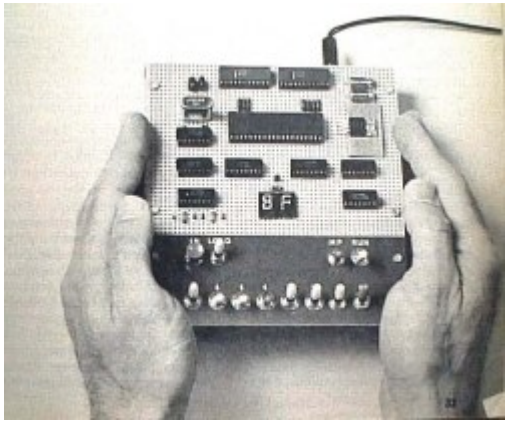
History
1970s

- Microprocessors were Becoming Ubiquitous
  - Toys
    - Mattel Big Track-late 70s
      - Dual opposed Wheel
      - Magnetic clutch
      - Programmable
  - Start of Hobby Computing
    - Apple][
    - Commodore PET
    - Radio Shack TRS-80
    - COSMAC ELF



My First Robot
1979

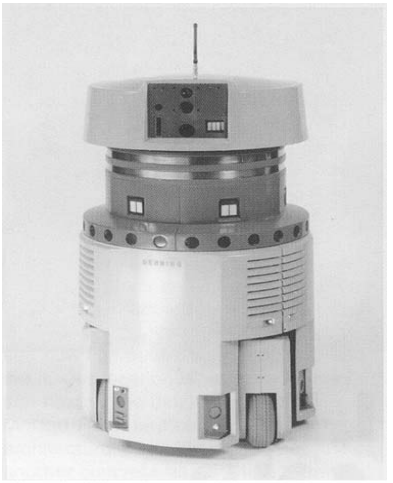
- Best Recollection
  - Bigtrack Chassis
  - Wire-wrapped RCA 1802 ELF
  - Bumper Switches
  - 2N2222 Motor drivers
  - Built EPROM programmer
  - 5V CPU
- Map room on TV screen
  - Built in video PIXIE controller

Denning Mobil Robotics
1985

- Autonomous
  - Self charging
    - Align and interface with base station
  - Able to plan path from room to room
    - Dead reckoning
    - IR beacons
  - Avoid obstacles
  - Sensors
    - Infrared
    - Ultrasonic
- Command Driven
  - Go to location on demand

DMR, Continued

- Prototype
  - Ultrasonic
  - Motor Control
  - Dual opposed wheels
  - Z-80
- Sentry
  - Syncro-Drive
    - 3 wheel drive
    - 3 wheel steer
  - Industrial sized



Denning System

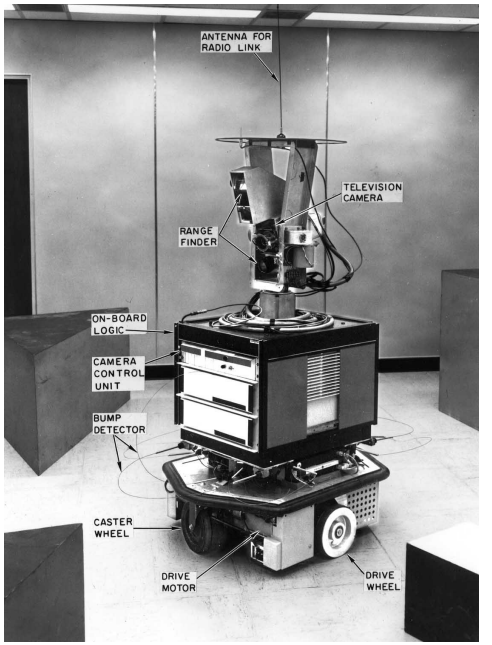
- Computers
  - 68000 Robot System
    - OS9
    - STD-BUS
      - Standard before IBM ISA
  - Z-80 Expert Systems
    - STD-BUS
    - Ultrasonic Ring
    - Motor Control
    - Radar
    - Other
- RS-232 Serial Bus
  - Multi-drop network
  - Software Protocol

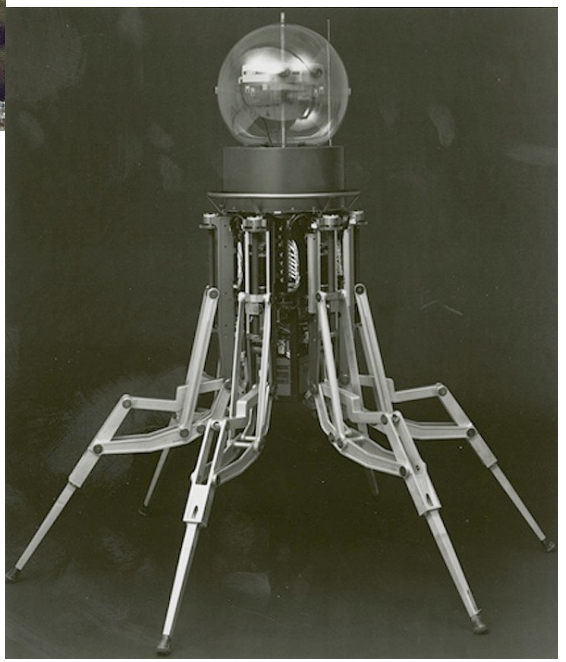
Why is Denning Still Important?

- A lot of innovation
  - Robotic Motion
  - Robotic Navigation
- Worked with university scientists
  - Hans Moravec
  - James Crowley
- Still Relevant Today
  - Code obsolete
  - System obsolete
  - Accomplishments Still Hard to Duplicate
  - Amazing for its time
  - Research still relevant and available on internet

Robots of the Past

- Shakey
  - Vision
  - Object Avoidance
- Kludge
  - Robot Mobility
  - 3 wheel drive
  - 3 wheel steer
- ODEX-I
  - Spider
  - All terrain walker
- HERO
  - Hobby





Robots of Today

- Vgo
  - Mobile teleconference
    - Linux PC Robot and Skype?
- White Box
  - Next Generation HERO
- Roomba
  - Domestic appliance
- Aibo
  - Cyberdog? Really?
  - Doctor Who K-9?
    - Sorry, can't talk about a robotic dog without mentioning K-9
      - Yes, I know its not new

Vgo
Tele-Presence

- Novel application
  - Forced fit
    - Better ways of accomplishing goal
- Cost/Benefit: $6000
  - 12 laptops
    - Redundancy
    - Reliability
    - Won't get stuck/lost
    - Batteries
- LinuxPCRobot with Skype
  - Small VGA screen

White Box

- The latest generation of HERO
  - HE-ROBOT
  - White Box PC-ROBOT
- PC On Wheels
- Stepper Motors
  - Poor torque
- Web Cam
- Cost
  - Chassis with no computer $4995 (robotshop.com)
  - Chassis with Mini-ITX: $5795
    - $800 for a motherboard?

Self Parking Cars

- Early adopters
  - More of a novelty than a reliable feature
- Algorithmic Simplification
  - Rigid “well known” problem solution
  - Driver controls gas and brake
  - Easily confused
    - Theory meets practice again
      - Object avoidance
      - Try a snow bank
- Problematic
- Cool beginning none the less
  - A good step forward

Blue Sky Projects

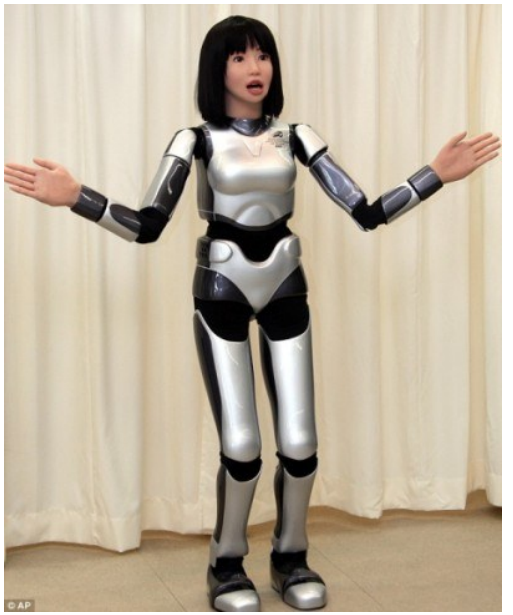
- Driver-less Vehicles
  - Google's Automated Car
  - DARPA Challenge
- Years from now
  - Liability Insurance alone!
- Would YOU trust your life?
  - Linux?
  - MS-Windows?
- Prediction
  - We are decades from driverless cars on populated roads
  - Research will augment safety systems

Holy Grail: Artificial Intelligence
Real AI vs Expert Systems

- What is AI
  - Machine thinking
- Is Google AI
- Is Amazon's recommendations?
- Is Watson?
- Is a self parking car?
- What is AI?
  - Depends on who you ask
    - Small AI vs Big AI
    - Intelligent tasks
    - Intelligence
- Robots need to think
  - We need to understand what thinking is
  - This is what it is really all about

State Of the Art

- Some very cool stuff
- Rest single purpose/conceptual
  - Facial Expression
    - Making Humans Comfortable
  - Mechanical Models
    - Walkers
    - Segway
    - Fembot
    - Roomba
    - Ping Pong
- Lots of Advancement, but..
  - How far have we come?
  - Is any of it “intelligent?”



Is this 25 years worth of Innovation?

- Roomba is little more than a BigTrack with a broom
- Segway is a feat of process control magic, but hardly a robot.
- The Walking Robots are more centered on structure and automation.
- Focus seems to be on mechanics, aesthetics, and mimicking human behavior.
- Self parking cars, don't, not really
- Researchers are still trying to nail down navigation and object avoidance in an organic environment
- Hobbyists and Engineers in their garage or basements can still impact state of the art.
- Robotics is the ultimate AI platform!

Problem with Robotics
Diverse Set of Disciplines

- Many Different Disciplines
  - Electrical/Electronics
    - Digital/Computer I/O
    - Analog Motor Amplifier/Drivers
    - Analog Sensors
    - Power Supplies
    - Efficiency
  - Mechanics
    - Chassis
      - Stability
      - Strength
    - Movement
    - Weight

Diversity, cont.

- Computer Science
  - Warning! Programmer with a screwdriver
  - real-time or near real-time techniques
  - High level process control
  - Low level Device I/O
  - Math and logical concepts
- Computer Infrastructure
  - Administration
  - Configuration
  - troubleshooting
    - Software
    - Hardware
    - Software and Hardware

Problem with Robotics
Cost

- People are very generalized, machines tend not to be.
- Its expensive to make a machine to do compound tasks
  - Robots usually cost more than the task is worth
  - Humans are cheap
    - $70K/year for 24x7 humans
      - "*Man is the best computer we can put aboard a spacecraft, and the only one that can be mass produced with unskilled labor*" Werner von Braun
  - You can steal a robot
  - You can sell robot parts
- Durability and Reliability
  - All robots today are unreliable
  - Require human assistance
  - Require maintenance
- Robots are dumber than the dumbest people.

Problem with Robotics
Environment

- The real problem is that robots are ill suited for an organic environment
  - Machines tend to work better in an environment intended for them.
    - Car's need roads
- Robots and environments could be managed.
  - R2D2
    - Impractical
    - Special interfacing
      - bluetooth?
      - I/R?
    - Sorry, You can't talk about robotics without mentioning R2D2 at least once
      - Yes I know its not new

Problem with Robotics
The 3D World is Tricky

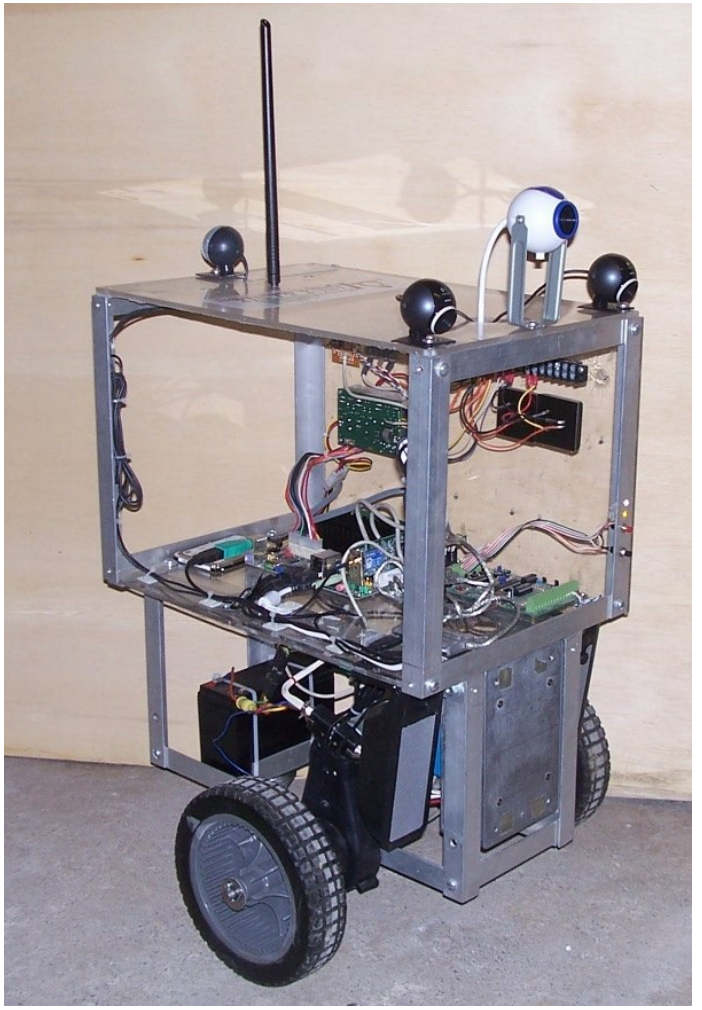
- Art vs Science
  - Engineering
  - Theory is Important
    - Just a start
    - Exceptions tend to be bigger than theory
  - Trial and Error
- Gasp, AGILE
  - Iteration
  - Experimentation
  - Learn as you are doing
    - The sum greater than the pieces
- Try to visualize how you solve the problems you want the robot to solve

Real World Example
Odometry: Differential Wheel Motion

- Wheels not infinitely thin
  - Radius calculations need to be fuzzy
    - Wheel width and tread will cause path inconsistency even on a perfect surface
- Surface not consistent
  - Dust, dirt, objects on floor, and wheel slip
  - Changing Surfaces, rugs, mats, etc.
- Power not infinite
  - Rolling over object requires change in current/torque
    - Current not infinite
  - Motor's power limited
    - Even if enough power is available, motor's internal resistance limits torque
- It will NEVER work like a simulation
  - 3D World has too much random
- Need positional feedback separate from motion system

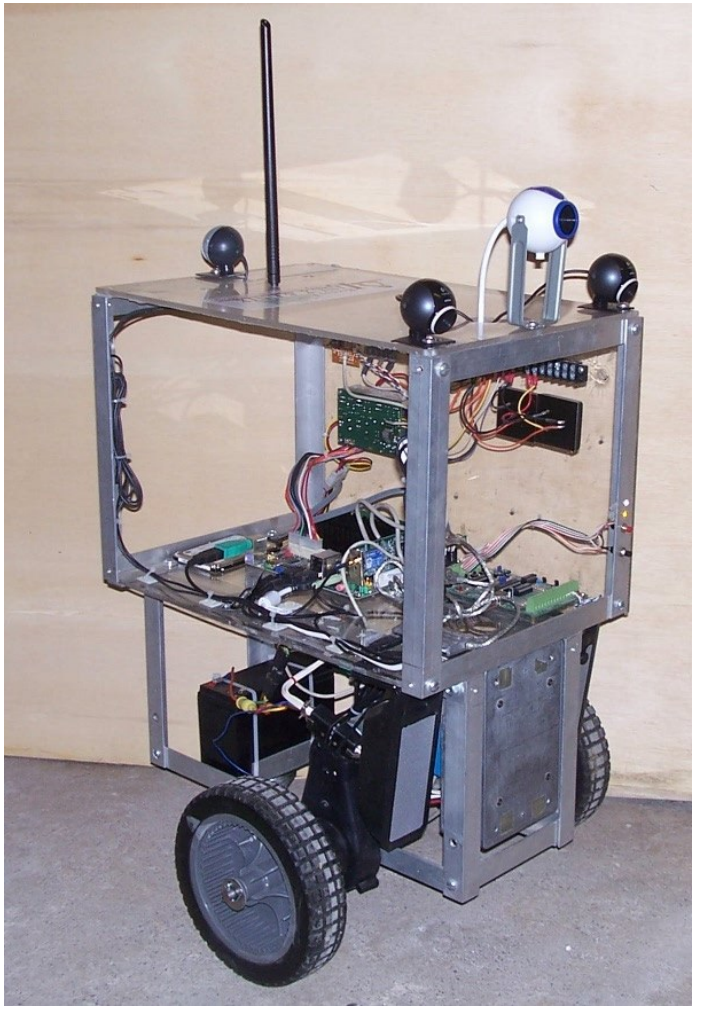
Linux PC Robot

- Why?
  - Its fun
  - Relatively inexpensive
    - Less than $500 in parts
    - WhiteBox Robot costs $5000~$7000
    - Vgo costs $6000
  - Hope to spur innovation
    - Hobbyist
      - electronics
      - computers
- Can be used to address the real problems
  - Navigation
  - Object avoidance
  - Goal seeking



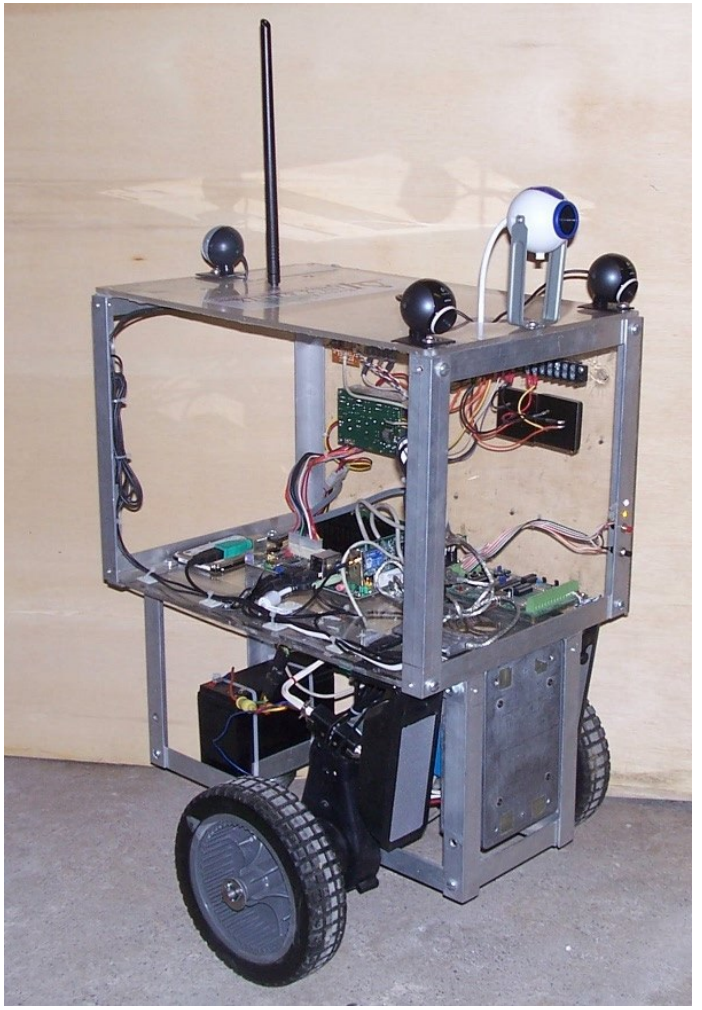
Linux PC Robot
Design Goals

- Mostly COTS - Consumer Off The Shelf
  - Standard Motherboard
  - Linux
  - Boot Disk
  - I/O Interface Card
  - Power Supply
  - Mouse Motor Encoder
  - Motor Amplifier
  - Battery
  - Networking



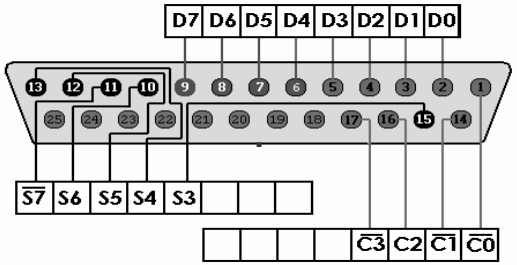
Design Goals, cont.

- Standard Linux development Environment
- PID Implementation
  - No special real time kernel
  - Tolerant of time period variation
  - No separate PIC development
- Joystick Interface
  - For manual operation
- Kids Ride Around Car
- Common materials
- Easy to build and augment



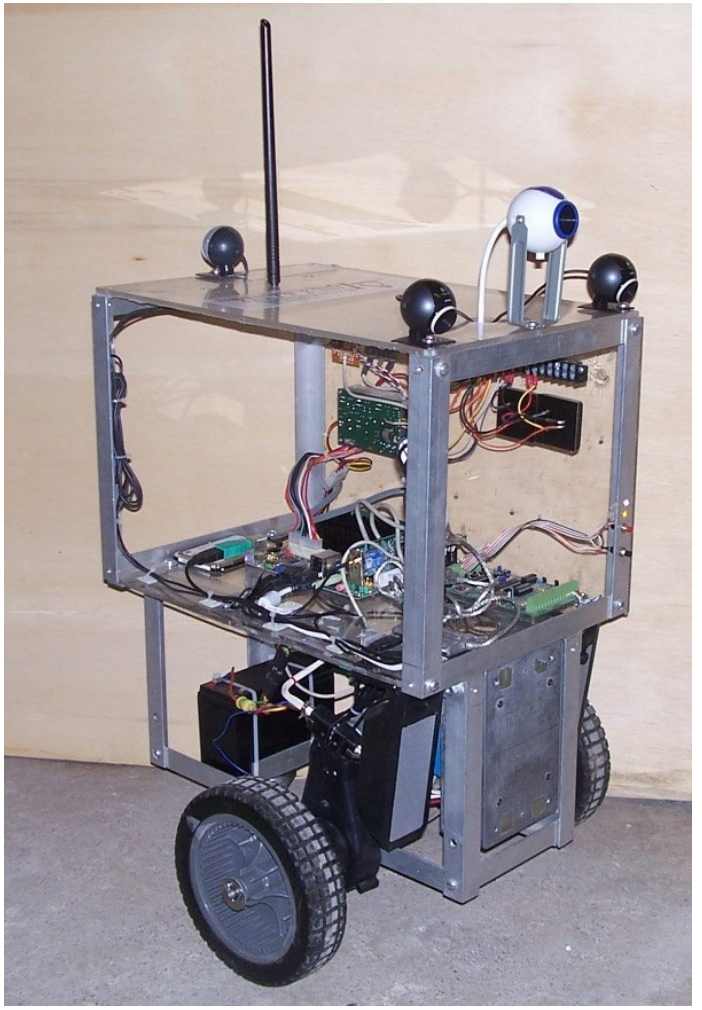
Design Goals, cont.
Use Standards

- Use standard interfaces and devices
  - Reduce development time and effort
  - Lower cost
  - No need to re-invent wheel
    - An old mouse is just a couple encoders
      - And encoders can look like mice!
    - A PS/2 port is just a serial port
    - A printer port is just an I/O port connector
    - A keyboard is just a bunch of buttons
  - Lots of existing utilities
  - A “standard” device can test your hardware
  - Existing libraries simplify development
  - RIP: ISA bus



Linux PC Robot
Problems

- One of a kind issues
  - Like custom cars!
  - No one to ask
  - Devices not meant for “that”
  - Thinking in analogy
    - How is this problem like another?
- It's not a server
  - Or a desktop or a laptop
- Not all things work as expected
- Shouldn't need a keyboard and display
- Getting to 100% wireless, a chore
- Networking issues across sites
  - wireless



Standard Motherboard

- Advantages
  - Standard Parts
  - Multiple Vendors
- Disadvantages
  - Power consumption
  - Form Factor
  - I/O
    - No built in i/o
    - No counter timers
- 8510M0
  - Intel Atom Dual Processor
    - Dual CPU
    - Hyper-threading
  - Cheap

Linux

- Swiss Army Knife
  - Server version
    - No GUI needed
      - Not usually anyway
    - Smaller footprint
  - Networking
    - Wireless
      - External antenna
  - Device support
    - USB
  - Lots and lots of utilities
    - Speech
    - Player/Stage
  - Ubuntu 10.04 LTS

Boot Disk and Storage

- Standard Hard Disk
  - Shock Sensitivity
- SSD Hard Disk
  - Expensive
  - Probably best choice
- Compact Flash
  - cheap
  - Mini-IDE/SATA interface
  - CF Adapter
  - More similar to embedded
- USB Stick
  - Requires Motherboard Support
    - Most have it these days
    - Not always reliable

Power Supply

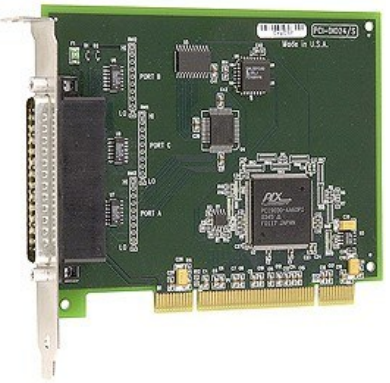
- http://www.mini-box.com/DC-DC
- M3-ATX-HV 95W - $65
- Efficiency
  - Computer probably uses more power than motors
  - PCs not very efficient, assume 110V power cord
- ATX requirements
  - Lots of current!
  - 3.3V, 5V, 12V,-12,-5
- Not simply power
  - Power on (16)
  - Power Good (8)

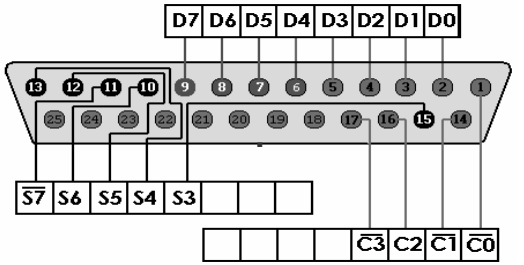
Battery

- Standard “SLA”
  - Gell Type
  - Cheap
  - Heavy, low Power to Weight Ratio (PWR)
- NiMH
  - Light, better PWR
  - More expensive
- Lithium-ion
  - Lighter, even better PWR
  - Even more expensive
  - Potentially dangerous still

I/O Interface Cards

- Peripheral
  - Velleman USB K8055
  - Vellemen Parallel/I2C K8000
- PCI Bus
  - PCI-DIO24
- PC Parallel Port
  - 278/27A or 378/37A
    - Must be root
    - Instructions outb, inb
    - www.linuxpcrobot.org Has more information
- You Do It Electronics
- RIP: ISA Bus



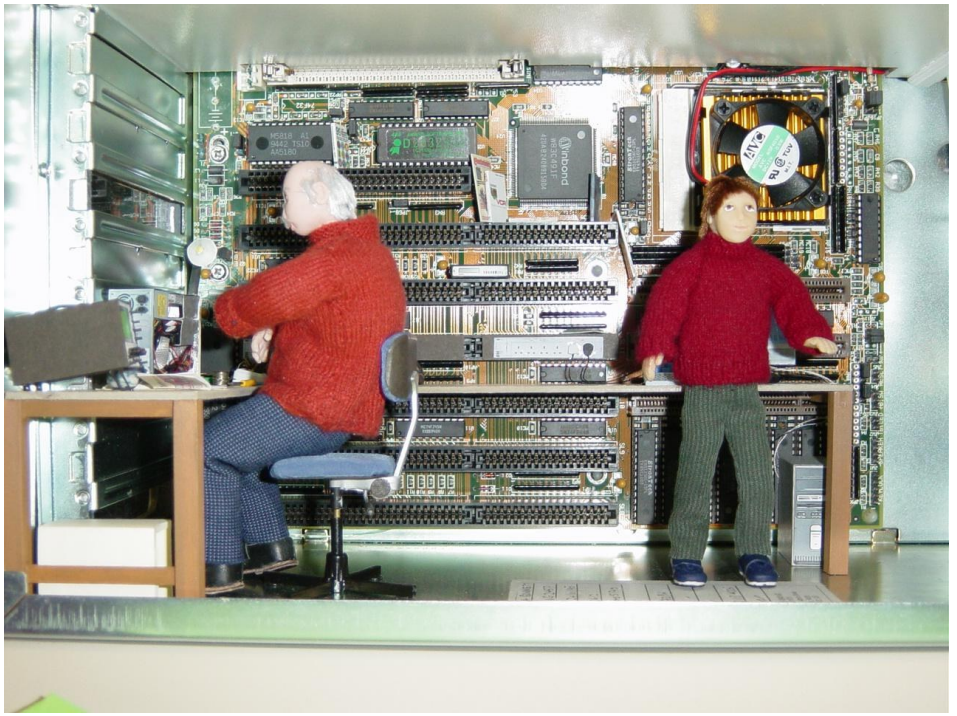


Joystick Interface

- Standard USB HID
- X/Y control
- 90% of I/O and interfacing done
  - Before IBM PC, needed two AD converters
  - IBM PC, time based R/C with comparator
  - Consumer USB units better than old Joystick port
- TCP/IP client/server
- virtual joystick

Stuff You Need to Build or Modify

- Motor Encoding System
  - PS/2 Mouse
- Motor Driver
  - H-Bridge
- Chassis
  - Keep the toy or Build a Frame
- Wheels
- Wiring Harness

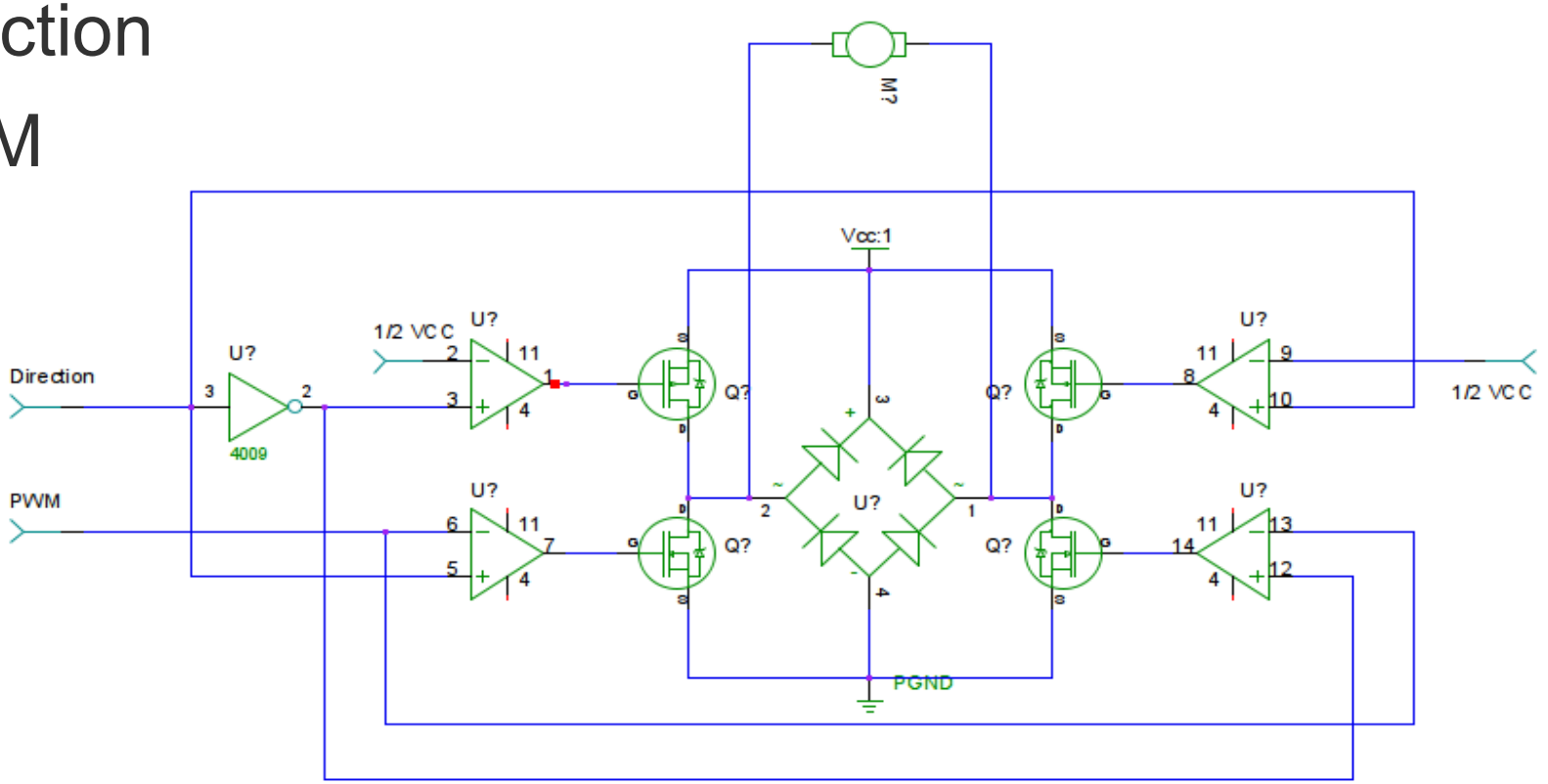


Mouse Motor Encoder

- Standard device
  - 90% of I/O and interfacing done
- PS2 vs USB
  - PS2 polling
  - USB auto-send
    - Not suitable for motor encoder
- Response Time
  - slow
- Outstanding issues
  - Motor shaft too fast, have to move pickups
  - Ball Mice all but extinct
    - Arduino based replacement?

Motor Driver
Custom Device

- H-Bridge
  - MOSFET
  - CMOS 12v logic
  - Direction
  - PWM



Chassis
Kids Ride Around Toy

- Handle good size payload
  - 50~60 LBS
  - Toy R US or Craigslist
- 6v Motors
  - Must have two motors
    - Differential drive
  - Work well with controlled 12V
  - Cheap
  - Designed for basic efficiency
    - Not best
    - Not worst, automotive
- Don't under estimate toy technology
  - Www.Modifiedpowerwheels.com
  - Durable
  - Cheap

Chassis
Alternatives

- Commercial
  - Affordable units very small
  - Not worth money
    - Unless you're rich or funded
  - Alternate Ideas
    - Wheel Chair
      - Very expensive, but cheaper than Vgo or WhiteBox
- Hybrid
  - Linux PC Robot
    - Fame and Toy Gear Motors
    - More flexible
    - Lighter than toy
- Smaller
  - Limited payload

Home Depot
Source of Materials and Inspiration

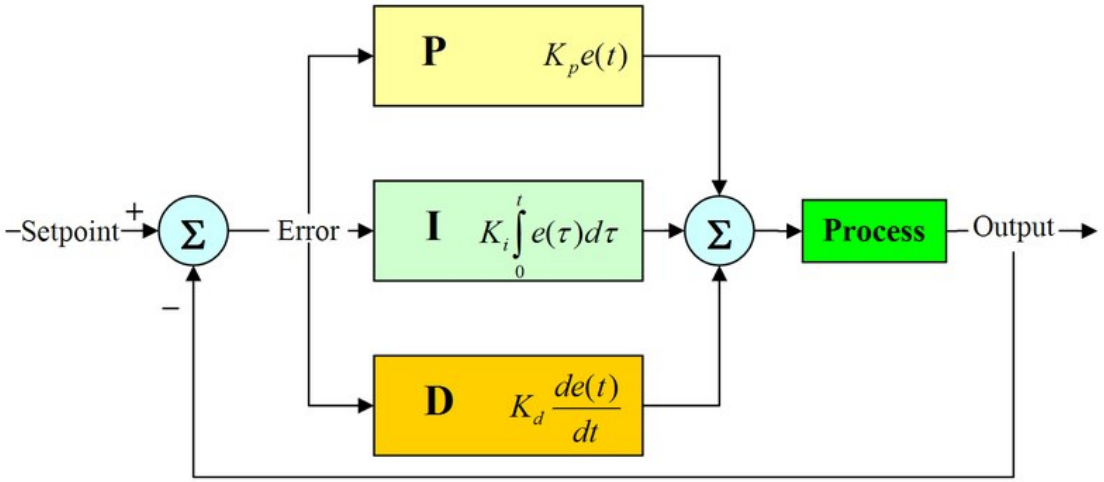
- Tools
  - Hacksaw
  - Drill
  - etc.
- Aluminum Framework
- ¼/20 and hardware
- Lawn Mower Wheels
  - Rubber tread
- Hardware Store Engineering
  - Got a problem? Walk around and look at things
  - Just because plumbing doesn't mean it can't be structural.

Software
Bringing Frankenstein to Life

- Must Haves
  - Motor Control
    - Www.linuxpcrobot.org
      - Resource not a product
    - Write your own
      - PID
  - Manual User Interface
- Cool Features available in more Linux Distros
  - Webcam Server
  - Video Conferencing
  - Motion Detection
  - Speech Synthesizer

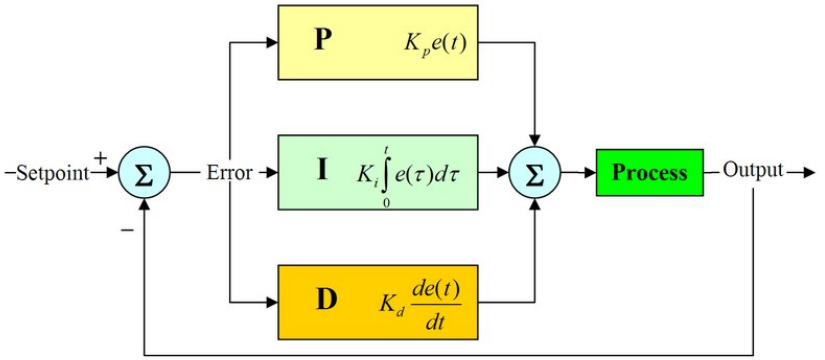
PID
Proportional Integral Derivative

- Gain based on instantaneous positional error (Proportional)
- Error is accumulated over time to reduce over-all positional error (Integral)
- The rate of change is compared for each cycle to reduce over-shoot and under-shoot (Derivative)



PID
Implementation

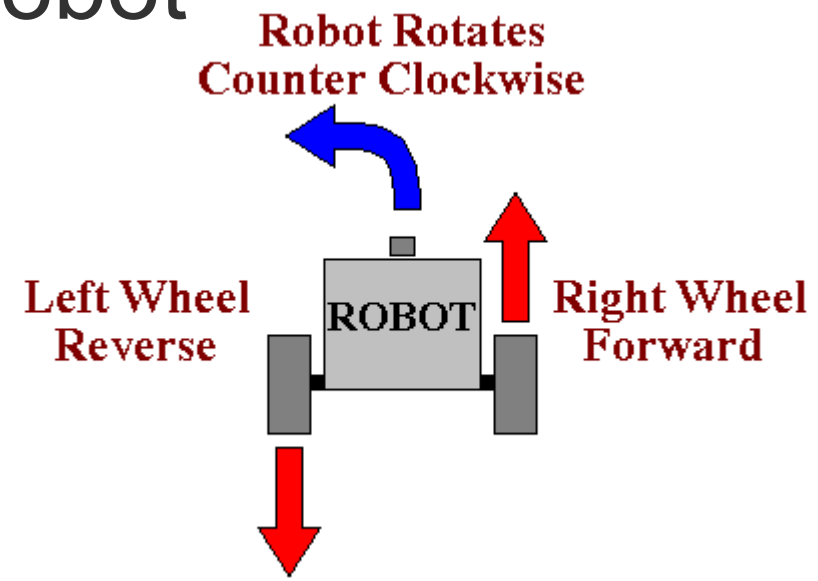
- Real Time
- Measured Time
  - near real-time
    - not really
    - Pentium and higher on-chip high precision timer
- Real Time vs Measured Time
  - Mathematically more complex
  - Unreliable but recoverable
  - Probably good enough
    - Analog world
    - Wheel slip



Prototype

- What are you building?
  - Mechanical Platform?
  - Software Development Platform?
- Dual Opposed Wheels
- Syncro-drive
  - Kludge
- Walking
  - Asimo vs ODEX
- Others
  - flying
  - drive/steer
- It doesn't need to be pretty
  - Really, it doesn't need to be pretty!

Motion
LinuxPCRobot

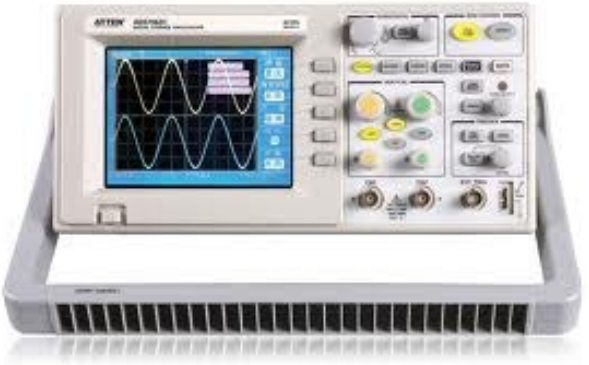


- Dual opposed wheels
  - Mechanically simple
  - tight control required
    - rotate
    - straight line
  - one moves forward, one moves backward
    - Surprisingly confusing when you are writing software
  - good enough for most tasks

Conclusion

- A lot of good problems left to solve
- Not expensive to start
  - A little time
  - A little money
  - A bunch of junk
- Computers hugely better today than 25 years ago
  - 64 bits vs 8bits
  - Gigabytes vs Kilobytes of RAM
  - Computers 1/10 the price for 1000x more power
  - Linux – Free and probably the most flexible system available
- I/O devices easily available as never before
  - Cameras
  - Joysticks
  - Wireless networking

Wrap up



- Aren't you sick of computers yet?
  - Shouldn't they work for a living
  - Shouldn't they interact with the 3D world
- Do some 3D hacking!
  - Don't be afraid of a soldering Iron
  - Get yourself an oscilloscope
  - Buy “The Art of Electronics”
  - Steal your daughter's barbie jeep and make it a robot
    - You know you want too
  - Have some fun

Resources

- http://www.linuxpcrobot.org
  - Source code and information
- http://www.mini-box.com
  - Small and mobile computing
- http://www.jameco.com
  - General electronics
- http://www.mpja.com
  - Electro-mechanical
  - Electronics
- http://www.digikey.com
- http://www.youdoitelectronics.com
- http://www.mwave.com