32-bit Microcontroller
- USB Host and OTG, Ethernet, Micro HDMI, Serial, ...

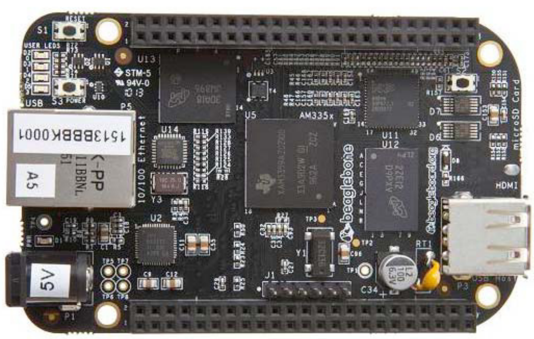

Figure 2: BeagleBone Black Rev C.

The BeagleBone Black board can satisfy the different requirements of various fields. Compared to Raspberry Pi, it has a lot more GPIO pins. Its analog-to-digital converter (ADC) modules associated with analog input pins. It can also generate precise analog output using dedicated digital-to-analog converter (DAC), such as MCP4725 12-bit I^{2}C DAC as shown in Figure 3. It is easy to use using the Adafruit library [5].

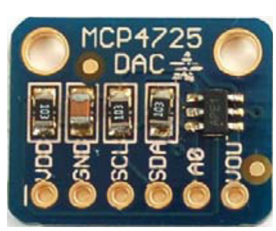

Figure 3: The MCP4725 12-bit I^{2}C DAC.

INTELLIGENTIZE

For the intelligent control system, it is important that more devices are monitored, controlled and managed. The Raspberry Pi and BeagleBone Black board can reach the balance between cost, speed and performance. The following is an example.

Image acquisition is part of the accelerator data acquisition system. The GigE Vision (Gigabit Ethernet) cameras have been widely used, which greatly simplify the system architecture. Its interface allows for very fast frame rates and long cable lengths. According to our experience, the camera power may need to be reset after a long period of work or at some specific conditions. In our case, the camera power supply and trigger fanout chassis were customized products, which cannot be controlled remotely. It will take a long time for the large distributed system.

In the SXFEL control system, the Raspberry Pi boards are embedded in the camera power supply and trigger chassis. It runs as the IOC, and integrated in the EPICS control system, as shown in Figure 4 and 5. The dedicated circuit was designed to control the camera power supply via electric relays, as shown in Figure 6.

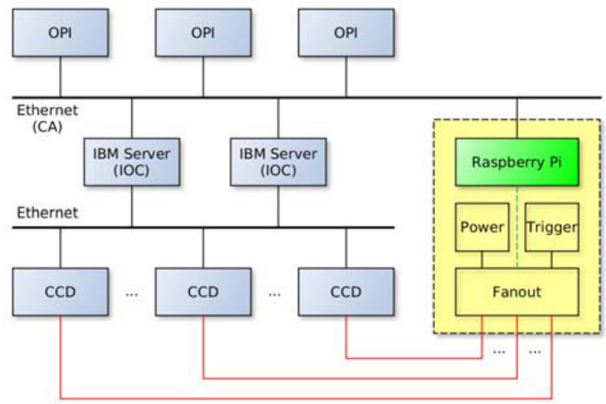

Figure 4: The system architecture (Raspberry Pi).

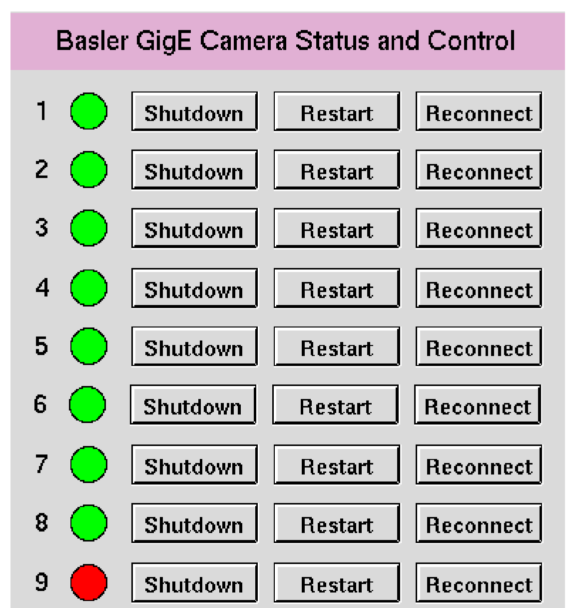

Figure 5: The camera power supply control panel.

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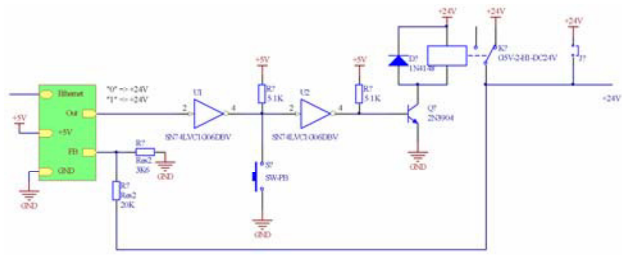

Figure 6: The dedicated circuit for the camera power.

CONTROLLER

In the modern accelerator control system, more and more network-based devices are adopted, which are well supported in EPICS community. The small single-board computers are good options for some cases, such as in power supplies, motor controllers, etc. as shown in Figure 7.

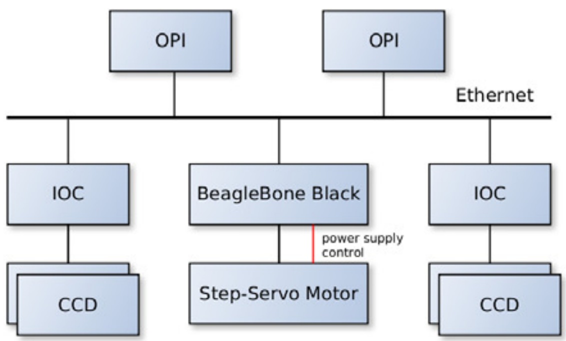

Figure 7: The system architecture (BeagleBone Black)

In the beam instrumentation system and LLRF (Low Level Radio Frequency) control system of SXFEL, the network-based step-servo motors (MOONS SSM24Q-3RG) are adopted, as shown in Figure 8. It integrates with controller, driver, encoder and digital I/O interface, which can be used as limit protection, illumination control, etc.

Figure 8: The MOON'S step-servo motors.

The motor can be accessed via TCP/IP protocol. We design a compact chassis, including power supply, motor control and encoder readout. The BeagleBone Black boards are embedded in the same chassis, and runs as the IOC.

CONCLUSION

The further development of accelerator control system requires the combination in both depth and breadth. Along with the process of high-speed and high-precision tracking control, the intelligentize of more devices is also a critical issue. For the non-compute intensive or non-data intensive applications, the embedded Linux boards can completely meet the requirements.

The active development community and open-source nature also make them better quality, higher reliability, more flexibility and lower cost. We can embed them into more devices, monitor or control more signal. More 'intelligent' devices will be helpful for the fault diagnosis, data mining and predictive analysis, which can improve the efficiency of the whole accelerator complex.

ACKNOWLEDGMENT

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[4] BeagleBone Black website: http://www.beaglebone.org
[5] Adafruit website: https://github.com/adafruit