Raspberry Pi is a series of small single-board computers designed and published by the Raspberry Pi Foundation. It is also a low cost and popular solution in building the EPICS Input/output Controller (IOC) owing to its high flexibility, expansion capability and affordability. EPICS is also adopted in the electron-positron collider, SuperKEKB accelerator. However, the requirement of the real time capability of the control system is critical since the specific demand of the injection system. The injector linac needs to switch lots of hardware parameters every 20 millisecond to perform the injection into several different storage rings. To assess the possibility and stability of Raspberry Pi based EPICS IOC within the 50 Hz beam repetition rate, we perform a latency test on the Raspberry Pi and compare the standard kernel and real time kernel.
Control System Overview

GUI, CLI
(Python, LabVIEW, Tcl/TK, ...)

Application Layer

Middle Layer

Local Controller Layer

Device Layer

Control network

Server
EPICS IOC

Archiver

PCI/PXI
oscilloscope

EPICS IOC

PLC

VME

PLC

EPICS IOC

EPICS IOC

ADC, DAC, SPI, ...

PS

RF

Monitor

Vacuum pump

Klystron
PS

Pulsed magnet

EPICS IOC

???
What is Raspberry Pi

- Low cost
- Small
- Highly customizable
- Tested at several accelerators:
  - Banana Pi used at TPS, Taiwan
  - Raspberry Pi used at SPES, Italy

Raspberry Pi 4 Model B (June, 2019)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
<td>Broadcom BCM2711 quad-core Cortex-A72 64-bit SoC @ 1.5GHz</td>
</tr>
<tr>
<td>Memory</td>
<td>2GB, 4GB or 8GB LPDDR4</td>
</tr>
<tr>
<td>Network</td>
<td>IEEE 802.11b/g/n/ac wireless Bluetooth 5.0 Gigabit Ethernet</td>
</tr>
<tr>
<td>I/O</td>
<td>USB, 40-pin GPIO header</td>
</tr>
<tr>
<td>OS</td>
<td>Debian, Raspberry Pi OS</td>
</tr>
<tr>
<td>Power</td>
<td>5V DC via USB-C connector</td>
</tr>
</tbody>
</table>

• 1 LINAC and 4(+1) Ring (HER, LER (+DR), PF, PF-AR)
• 50 Hz Pulse-to-Pulse Modulation (PPM)
• Different injection mode with different control parameters

Reference
1. DESIGN AND IMPLEMENTATION OF EMBEDDED APPLICATIONS WITH EPICS SUPPORT FOR ACCELERATOR CONTROLS, IPAC2016, Busan, Korea
2. NEW CONTROL SYSTEM FOR THE SPES OFF-LINE LABORATORY AT LNL-INFN USING EPICS IOCS BASED ON THE RASPBERRY PI, fICALEPCS2013, San Francisco, CA, USA

Detail is described at The fault analysis of timing system in SuperKEKB (WEPP24)

PASJ2020 THPP21, D. Wang – 3/7
Real Time Test of RPi with two kernels

- Use `cyclictest` tool in RT-tests toolbox
- Open source
- Easy to use
- Several conditions will be tested:
  - CPU frequency
  - CPU stress method
  - Thread sleep time
  - Std kernel and RT kernel
- Mostly use `hackbench` to stress the CPU, `cat /dev/zero > /dev/null` and `pi_stress` (based on Priority Inversion) also used for comparison
- Compile the real time kernel from: https://github.com/raspberrypi/linux/tree/rpi-4.19.y-rt

- Standard kernel supports CPU frequency: 600MHz, 750MHz, 1000MHz, 1500MHz
- RT kernel supports 600MHz and 1500MHz

The CPU stress method comparison based on Std kernel

No stress

Use `cat /dev/zero > /dev/null` to stress single CPU

hackbench

Pi_stress

Note that the vertical axis scale changes
Real Time Test of RPi with two kernels

The CPU stress method comparison based on RT kernel

- **No stress**
- **Use `cat /dev/zero > /dev/null` to stress single CPU**
- **hackbench**
- **Pi_stress**

Program running time comparison

- **Hackbench stress on Std kernel, runs for 10 minutes**
- **Hackbench stress on Std kernel, runs for 50 minutes**

- The average latency remains the same between Std and RT kernel
- The maximal latency of RT kernel is half of the Std kernel
- Stress all CPUs will obviously increase the latency while stressing one CPU will only increase one core’s latency
- Priority Inversion stress is a little bit difficult for RPi to handle
- The program running time does not affect the latency both on Std and RT kernel
Real Time Test of RPi with two kernels

With the increase of CPU frequency, the latency decreases.

Even on the lowest CPU frequency of RT kernel, the maximal latency (90 us) is still smaller than the high performance CPU of the standard kernel (110 us).

The best latency is 8 us for average latency and 50 us for maximal latency on RT kernel.

CPU temperature is acceptable with 1.5 GHz on RT kernel without cooling (~65 °C).
Real Time Test of RPi IOC with two kernels

- 25 Hz square wave (half of the SuperKEKB beam repetition rate)
- Use hackbench to stress the CPU
- EPICS version: 3.14.12.8
- Set IOC priority as 90 (by `chrt` command)
- CPU frequency is 1.5 GHz
- Two PVs only in the IOC
- Device driver uses Linux `epoll` mechanism

Conclusion: Unlike the `cyclictest` result, there is no much difference between IOC on Std kernel and RT kernel. Owing to the interrupt handling and context switch strategy, EPICS IOC on RT kernel takes lightly longer time while the stability is better.