

CST 8703 Lab 1 - First Real-Time Kernel Jitters

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2022-05-01

Real-Time Systems and Embedded Programming

Submission Deadline: May 01, 2022

Realtime profiling tools will be used to characterize the latency and time variation (jitter) of the system, and demonstrate the utility of a preemptible kernel in a hard realtime operating system. A cyclic program with a fixed step timer will be created and timing analyzed.

Background

Hard real-time systems require operations to meet specified timing deadlines and a missed deadline is considered a system failure. For example, a digital control system such as a robotic manipulator may require a fixed interval timer. Filtering and closed-loop control systems are tuned based on a loop duration, also referred to as a “step size”. If this duration deviates from a specified tolerance, the control system may go unstable and lead to catastrophic failure. If the control loop itself is robust and won’t go unstable with variation in loop step size, a deviation from a robot trajectory, even over a short duration, may cause damage to surroundings or an individual interacting with the robot.

Linux was not initially designed as a real-time operating system and meeting strict deadlines was less of a priority compared to providing a solid desktop computing user experience. The [Linux real-time project](#) was established to incorporate changes into the mainline Linux kernel that allow the scheduler to be preempted by real-time processes. These changes (patches) can be enabled when configuring the Linux kernel. The following table provides links from the Linux Foundation with resources specific to the PREEMPT_RT kernel patch development:

Link	Description
Technical basics: Important aspects for real time	A must-read regarding basics of preemption and real-time Linux
HOWTO: RTOS and RT Applications	Getting started with real-time application development for Linux

Testing the embedded platform and the timing of your application is a necessary step in evaluating the capabilities of the software to meet hard timing deadlines. Hardware is typically supported by commercial RTOSes with Board Support Packages (BSPs) but with most free Linux distributions there are no officially supported real-time platforms. The [Open Source Automation Development](#)

Lab (OSADL) runs a quality assessment “farm”, testing Linux configured with PREEMPT_RT on many platforms and distributions. Some of their boards under test are Raspberry Pis with latency plots and kernel configuration scripts made available online. The following plot is a sample latency histogram of a Raspberry Pi on the test rack:

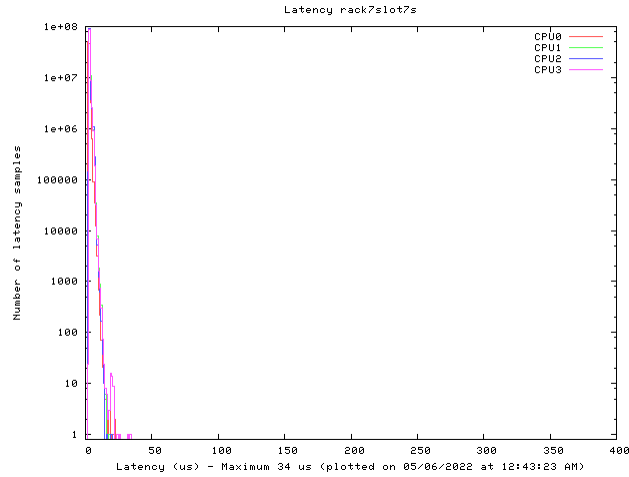


Figure 1: Latency plot of Raspberry Pi 4 on OSADL test rack r7s7s

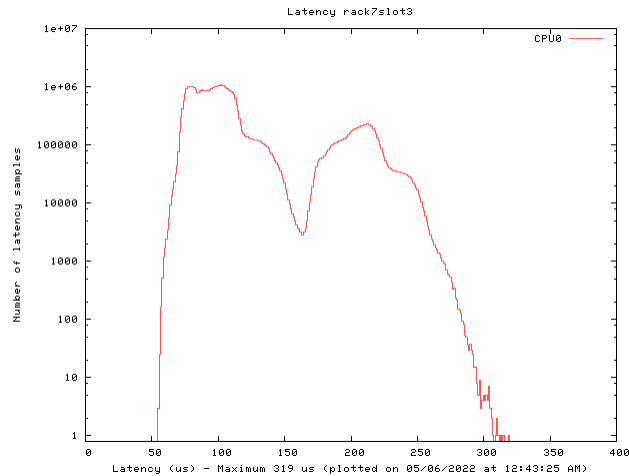


Figure 2: Latency plot of original Raspberry Pi (single core CPU) on OSADL test rack r7s3

Latency is a key metric of realtime performance. It is the delay after a timer is triggered before processing begins. For a timed loop, the latency must be low enough to allow sufficient processing time such that it can complete before the next timer deadline occurs. Debugging errors caused by spikes in latency can be difficult to track down since source of latency can come from the OS performing other tasks, and may not be easily reproducible.

The program **Cyclictest** is a very useful tool for testing real-time performance (specifically timing latencies). In this lab, system latencies will be tested with **cyclictest**. Jitter is another metric commonly used in reference to network communications.

Materials

1. Raspberry Pi 4 or Raspberry Pi Zero 2 W.

2. Desktop computer with Linux, Windows, or Mac operating system.
3. Wired or wireless local network.

Methods

Prerequisites

The program `cyclictest` is part of the package `rt-tests` and timing plots are generated with Python. Install the prerequisites on your pi with the commands:

```
sudo apt install -y \  
    python3-numpy \  
    python3-matplotlib \  
    rt-tests
```

Cyclictest System Latency Performance

First check the kernel version with the command

```
uname -r
```

There should be no `-rt39` shown. This is the default (not fully preemptible) kernel installed on the Raspberry Pi. Run the script

```
./script/run_cyclictest.sh
```

The script will take a few minutes to complete. Some warnings appear which can be ignored. When it's complete, there should be a new `data` folder created containing the histogram output text files and latency plots. The following figure shows an example output latency plot from a Raspberry Pi Zero 2 W without a preemptible kernel (no `PREEMPT_RT` patch):

One filename is prefixed `cyclictest_noload` which was captured from running `cyclictest` without cpu-heavy processes running in the background. The other files prefixed `cyclictest_highload` was run with commands that intentionally utilize all four cores on the processor. Inspect the script `run_cyclictest.sh` to understand the commands that were used to generate the latency histogram plots.

A preemptible kernel can be installed on a Raspberry Pi by following the [directions on kdoren's GitHub repository](#). In order to install this kernel, run the script:

```
./script/install_raspi_rt_kernel.sh
```

Restart the Raspberry Pi. The new kernel should be installed. Check the kernel version with the command

```
uname -r
```

Verify that the kernel version contains `-rt39` which signifies the `PREEMPT_RT` patch was applied. Test the patched version by running `cyclictest` again:

```
./script/run_cyclictest.sh
```

Four more files should be added to the `data` folder with the new kernel suffix name.

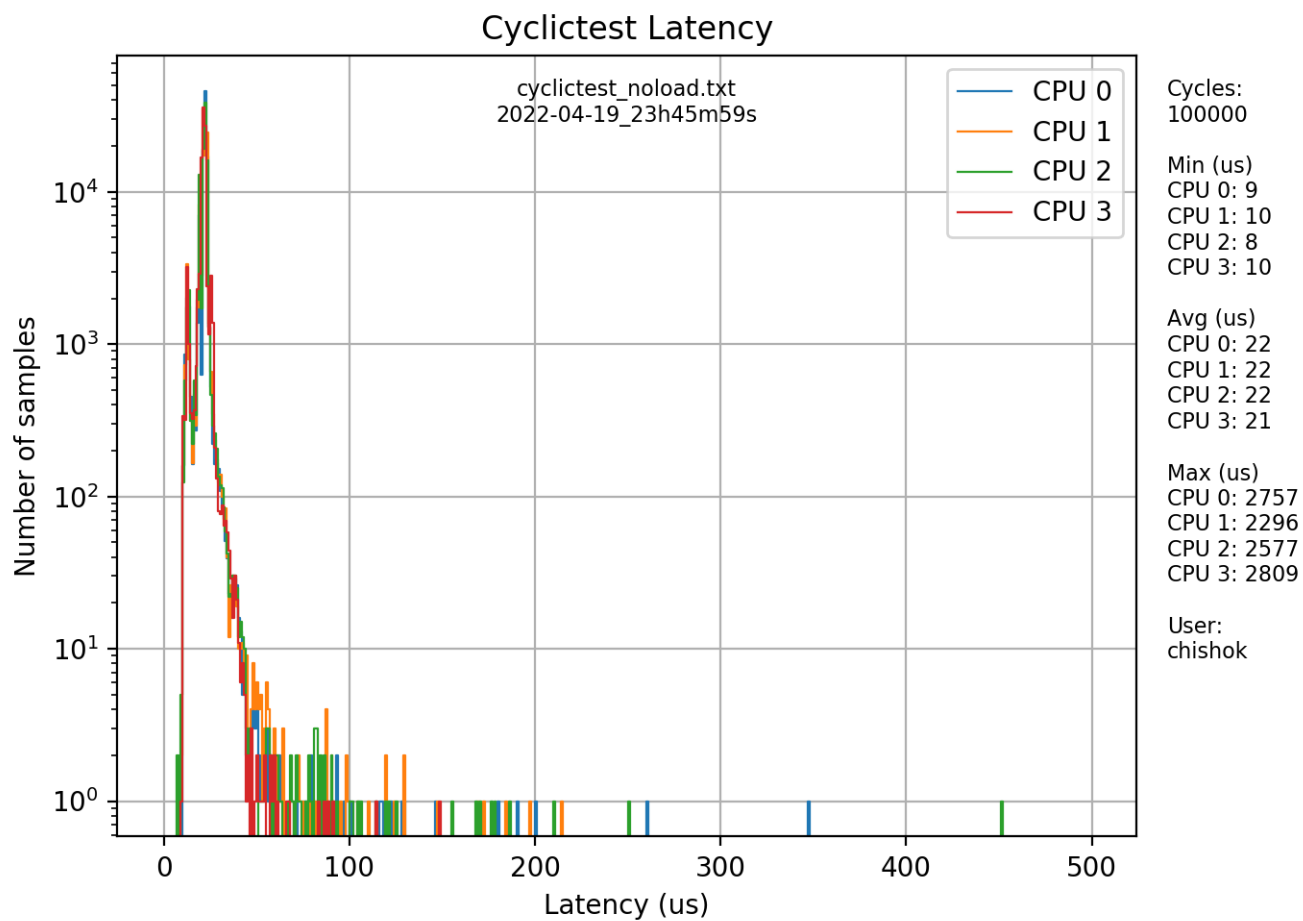


Figure 3: Sample latency plot without PREEMPT_RT patch

Implement timer

Alter the target program `JitteryTimers` to implement a cyclic timer. Make your modifications between the comments

```
/*  
 * STUDENT WORK SECTION BEGIN  
 * =====  
 */
```

and

```
/*  
 * =====  
 * STUDENT WORK SECTION END  
 */
```

The files `main.c` and `ac_timing.c` require modifications. Refer to Linux foundation real-time HowTo pages online for hints on implementing the timed loop.

Test the timed loop by running the script

```
./scripts/run_submission.sh
```

The program will be run three times at different step sizes and durations. The output of the script should look something like:

Arguments parsed

```
step_size (us): 1000  
duration (s): 5.00  
filename: data/timeLogTs1000.dat  
priority: 90
```

Number of execution steps: 5000

Process info:

```
timestamp: 2022-05-06 07:56:47  
process id: 114288  
thread policy: SCHED_RR  
thread priority: 90  
thread id: 139912015099712
```

Number of bytes written to file 'data/timeLogTs1000.dat': 20000

Arguments parsed

```
step_size (us): 500  
duration (s): 5.00  
filename: data/timeLogTs500.dat  
priority: 90
```

Number of execution steps: 10000

Process info:

```
timestamp: 2022-05-06 07:56:54  
process id: 114372
```

```
thread policy: SCHED_RR
thread priority: 90
thread id: 140333485930304
Number of bytes written to file 'data/timeLogTs500.dat': 40000
```

```
Arguments parsed
step_size (us): 100
duration (s): 5.00
filename: data/timeLogTs100.dat
priority: 90
Number of execution steps: 50000
```

```
Process info:
timestamp: 2022-05-06 07:57:01
process id: 114428
thread policy: SCHED_RR
thread priority: 90
thread id: 140471629178688
Number of bytes written to file 'data/timeLogTs100.dat': 200000
```

Three plots are generated in the **data** folder showing the jitter and timing errors of each run. For example, the run with step size of 1000 microseconds should look like:

Analysis

Refer to the cyclicttest latency plots and jitter time log when discussing the following points:

1. Compare the cyclicttest latency plots.
 1. What are the differences between high-load and no-load latencies?
 2. What is the difference between linux with the PREEMPT_RT patch applied and without.
2. Compare jitter and latency from the your implementation of a cyclic timer. What may be affecting the jitter and absolute error? Do you see drift in any of the time logs?
3. What are possible sources of latency in the system?

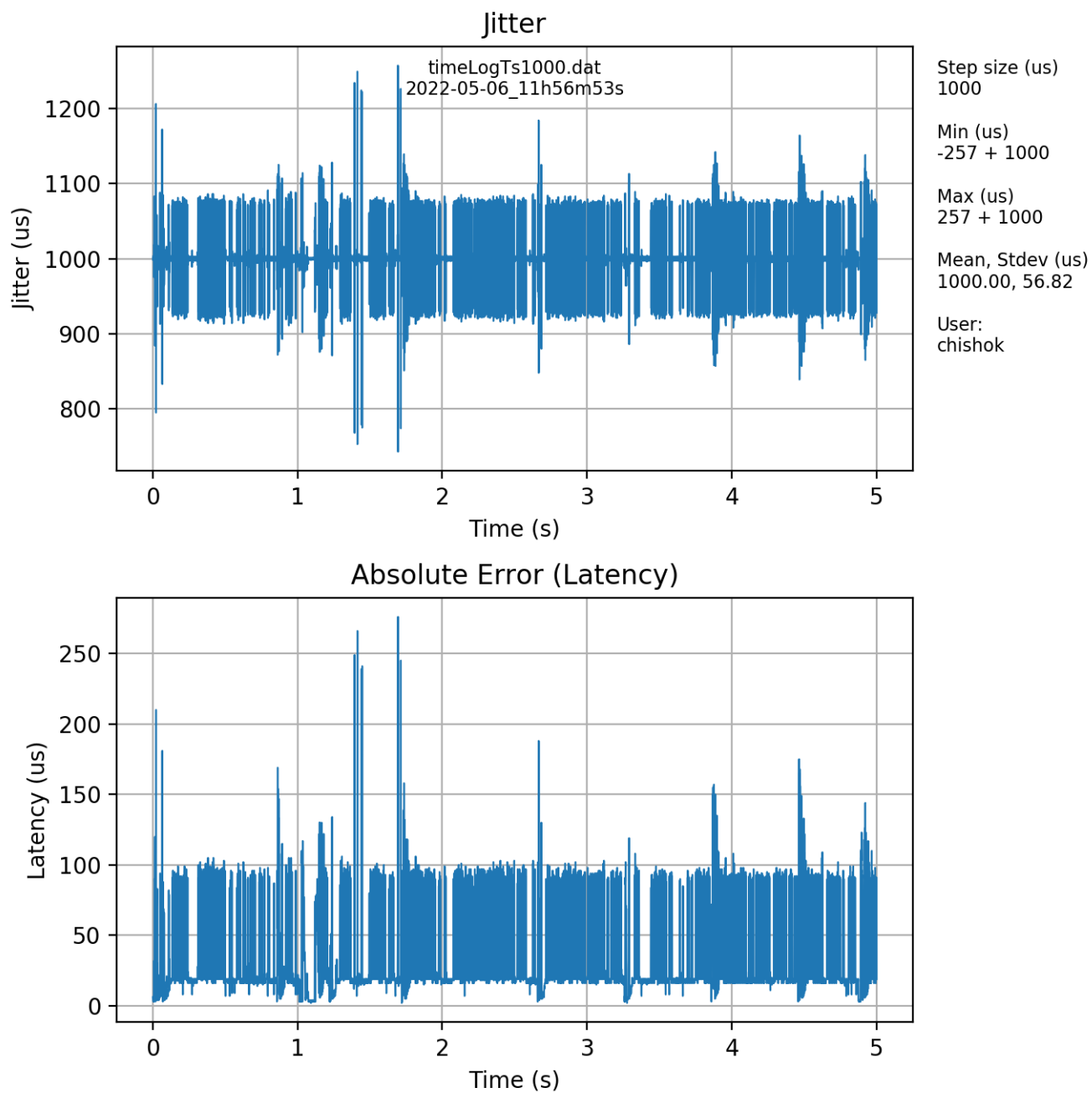


Figure 4: Jitter from time logged