Virtualization of a Real-Time Operating System for Robot Control with a Focus on Real-Time Compliance

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Introduction

- Robots perform time-critical tasks
- Delays → catastrophic consequences
- General-Purpose Operating System vs. Real-Time Operating System

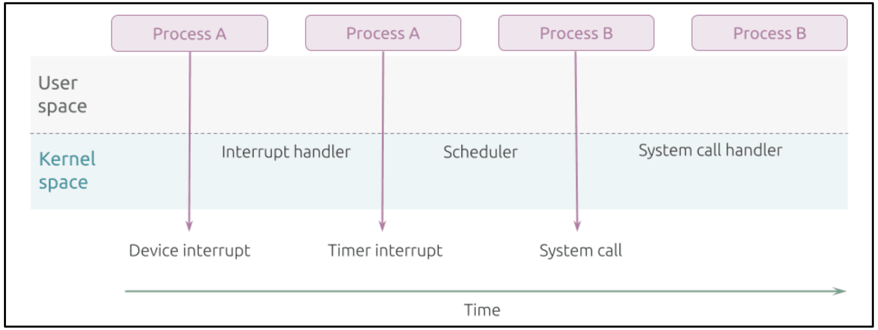


Figure 1: Non-preemptible Kernel [1]

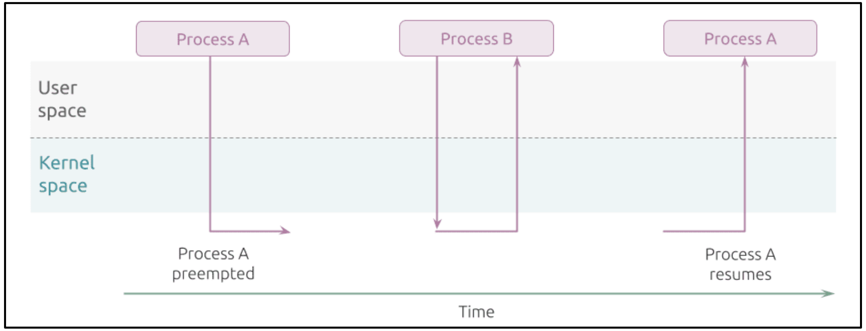


Figure 2: Preemptible Kernel [1]

Problem and Task Definition

Virtualization of Real-Time Operating Systems	
Advantages	**Disadvantages**
Scalability & flexibility	Increased overhead and latency
Cheaper	Performance variability
Remote management	Complexity

- **Research Question:** Is it possible, and if so, how can the latency of a real-time operating system virtualization be reduced using Yocto, Xenomai, and QEMU to a level that is closer to that of bare metal (below 50 µs)?

Application Context and Conditions

- This work was written at SIGMATEK GmbH & Co KG

- **Host OS:** Ubuntu 22.04.4 LTS, PREEMPT-RT

- **Guest OS:** Salamander 4
  - Built with Yocto [2]
  - Virtualized through Quick Emulator (QEMU) [3]
  - Hard real-time with Xenomai 3 [4]

- Trace-cmd [5] and Kernelshark [6] for kernel tracing and visualization

Methodology

Asses Initial Situation

Measure initial latency difference between bare metal & untuned virtualization with the latency tool of Xenomai

Real-Time Performance Tunings

Sequentially tune virtualization through configurations of BIOS, kernel, host, guest and QEMU

Comparison

Measure the latency difference with the latency tool

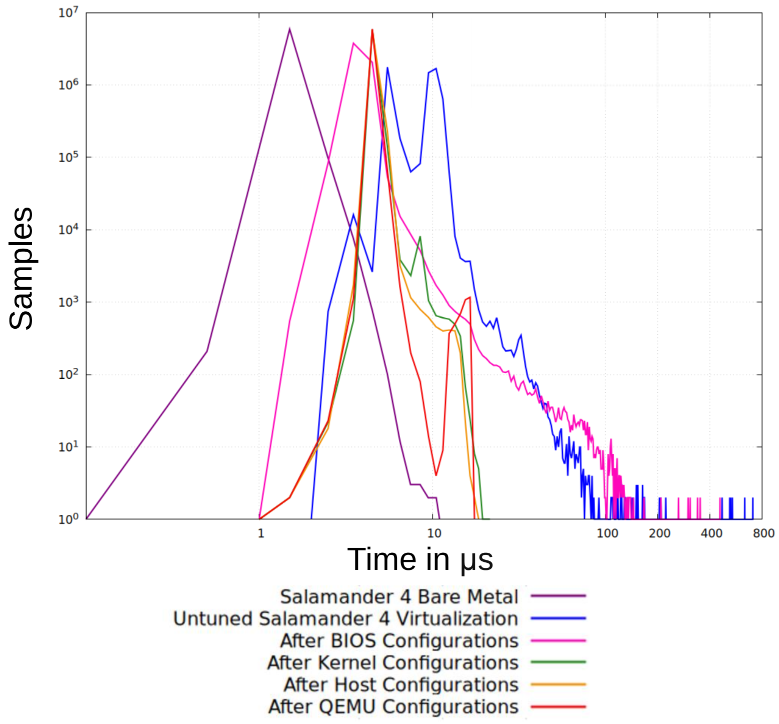
Validation

Measure the latency difference with a real-time robotic application

Results – Latency Tool

- 10 minutes with a sampling period of 100 µs, priority of 99

Figure 1: Comparison of Latency Distributions



Version	Latency (µs)			Overruns
	Min	Avg	Max	
Bare Metal	0.613	1.380	10.709	0
Untuned Virtualization	2.536	8.940	707.622	43
After BIOS Configurations	0.969	3.948	457.545	22
After Kernel Configurations	2.545	4.811	21.694	0
After Host Configurations	2.591	4.834	18.441	0
After QEMU Configurations	2.614	4.779	17.134	0

Table 1: Comparison of Latency Results

Results – Robotic Application

- Difference between command issuance time and signal arrival at PWM
- 1,000 samples

Version	Latency (ms)			Std Dev (ms)
	Min	Avg	Max	
Bare Metal	1.211	1.347	1.49	0.082
Untuned Virtualization	3.1	24.603	129.46	13.876
Tuned Virtualization	1.219	2.62	3.988	0.812

Table 2: Comparison of Robotic Application Latency Results

Discussion

✓ Latency Tool

- Worst latency decreased from 707.622 µs to 17.134 µs
- No overruns
- Close to bare metal’s 10.709 µs
- Goal achieved

✓ Robotic Application

- Worst latency dropped from 129 ms to 3.988 ms
- Close to bare metal’s 1.49 ms
- Tunings validated

Outlook

- Additional configurations

- Other hypervisors and virtualization technologies

- More testing under workloads

References

- [1] https://ubuntu.com/blog/what-is-real-time-linux-ii
- [2] https://docs.yoctoproject.org/
- [3] https://www.qemu.org/
- [4] https://xenomai.org/
- [5] https://trace-cmd.org/
- [6] https://kernelshark.org/

Priorities for Different Scheduling Policies

Table 11: Minimum and Maximum Priorities for Different Scheduling Policies

Scheduling Policy	Min Priority	Max Priority
SCHED_OTHER	0	0
SCHED_FIFO	1	99
SCHED_RR	1	99
SCHED_BATCH	0	0
SCHED_IDLE	0	0
SCHED_DEADLINE	0	0