Talk Roadmap

Technology Context

Current State of Robotics

Robots as Co-X

Future Robotic Ecosystem
Best Wishes for an Exciting Robotics New Year!

Popular Electronics, Dec 1958
Driving Factors

Exponentials – x2 at regular intervals

- Moore’s Law – Processors – 1.5 years
- Kryder’s Law – Storage – 1.5 years
- Butter’s Law – Network – 9 months
Moore’s Law

- x2 every 1.5-2 years
- 54 years later…
  - 27-36 doubles
  - $2^{27} = 128 \text{ M}$, $2^{36} = 64 \text{ B}$
- ~7 B transistors on largest chips now
Kryder’s Law

2 TB Hard Drive $89.99
newegg.com
2TB in punch cards = ?

= 60,000 tons = USS JFK

US Library of Congress = 10 Tb

= 650 B-52s (out of 744)
Butter’s Law

“NEC and Corning achieve petabit optical transmission”

SPIE Optics.org, 22 Jan 2013

1 Pb/s = 10^{15} b/s = Entire LoC in 0.01 s
Robotics Follows Exponentials

Stanford AI Lab Cart 1979, 3 meters/hr

DARPA Grand Challenge 2005, 30Km/hr

10,000x in 26 years, 2x every 2 years
The Robotics Equation

Sensors, Computing devices, Actuators, Communications

Defense & Security, Medicine & Elder care, Consumer, Manufacturing, Nano-technology, Entertainment

Tasks that are too - Dull - Dangerous - Dirty for humans

The 3 Ds
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“I can envision a future in which robotic devices will become a nearly ubiquitous part of our day-to-day lives... to see, hear, touch and manipulate objects in places where we are not physically present.”

— Bill C. Gates, Chairman, Microsoft
Yesterday’s Robots
Today's Robots
Robotics Research

Human-Robot Interaction

Sensing & Manipulation

Autonomy & Navigation

Biomedical Robotics

Assistive Robotics

Manufacturing

Odometry & Mapping

Soft Robotics
Tree-Climbing Robot

Invasive insect detection

C⁴I?

Drones over desert ✔

Drones over jungle ✗
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DARPA Robotics Challenge

Future Robotic Ecosystem
DARPA Robotics Challenge

Fukushima Disaster

Too dangerous for humans ...
... send a robot

Too bad robots can’t ...

• Traverse rubble
• Attach hose
• Close valves
• Open doors
• Climb ladders
• Use tools
• Remove debris
• Drive vehicle ... YET!
**Other Disasters**

- **Deepwater Horizon**
- **Hurricane Katrina**
- **Oso Mudslide**
- **Soma Mine**
Capabilities Gap

• Supervised Autonomy
  • Not tele-op

• Mobility
  • Go where needed

• Manipulation
  • Operate in human environment

• Perception

All hard – integrating harder still
DARPA Robotics Challenge

1. Virtual Robotics Challenge – Simulation SW
   Best teams have 5 months for SW → HW
   $2M Atlas Robot + $750K Funding

2. DRC Trials – Select winners
   Best teams have 12+ months
   $1M Funding

3. DRC Final – Select winner
   $2M Prize
DARPA Robotics Challenge

**Phase 1**

- **A**: ≤ 5 Teams
  - Build: ≤ $3M each

- **B**: ≤ 12 Teams
  - Sim: ≤ $375k each

- **C**: ≤ 100 Teams
  - Sim: No funding

- **D**: m Teams
  - Build: No funding

**Phase 2**

- Port to ATLAS
  - ≤ 6 Teams
  - ≤ $750k each

- ≤ 8 Teams
  - ≤ $1M each

1 Team
  - $2M Prize

- Spring 2015
Virtual Robotics Challenge

• Perform subset of tasks ...
• ... in simulation ... *How hard can this be?*
• ... port to robot later. *How hard can this be?*
• Using
  • ROS
  • Gazebo simulator
  • Rviz visualization
  • Some Boston Dynamics, Inc. software
Manipulation
Walking
Operator Control

- Minimize cognitive load on operator
  - Limited set of robot actions
  - Allow, but don't require, joint level control
  - Reduce uplink bandwidth

- Provide minimum feedback to user
  - Maintain situational awareness
  - Reduce downlink bandwidth
Boston Dynamics Inc. ATLAS

- 28 DOF
  - 6 per limb
  - 3 back
  - 1 neck (pitch)
- Interchangeable hands
  - Sandia / iRobot / Robotiq
  - Custom-made pipes
- Sensors
  - MultiSense Head
  - KVH IMU
  - Foot pressure sensors
- Power
  - Hydraulic with on-board pump
  - Tether for 480V / Cooling / Comms
# Hands

<table>
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<th>iRobot</th>
<th>Sandia</th>
<th>Robotiq</th>
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<td>DoF</td>
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<td>Drive</td>
<td>Worm gear</td>
<td>Gears</td>
<td>Worm gear</td>
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<tr>
<td>Max tensile stress (lbs)</td>
<td>3 / 11 / 5</td>
<td>17 / 24 / 1</td>
<td>Palm: 50+/ 50+ / 20 Tip: 50+ / 20 / 20</td>
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<tr>
<td>Max shear stress (lbs)</td>
<td>32 / 14</td>
<td>11 / 9</td>
<td>Palm: 25 / 45 Tip: 17 / 25</td>
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</table>
Carnegie Robotics
MultiSense SL

- Stereo
- LIDAR
- Video
Situational Awareness Cameras

WPI-CMU DARPA Robotics Challenge Team
Software Packages

- Robot Operating System (ROS)
- Gazebo – Simulation
- MoveIt! – Manipulation
- RVIZ – Visualization
- OpenCV – Open source Computer Vision Lib
- Point Cloud Library
Door Handle Move It

WPI-CMU DARPA Robotics Challenge Team
Door Reality
MoveIt Valve Turn

WPI-CMU DARPA Robotics Challenge Team
How We Did It

- Kept eye on the prize
- Understood our strengths & weaknesses
- Compensate for shortcomings by
  - Partnering with engineers & CMU
  - Get ready for ATLAS before anyone else
  - Use ATLAS the most (312 hrs vs. 260 hrs)
- Maintain esprit de corps
In Progress

- Full body control
- Razor controller
- Better collision detection
- Fall & recovery behavior
Full Body Controller
Full Body Controller
Self-Collision Detection
What’s Happening Now

http://drcvideo.wpi.edu/zm/index.php
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Tech Drivers

- Robotics *rode* Moore’s Law
- Robotics *will drive* future exponentials
- Laser range finder:
  - Past:
  - Present:
  - Future:

![Laser Scanner Cost Chart](chart.png)
Robotics Ecosystem

- Systems Engineering
  - Life cycle analyses
  - DOTMLPF
- Software
  - How to engineer & compose behavior
- Simulation
  - For developing future systems
  - In future systems
  - Need better physics-based simulation
- Human-in-the-loop
  - Cyber-Physical Systems (CPS)
Lessons from Radiation Protection

- Distance
- Shield
- Time
Robotic Warfighter Protection

- **Distance**
  - Packbot

- **Shield**
  - Talos “Iron Man”

- **Time**

  Challenge: Can we use robotics to increase speed of operation?
The Next Disruptive Technology

WIRED FOR WAR
THE ROBOTICS REVOLUTION AND CONFLICT IN THE 21ST CENTURY
P. W. SINGER
The Future … ... Is Here

Best Wishes for an Exciting Robotics New Year!
Acknowledgements

• This work is sponsored by the Defense Advanced Research Project Agency, DARPA Robotics Challenge Program under Contract No. HR0011-14-C-0011.

• Equipment: NVIDIA, Axis Communications

• Thanks to many colleagues and contributors
Thank You!