Embedded Systems Programming Instruction Using a Virtual Testbed

Gerald Baumgartner
Dept. of Computer and Information Science
gb@cis.ohio-state.edu

Ali Keyhani
Dept. of Electrical Engineering
Keyhani.1@osu.edu
Summary

Problem
- DSP-based embedded systems are everywhere
- Market is growing exponentially
- High demand for skilled programmers

Solution
- Develop Virtual DSP Testbed
- Uses actual DSP, simulates outside world
- Realistic low-cost teaching environment

- Develop courses based on virtual testbed
- Implement at Ohio State, disseminate nationally
DSP Embedded Systems

Micro to Macro Applications
Motors Are Everywhere:
From Simple to Sophisticated

- Hand-held power tools to Precision-control robots
- Panel-based settings to intelligent spin control
- Window lifts to brake-by-wire
- Single speed to variable speed fans and blowers

*Motion Tech Trends
February 1999
Problem: Teaching DSP Programming

• Embedded systems must be programmed

• Requires large numbers of programmers

• Traditional teaching
  – Interact with actual external devices
    • Expensive, supervised lab, few students
  – Dry course or simple-minded simulation
    • Large classrooms, unrealistic, boring
Teaching with Virtual Testbed

• Actual DSP, simulated devices
  – Realistic programming environment
  – Inexpensive lab (PCs and DSP boards)
  – Testing on real hardware when the program works
  – Allows larger classrooms (e.g., 40 seats)
  – Works even for remote learning

• Control of complicated, real hardware devices in later specialized courses
The Virtual Testbed

Executes native code for embedded processor; communicates with the simulator on the PC.

Runs simulation program, including:
(a) Circuit simulations
(b) Control Timings
(c) User Interface
Controls simulation timing.
Architecture of Virtual Testbed

- User code runs on actual DSP
- Access to devices is intercepted
- Device requests sent to simulators
- External devices are simulated
- Results/interrupts sent back to DSP
- Simulation clock synchronized with DSP clock
- Transparent to user code on DSP
Components of Virtual Testbed

- Programming tools (compiler, etc.)
- Simulators for external devices
- Custom device drivers for DSP
- Software instruments (voltmeter, etc.)
- Web-based graphical user interface
- Component-based simulation builder
Hardware and Software Layers

User Code on DSP

Custom Device Drivers

Devices

Serial Port
RMI-Based Software Model of DSP

- Simulators talk to software model of DSP
- Allows multiple DSPs on same host
- Allows simulators on remote host
- Simplifies porting to new processor
Remote Access to Virtual Testbed

- DSP EVM Boards
- PC or Mainframe Computer
- Server site
- WWW Server
- INTERNET
- Internet users

Executes DSP native code
Proposed Embedded Systems Design Program

CIS 201, EG 167, etc.
Computer Literacy and Introductory Programming Courses

CIS 694J
Object-Oriented Programming for Engineers and Scientists

EE/CIS 694T
Applied Component-Based Programming for Engineers and Scientists

EE/CIS 894U
Applied Use-Case Driven Object-Oriented Analysis and Design for Engineers and Scientists

EE/CIS 894V
Applied Enterprise Distributed Computing Engineers and Scientists

CIS/EE 694X (Au 02)
Intro to Embedded Syst. Prog

EE/CIS 694Y
Embedded Systems Programming II

EE/CIS 694K (Wi 03)
Design of Embedded Systems

CIS/EE 794
Software Architecture for Embedded Systems

EE 694Z
Embedded Electromechanical Systems Design I

EE 894
Embedded Electromechanical Systems Design II
Introductory Courses

• CIS/EE 694X: Intro to Embedded Syst. Prog.
  • Intro to DSP, accessing devices, using timers, interrupts, AD/DA converters, signal processing, motor control
  • Program traffic light, answering machine, audio CD player with oversampling and motor control
  • First pilot course: Autumn 2002

• EE/CIS 694Y: Embedded Systems Prog. II
  • Use of high-level design tools, multitasking, task scheduling, real-time operating system
  • To be developed
Advanced Courses

- **EE 694Z: Embedded Electromechanical Systems Design I**
  - Design of AC drives, Dynamic of Induction Machines,
  - D-Q Rotating Reference frame, PWM techniques
  - DSP Control of AC Machines
  - Sensor less control of induction machines

- **EE 894: Embedded Electromechanical Systems Design II**
  - Advanced PWM techniques, Switch Reluctance and PM machines, Design electric drives for Switch Reluctance machines, Electric brake and Electric Propulsions, DSP
  - Control and four quadrant operation
Capstone Project Courses

- **EE/CIS 694K: Design of Embedded Systems**
  - Variety of realistic design problems
  - Both circuit design and software design
  - Scheduled for Winter 2003

- **CIS 794: Software Architecture for Embedded Systems**
  - Design the architecture of a large embedded system
  - Possibly multiple communicating embedded systems
  - To be developed
CIS/EE 694X: Introduction to Embedded Systems Programming

• Syllabus
  – Interfacing to digital devices, program traffic light
  – Interrupts and timers, again program traffic light
  – Interfacing to analog devices, answering machine
  – Audio signal processing, oversampling of music
  – Stepper motor control, program audio CD player

• Course modules structured around projects

• Enrollment: 26 (comparable lab course: 10)
• Waiting list: 25 (because of lack of DSPs)
Control Program for Traffic Light

- Sample sensors in road
- Switch traffic lights
- Measure traffic volume
- Control timing
- Access devices through device driver functions

- Lab1: using polling and timing loops
- Lab2: using interrupts and hardware timers
Using the Virtual Testbed
EE/CIS 694K: Example Capstone Project

- Example: power converter for un-interruptable power supply
Power Converter Learning Modules

Experiment with basic inverter topology:

1. Experiment with different combinations of switch conditions

☐ T1  ☐ T2

☐ T4  ☐ T5

Output Voltages

Van = +Vdc

Figure 1. Basic Three-phase inverter topology

A basic three-phase inverter topology of the power converter is shown in Fig. 1. The basic operation of the converter requires that both switches cannot be closed at the same time. Furthermore, since the turn on time and turn off time of the power switching devices need a finite amount...
Virtual Instruments/Circuit Mode
Conclusion

• High demand for skilled DSP programmers
• Development of Virtual DSP Testbed
• Development of embedded systems programming and design courses
• Integration with similar cross-disciplinary course development efforts
• National dissemination