Real-Time and Embedded Linux for Manufacturing and Robotics

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Embedded Linux

- *Embedded systems* are computers built into special-purposes devices
- Free, portable Linux is popular for embedded systems
  - highly customizable for minimal use of computing and power resources
  - ability to run without vibration-sensitive rotating hard disks

Sharp Zaurus PDA

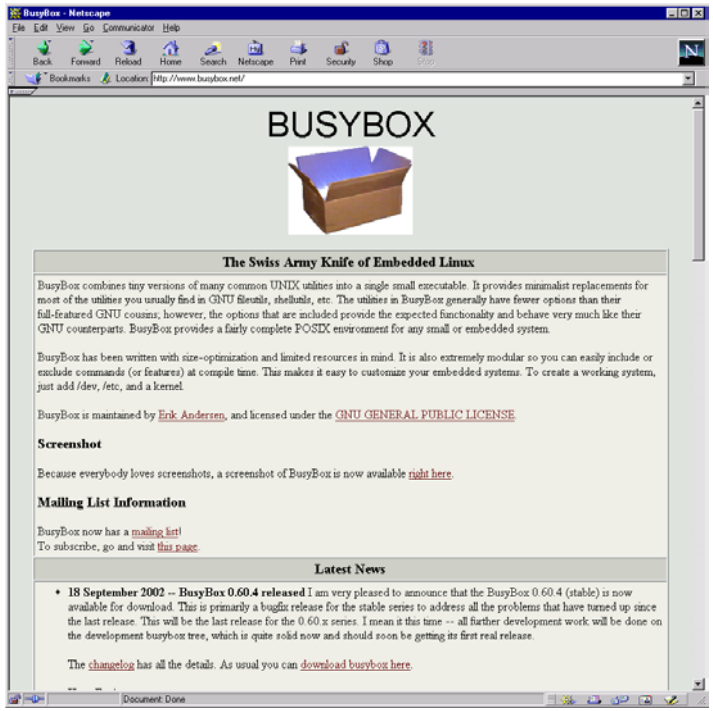
Kerbango Internet radio

Sony CoCoon channel server

Panasonic broadband terminal

Embedded Linux Distributions

Dozens of embedded Linux distributions are available; see LinuxLinks.com



We used BusyBox for a robotics project; BusyBox is distributed free as open source

Embedded Linux Consortium

- Agilent Technologies
- Amirix Systems, Inc.
- Birdstep Technology
- China MobileSoft
- Concurrent Computer Corporation
- Finite State Machine Labs, Inc.
- IBM
- LynuxWorks
- M-Systems Ltd.
- Metrowerks
- Micro/sys, Inc.
- MontaVista Software
- Panasonic
- Real-Time Innovations
- Red Hat, Inc.
- Samsung Electronics Co., Ltd.
- Sharp Electronics
- SnapGear
- Sony Electronics, Inc.

Real-Time Linux

- Linux (regular or embedded) is not *real-time*
  - it is optimized for fastest average throughput, but no single task is guaranteed a timing deadline
  - tasks may suffer tens or hundreds of milliseconds of delay due to interference by other tasks
- Changes to Linux scheduler for real-time operation are available, and free
  - RTL from New Mexico Tech: X86, PowerPC, Alpha
  - RTAI from Milan Polytech: X86, PowerQUICC
- RTL and RTAI provide similar mechanism
  - RT scheduler runs RT tasks first
  - Linux is run as the last task, and is preempted for RT tasks
- RT tasks can easily communicate with regular tasks

RT Linux Examples

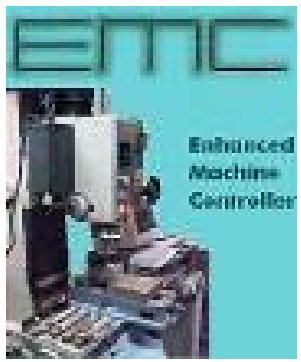
Jet engine testing for the Joint Strike Fighter by Pratt & Whitney

The 10- and 12-Meter Radio Telescopes at the Kitt Peak Observatory use RTLinux for data collection and antenna control tasks

FlightSafety uses RT Linux real-time ethernet drivers on 5 computers to run the avionics chassis, touch screen and host computer for an FAA B/C/D certified flight simulator

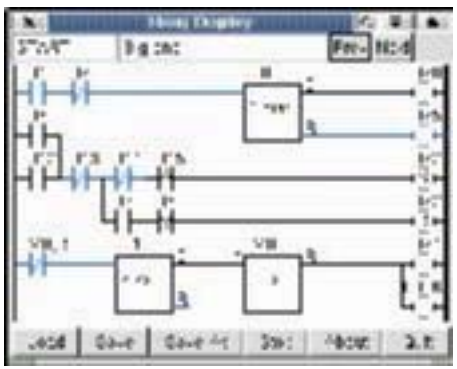
NASA FlightLinux uses real-time Linux for onboard spacecraft systems

RT Linux Examples



The EMC uses RT Linux for servo- and stepper motor control of machine tools and robots

Fujitsu Automation Limited and Fujitsu Laboratories uses RTLinux to control their bipedal 48cm tall robot, HOAP



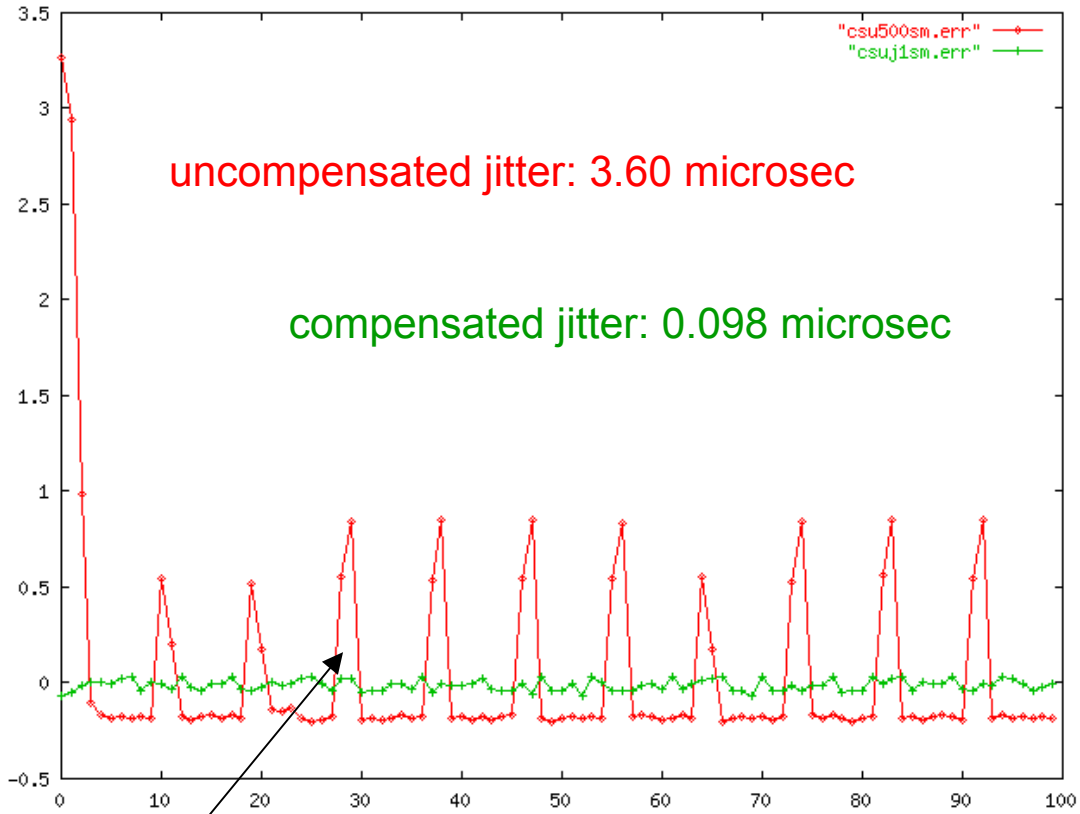
The Classic Ladder project uses RT Linux to create PLC's in software

Platino uses RT Linux for controlling their laser cutting machines

RT Linux Performance

We have run stepper motor control tasks at 10 microsecond periods, for a full step rate of 50 kilohertz

Jitter due to hardware effects (cache, bus contention) can be reduced to 0.1 microseconds using a “timer advance” software technique



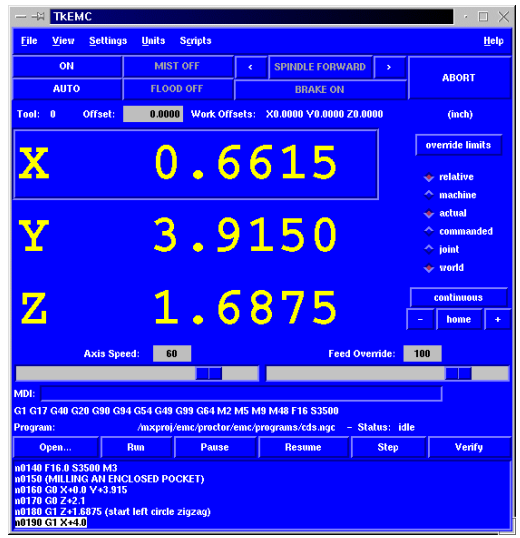
If this is an inch, normal Linux jitter is 19 miles!

Machine Tool Application

The Enhanced Machine Controller (EMC): NIST software to test machine tool and robot standards

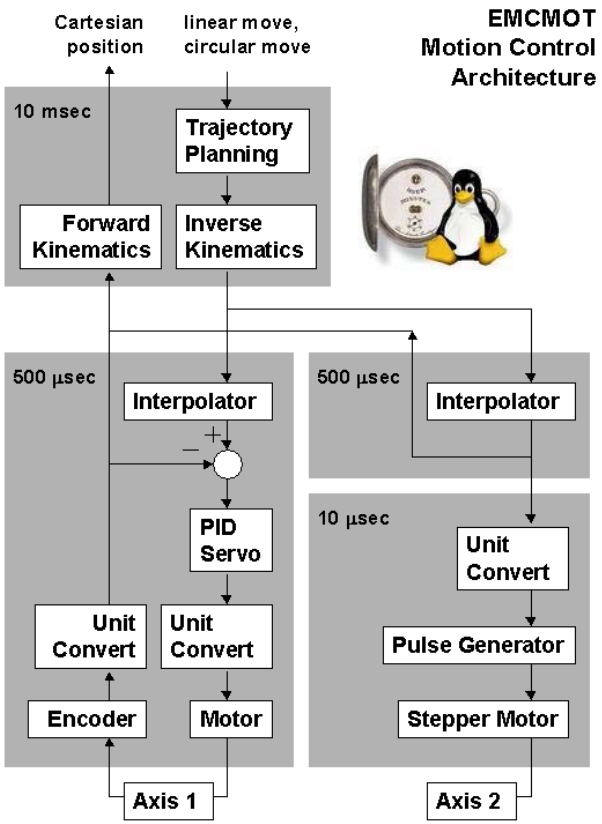
PC-based control uses simple I/O board connected to power electronics for motors

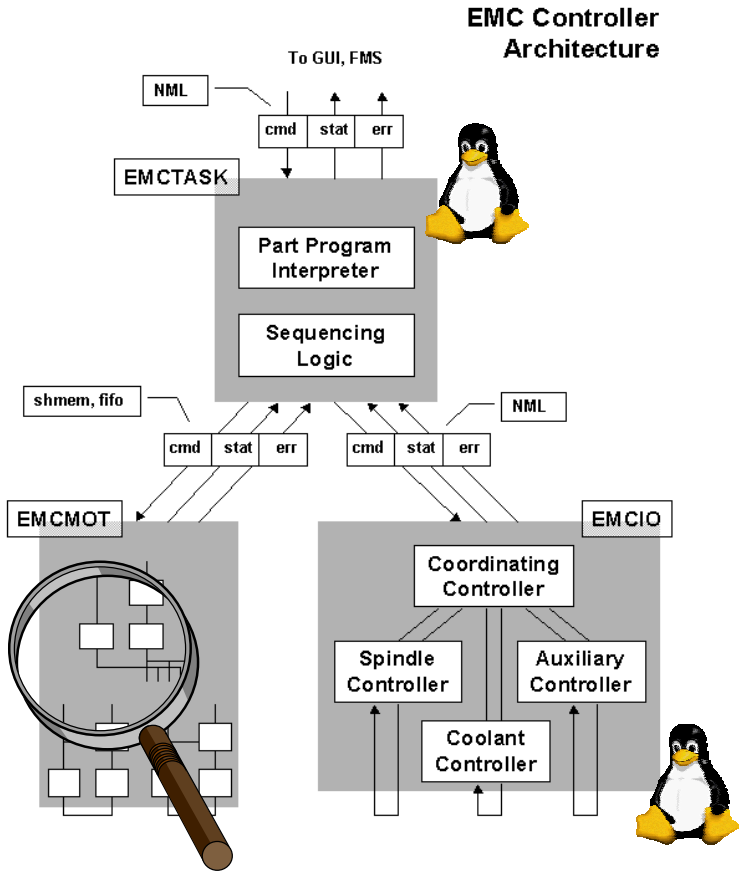
Tcl/Tk graphical user interface runs in both Linux and Windows



Installed on a Bridgeport 3-axis milling machine typical of small job shops

EMC Architecture





Motion controller runs in real-time, with periods ranging from 10 milliseconds to 10 microseconds

Other processes run in regular Linux on nominal 10-millisecond periods

EMC Software

"Chips," the EMC mascot

- NIST government software is public domain, so anyone can use it for any purpose
- Small shops and hobbyists have commercialized EMC

home page at
`www.linuxcnc.org`

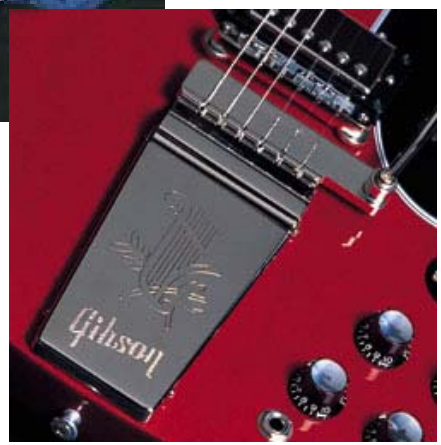
SOURCEFORGE™

EMC open-source software is maintained at SourceForge,
`www.sf.net/projects/emc`

The "Brain Dead Install" CD simplifies EMC installation

EMC retrofit on Wells-Index knee mill machining cast iron molds at Unique Machining, Millersville, MD

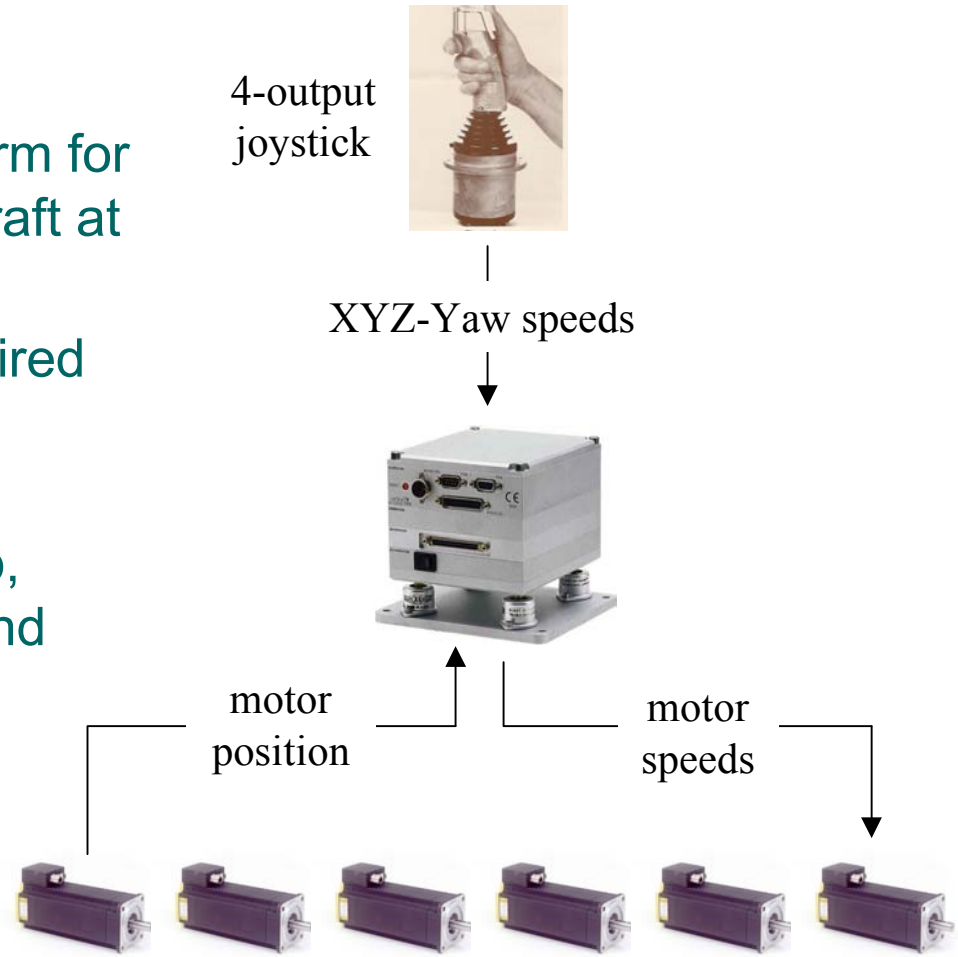
Engraved tailpiece on Gibson Maestro guitar, machined with EMC retrofit by Dan Falck for Gibson Guitars



EMC retrofit on Bridgeport knee mill drilling copper tubing for heat exchangers at Flat Plate, Inc., York, PA

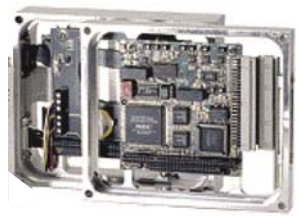
Robot Crane Application

- U.S. Air Force project to demonstrate scaleable platform for paint removal of KC-130 aircraft at Warner Robins ALC
- Hazardous environment required sealed enclosure, no rotating computer media
- Operator is suspended in cab, uses joysticks to move cab and media sprayer with controlled XYZ-Yaw motion



Our Computing Needs

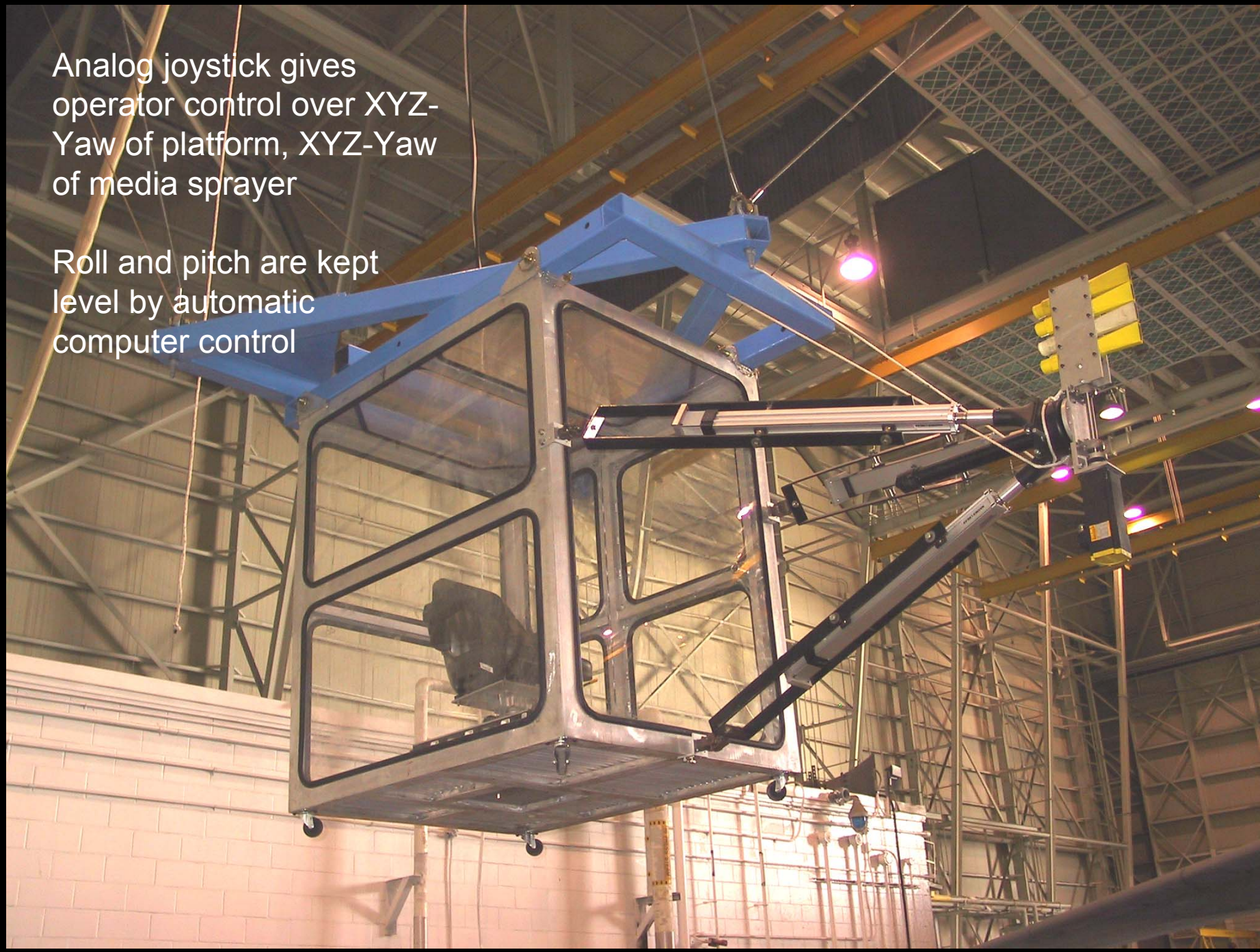
- Solid-state “hard disks” for shock- and vibration resistance
- Real-time control for XYZ-Yaw joystick control
- 8 serial “COM1..COM8” ports to motor controllers
- Analog input, digital I/O to sensors and relays
- Our system:
  - PC-104 with Pentium Geode processor
  - BusyBox Linux, New Mexico Tech RTL
  - DiskOnChip 96 Mb Flash
  - Qt/Embedded small X-Windows replacement
  - Touch screen w/ custom driver
  - RS-232/422 serial; analog input, digital I/O
  - Ethernet for development

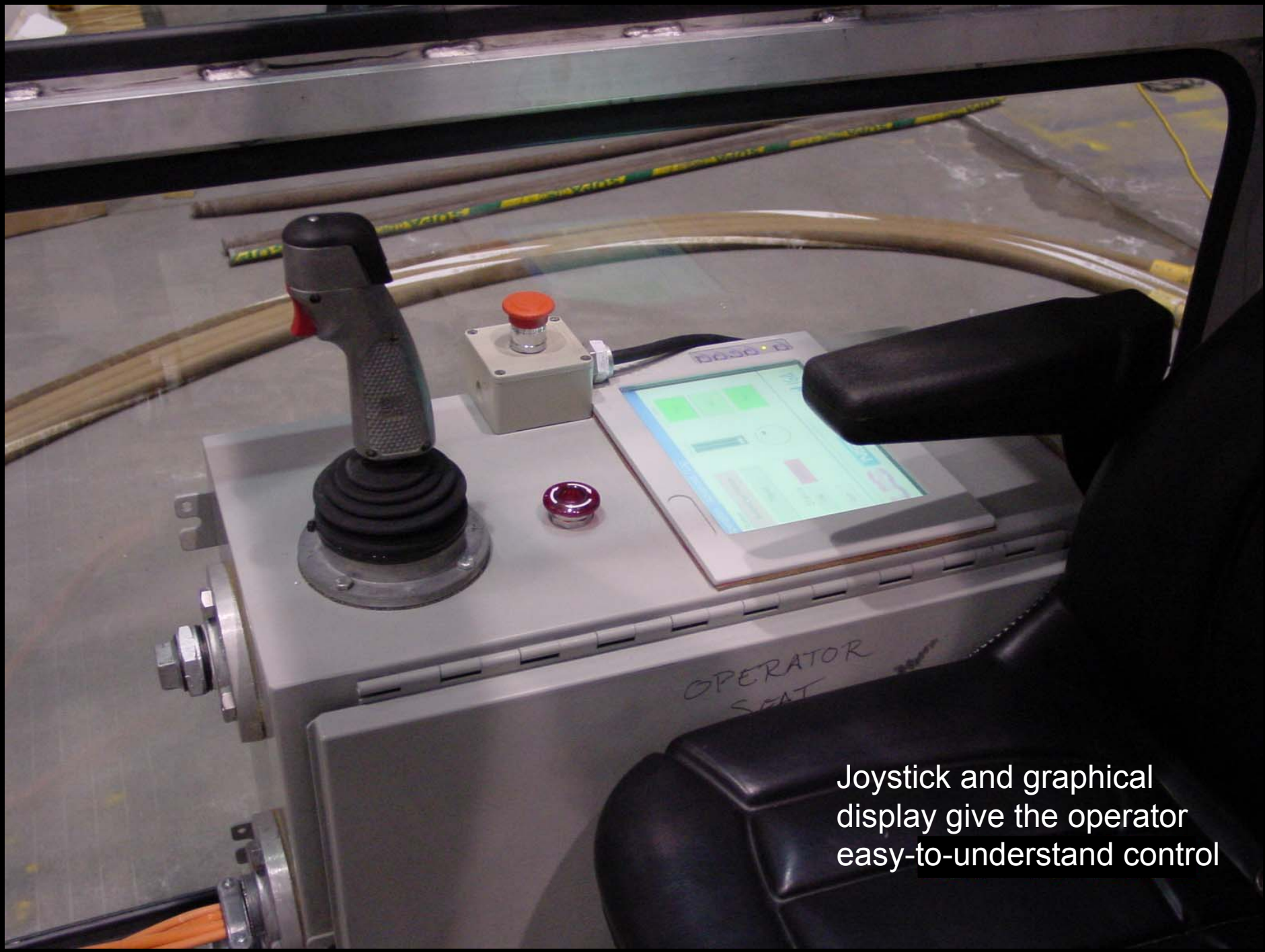


Operator platform is suspended from fixed ceiling pulleys by flexible cables

Motors at center of ceiling mounts control each cable

Serial RS-232 cables link each motor to embedded RT Linux computer


Analog joystick gives operator control over XYZ-Yaw of platform, XYZ-Yaw of media sprayer
Roll and pitch are kept level by automatic computer control



Joystick and graphical display give the operator easy-to-understand control

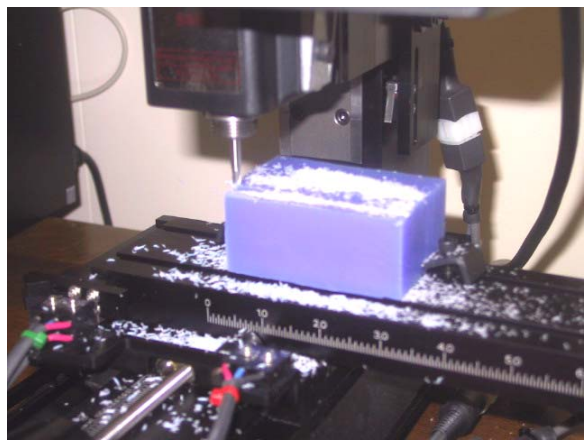
Platform gives smooth, fast motion controlled by operator to access large sections of KC-130 aircraft

Summary

- Linux is a free operating system with embedded- and real-time distributions, useful for research and commercial applications
- Embedded systems need small footprints, low power; real-time systems need guarantees on timing; equipment controllers typically need both
- NIST has used both for automation projects ranging from stepper motor control with 10 microsecond timing to distributed control with real-time serial links

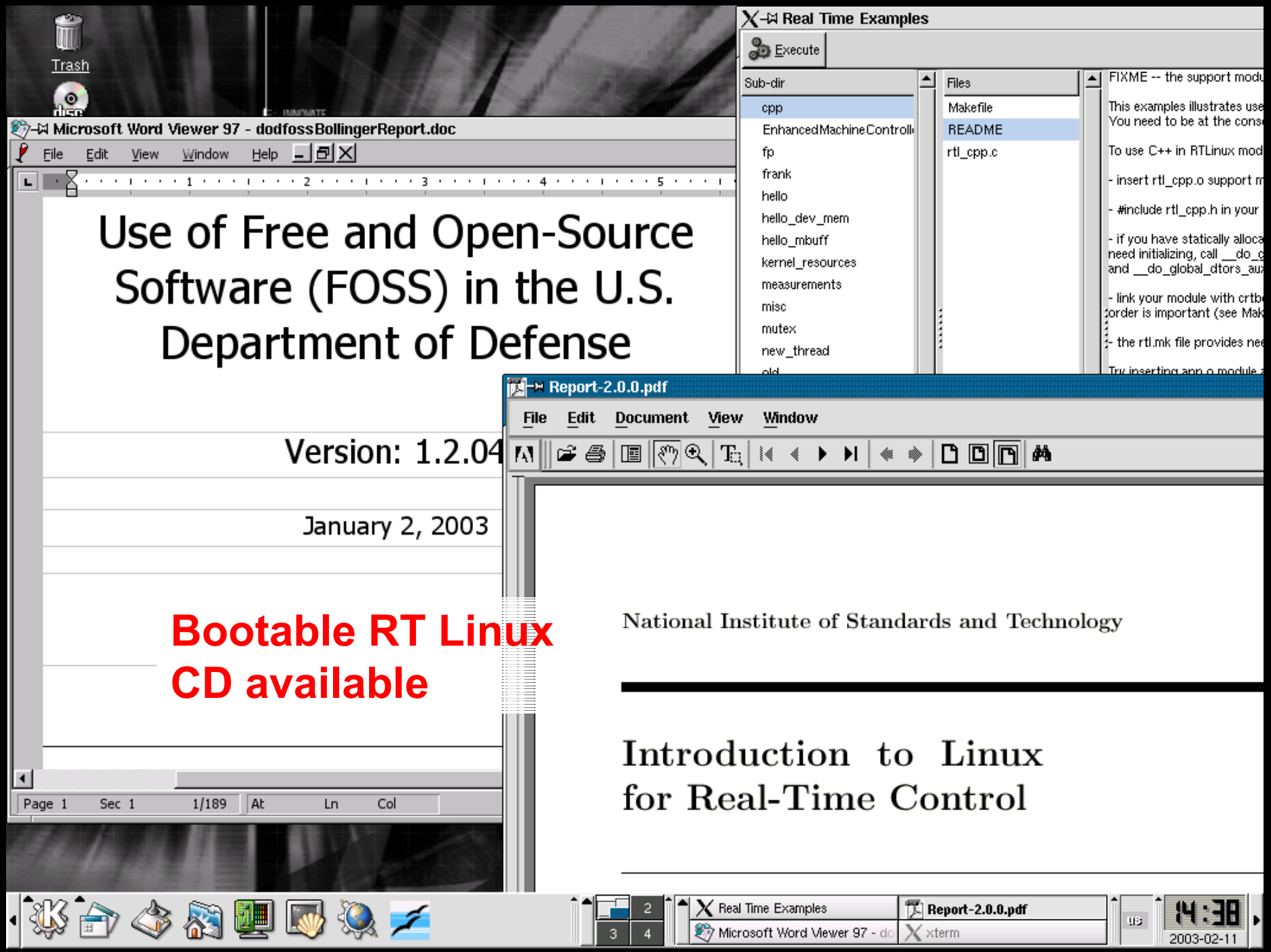
Machine Tool Demo

- Sherline mill retrofit with stepper motors
- 300 MHz Pentium II, 64 MB RAM
- EMC computes stepper motor pulses every 20 microseconds (50,000 times per second)
- Runs standard numerical control (NC) programs from computer-aided design/ manufacturing (CAD/CAM) systems



Real-Time Linux Demo

- Fantazein clock, hacked according to Lineo's Stuart Hughes
- RT Linux gets interrupt from wand sensor, schedules timed releases of byte column outputs to parallel port
- 400 microseconds/byte column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Use of Free and Open-Source Software (FOSS) in the U.S. Department of Defense
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Bootable RT Linux CD available
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Real Time Examples
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