

Embedded Systems Laboratory

- Using ARM Cortex M4
- From the Basics to Applications



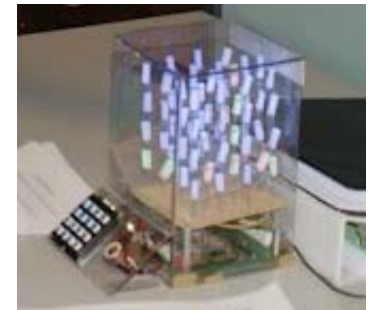
Why M4?

- Market share
- Complexity
- Parallelism
- Verification

Jonathan Valvano

Outline

1. Objectives
2. Approach → Takeaways
3. Boards, Books and Labs
4. Successes → Competitions
5. Conclusions



Engineers make two things:

- Systems
- Interfaces between systems

1. Objectives



- **Outcomes, Measureables**
 - Career opportunities
 - Economic growth
- **Educational effectiveness**
 - Improved performance
 - Reduced resources
- **Educational team**

2. Takeaway: Bottom up (what?)

- **From simple to complex**
 - **Transistors → Gates → Computer → Systems**
 - **Assembly → C → Java/C++**
- **Abstraction**
 - **Understand → Put it in a box → Use the box**
- **Systems**
 - **Take two boxes → Connect together**

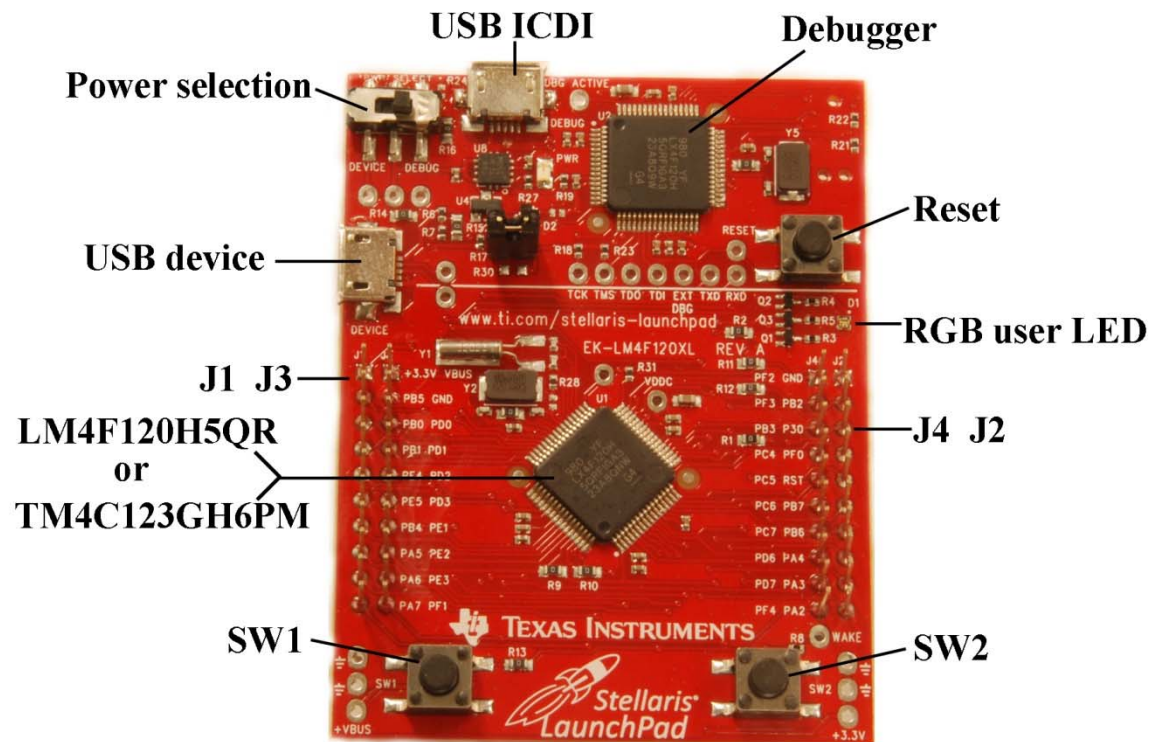
2. Takeaway: Lab-centered

Students learn by doing

- **Equipment must work**
- **Assignments must be clear**
- **Tasks support learning objectives**
- **Professors must do labs**

2. Takeaway: Empower Students

- Students should have their own board

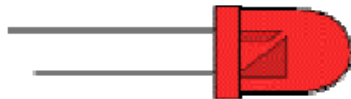


Jonathan Valvano

2. Takeaway: Empower Students

Students need to learn outside of lab

- Students should have their own DVM
- Show labs to friends and parents
- Encourage them to work beyond lab
 - Find sources of free parts
 - Give simple stuff away



Jonathan Valvano

2. Takeaway: Flexibility

Students learn at different speeds and in different ways

- **Some need structure**
 - **Demonstrate working labs**
- **Some thrive on open ended design**
 - **Let students negotiate deliverables**
- **Allow for extra credit**
- **Create an open-ended design lab**

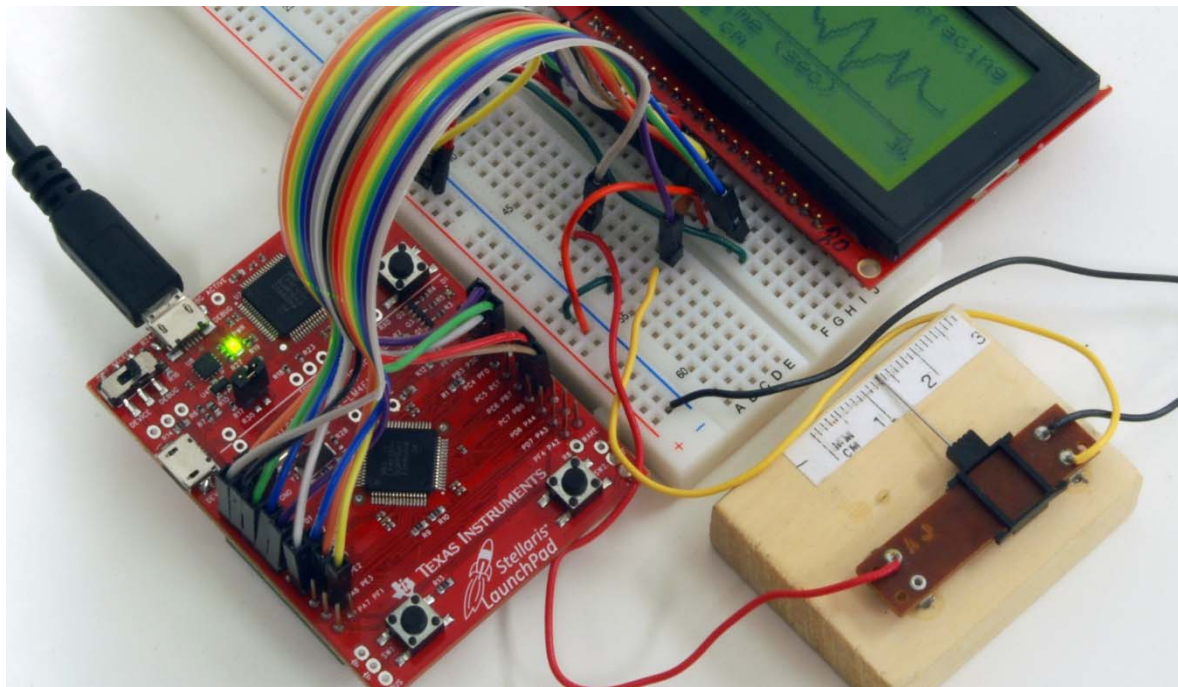
2. Takeaway: Team-approach

It takes a village to educate

- **Empower the TAs**
 - Invite them into the decision circle
- **Empower the staff**
 - Invite them into the decision circle
- **Make excuses to show off projects**
 - Chairman, Dean, Newspaper

3. Boards, Books and Labs

Stellaris LaunchPad LM4F120/TM4C123



- 43 I/O pins
- 32k RAM
- 256k EEPROM
- 80 MHz Cortex-M4
- serial, SPI, ADC
- timer, PWM, DMA
- interrupt controller
- JTAG debugger
- serial through USB
- floating point

EK-LM4F120XL → EK-TM4C120GXL

Jonathan Valvano

\$12

3. Boards, Books and Labs

LaunchPad needs graphics



<insert
video>



Name	Pixels	Color	Cost (100)	Website
Graphic LCD 1.77" 84x48 - Nokia 5110, 5 pin, 8 wire	4032	no	\$7.96	https://www.sparkfun.com/products/10168
Sitronix ST7735R 18-bit color 1.8" TFT LCD display	20480	yes	\$19.96	http://www.adafruit.com/products/358
Monochrome 0.96" 128x64 OLED	8192	no	\$15.60	http://www.adafruit.com/products/326
Monochrome 1.3" 128x64 OLED	8192	no	\$19.60	http://www.adafruit.com/products/938
OLED Breakout Board - 16-bit Color 0.96"	6144	yes	\$23.96	http://www.adafruit.com/products/684
Kentec EB-LM4F120-L35 , 3.5 in, 15 pin, booster 320x240x16	76800	yes	\$35.00	Newark 48W2063

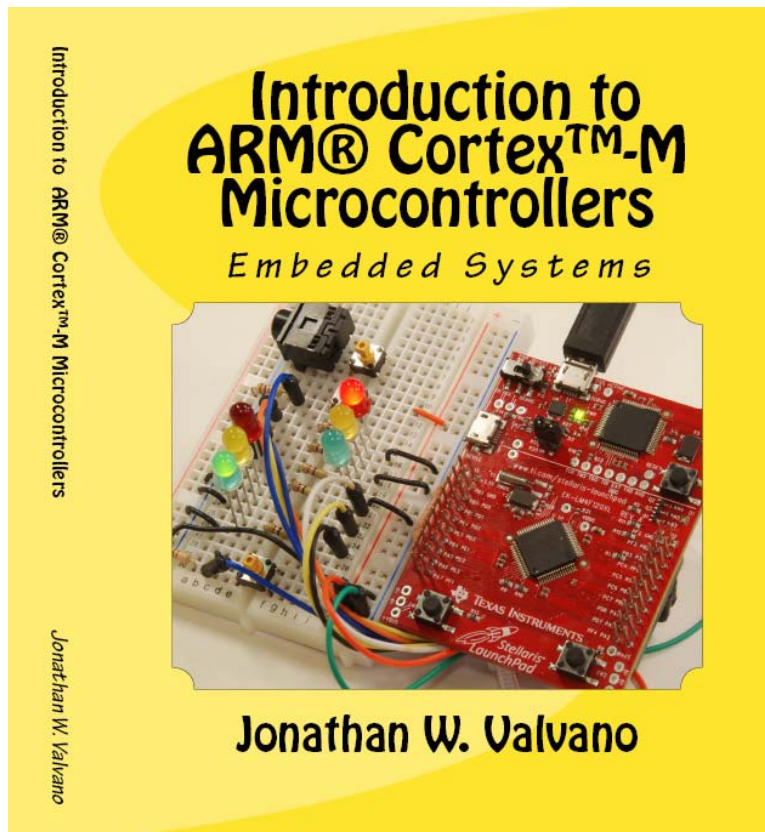
3. Applications



- **Compiler, Simulator, Debugger**
 - Texas Instruments Code Composer Studio
 - Keil uVision
- **Circuit design and PCB layout**
 - PCB Artist
 - National Instruments Multisim, Ultiboard
- **Design tools**
 - Texas Instruments Filter Pro

3. Introduction EE319K

Volume 1 (freshmen EE or BME)



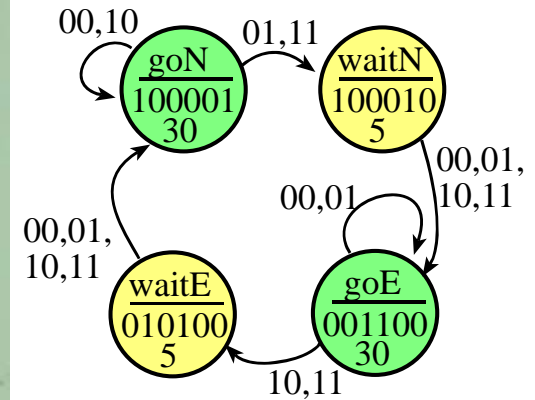
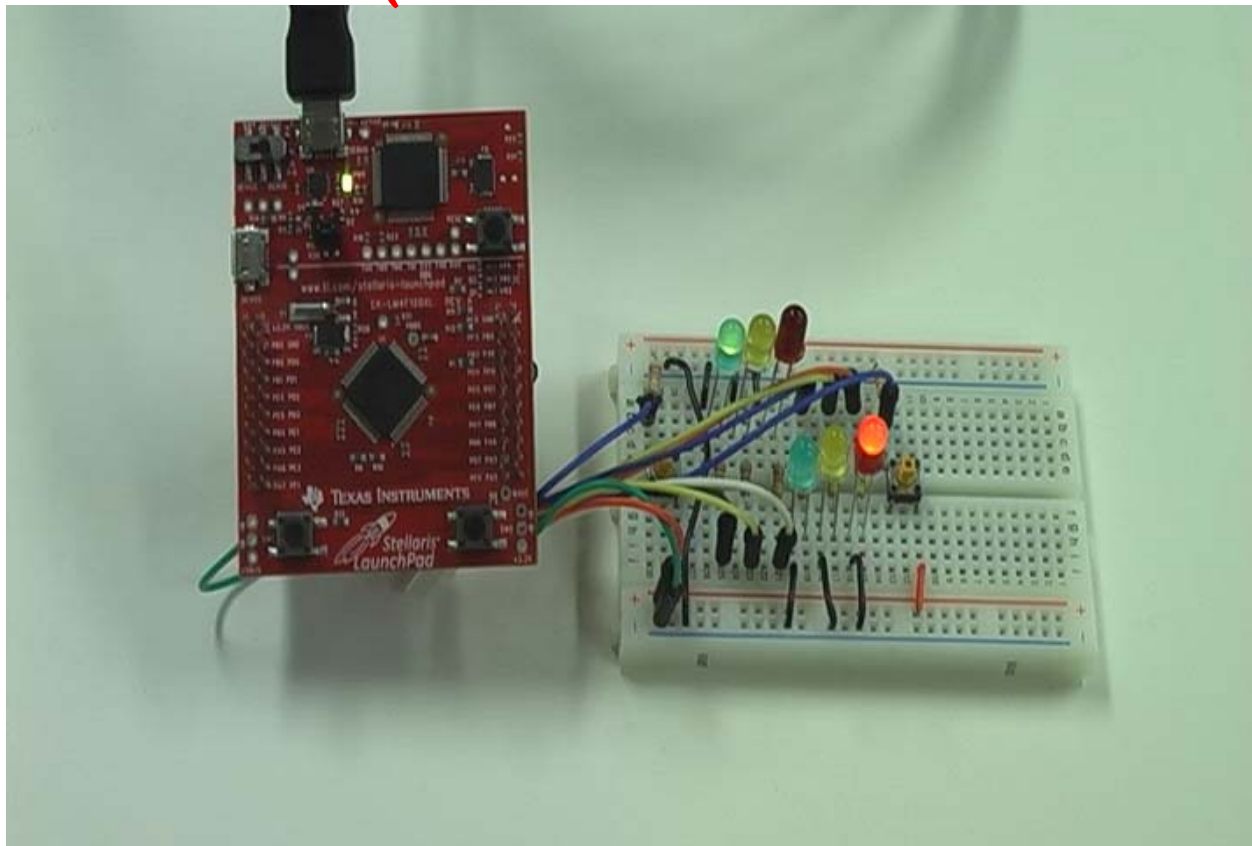
- Assembly language programming
- Switch and LED interfacing
- Design and Debugging
- Finite State Machine
- Local variables and C programming
- DAC output and interrupts
- LCD/OLED interface, fixed-point
- ADC input, systems design
- UART and distributed systems
- Capstone design (video game)

Jonathan Valvano

500 pages, \$41

3. Introduction EE319K

Volume 1 (freshmen EE or BME)



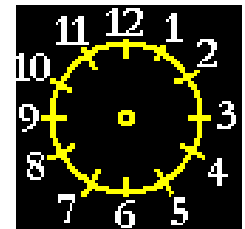
3. Interfacing and Systems EE445L

Volume 2 (junior EE)



Jonathan Valvano

- Graphics device driver
- Hardware/software debugging
- Design and debugging
- Alarm clock
- Stepper motor
- Music player
- Temperature data acquisition
- ZigBee wireless network
- PCB layout, power
- Capstone design (open ended)

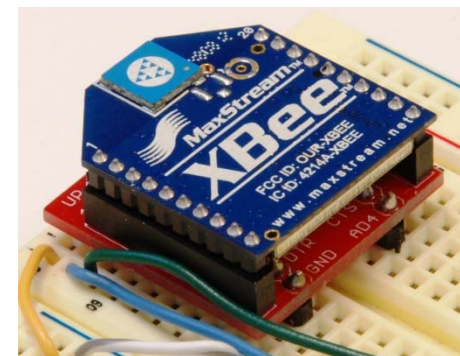
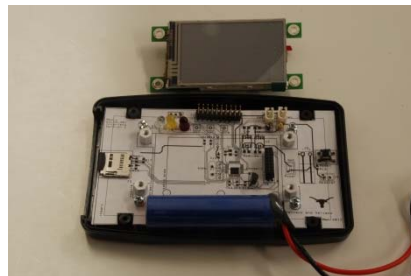
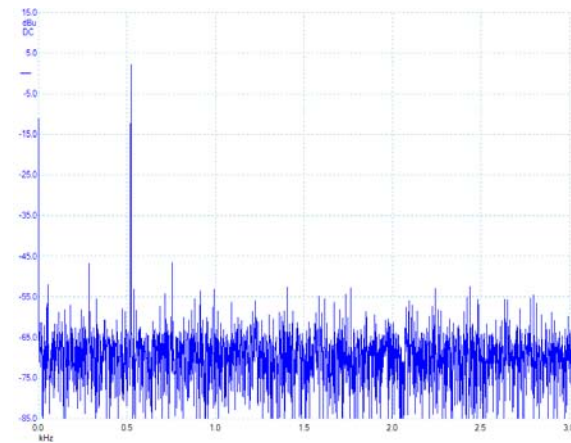
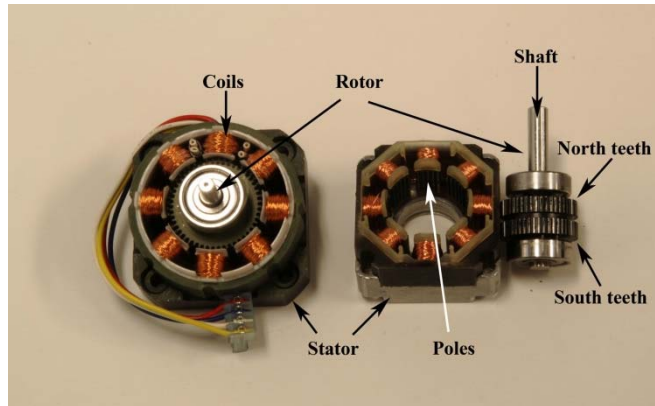


Kindle version

600 pages, \$42

3. Interfacing and Systems EE445L

Volume 2 (junior EE)

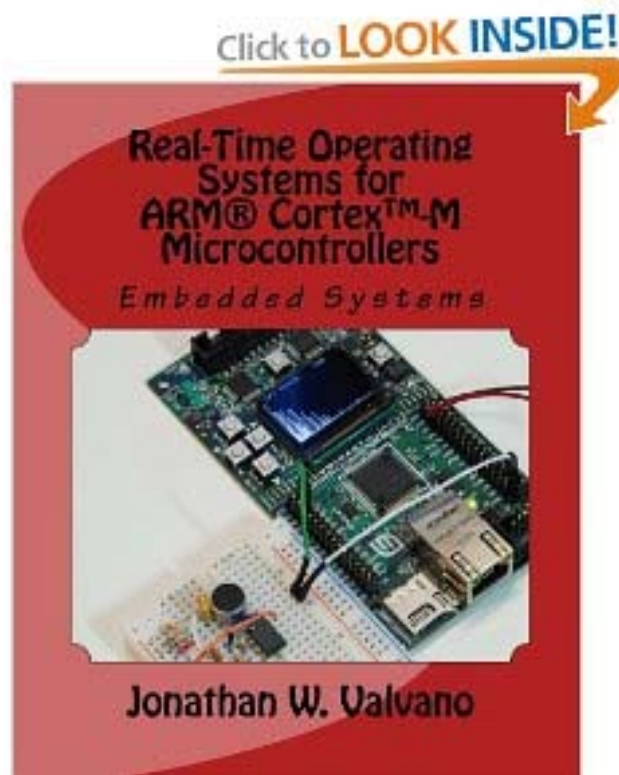


Jonathan Valvano

<insert video of an
EE445L stepper >

3. Real-Time Operating Systems EE445M

Volume 3 (senior/grad EE)



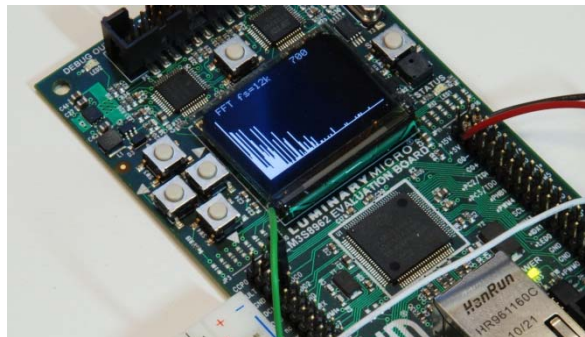
- Memory manager, device driver
- Thread switching RTOS
- Blocking semaphores
- Digital and analog filters
- File system
- CAN or Ethernet network
- Autonomous robot racing

Jonathan Valvano

400 pages, \$36

3. Real-Time Operating Systems EE445M

Volume 3 (senior/grad EE)



<insert video of an
EE445M spectrum>

3. Support for teaching

Web site (download and edit)

- Examples for LM3S811, LM3S1968, LM4F120
- PowerPoint slides
- Lab manual
- Data sheets
- <http://users.ece.utexas.edu/~valvano/>

EdX Course Spring 2014

Launchpad tester

Adopt a book →

Free parts for Launch

<http://users.ece.utexas.edu/~valvano/arm/tester/>



Jonathan Valvano

4. Competitions: Motivations

Students need to appreciate relevance

- **Appropriate use of teams**
- **Build things that are fun to play with**
 - **Show off to friends, family, interviewers**
- **Competitions**
 - **Fun, intense**
- **Open-ended**
 - **Creativity, life-long learning, springboard**

4. Competition

Volume 1 (freshmen EE or BME)

- Handheld game
- Peer review
- Teams of 2



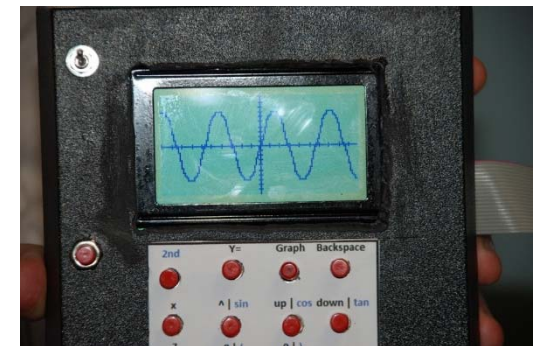
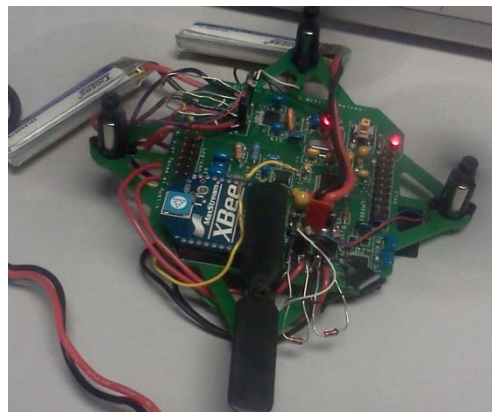
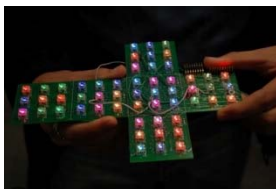
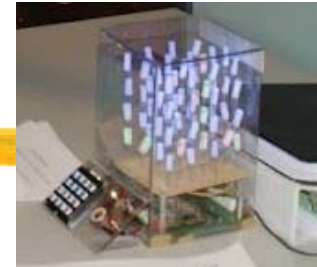
EE319K
Introduction to Embedded Systems
Univ of Texas at Austin

Jonathan Valvano
December 2012
<http://users.ece.utexas.edu/~valvano>

4. Competition

Volume 2 (junior EE)

- Requirements document
- Design cycle
- Design for test
- Systems Engineering
- Verification

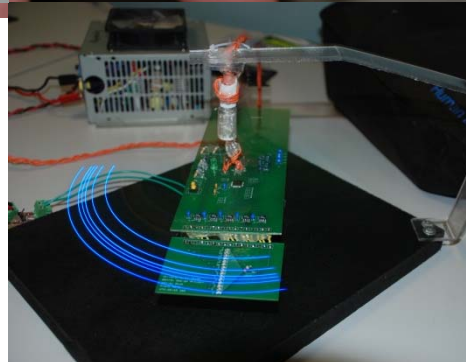
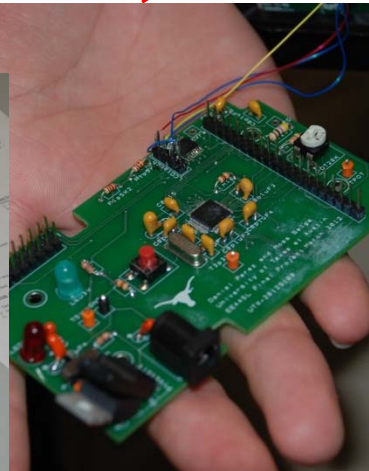


<http://www.youtube.com/watch?v=K9FD50qpGwg>

Jonathan Valvano

4. Competition

Volume 2 (junior EE)

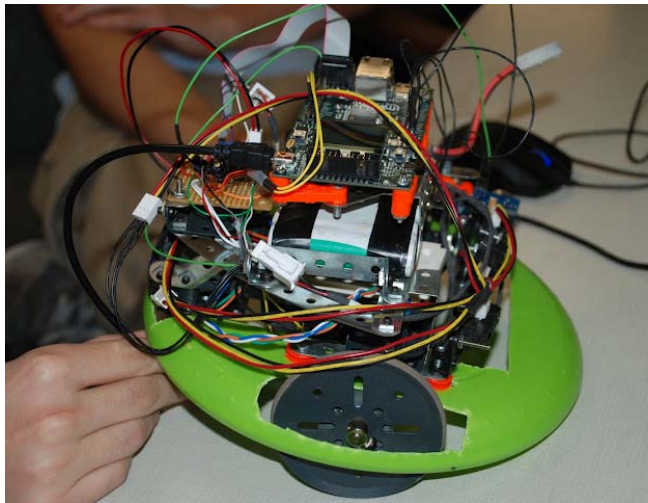


Jonathan Valvano

5. Competitions

Volume 3 (senior/grad EE)

- Autonomous Robot Racing
- Teams of four



EE345M/EE380L.6
Formula 0001 Racing
Univ of Texas at Austin

Jonathan Valvano
May 2011
<http://users.ece.utexas.edu/~valvano>

6. Conclusions



- Bottom-up
- Lab-centered
- Empower the students
- Motivate the students
- Be flexible
- Be a team builder
- Make a plan and do it

Interesting web sites

Example code

<http://www.ti.com/tool/sw-lm3s>

<http://users.ece.utexas.edu/~valvano/arm/>

<http://www.ti.com/tool/ek-tm4c123gxl>

Free samples

<http://www.ladyada.net/library/procure/samples.html>

Compilers

<http://www.ti.com/tool/ccstudio>

<http://www.keil.com/arm/mdk.asp>

Jonathan Valvano

For more information

Jonathan Valvano

<http://users.ece.utexas.edu/~valvano/>

EE319K Introduction

EE445L Interfacing and systems

EE445M Real-time operating systems

valvano@mail.utexas.edu

Texas Instruments

univ@ti.com

Jonathan Valvano

4. Top ten fundamental topics (10,9,8)

- **Design for test**
 - Begin each project with a plan for testing
- **Current, voltage, power, energy, time**
 - Intuition comes from repeated experiences
- **Resistance, capacitance, inductance**
 - Capacitance is good for analog filters
 - Capacitance is bad for digital signals
 - Motors have L and emf

4. Top ten fundamental topics (7,6,5)

- **Pointers and numbers**
- **Networks and Parallel Systems**
 - **Collection of interfaces**
 - **Share physical media**
 - **Share a data protocol**
- **Real-time Systems**
 - **Hardware-software synchronization**
 - **Bounded latency, buffered I/O**

4. Top ten fundamental topics (4,3,2)

- **Size matters**
 - Cost, power, size, weight, noise
- **Requirements document**
 - What are we doing?
 - When are we done?
- **Time**
 - Manage it like a resource, time jitter
 - Measure period, pulse width, frequency

4. Top ten fundamental topics (1)

- **Quality matters**
 - **When you make a mistake, somebody dies**
 - **Take responsibility**
 - **Design a good test procedure**
 - **Customers like products that work**

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products

Audio	www.ti.com/audio
Amplifiers	amplifier.ti.com
Data Converters	dataconverter.ti.com
DLP® Products	www.dlp.com
DSP	dsp.ti.com
Clocks and Timers	www.ti.com/clocks
Interface	interface.ti.com
Logic	logic.ti.com
Power Mgmt	power.ti.com
Microcontrollers	microcontroller.ti.com
RFID	www.ti-rfid.com
OMAP Applications Processors	www.ti.com/omap
Wireless Connectivity	www.ti.com/wirelessconnectivity

Applications

Automotive and Transportation	www.ti.com/automotive
Communications and Telecom	www.ti.com/communications
Computers and Peripherals	www.ti.com/computers
Consumer Electronics	www.ti.com/consumer-apps
Energy and Lighting	www.ti.com/energy
Industrial	www.ti.com/industrial
Medical	www.ti.com/medical
Security	www.ti.com/security
Space, Avionics and Defense	www.ti.com/space-avionics-defense
Video and Imaging	www.ti.com/video

TI E2E Community

e2e.ti.com