Consulting in Field Robotics

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Overview

- What: Field Robotics: A New Market
- Why: Field Robotics Applications
- Why Now: Recent Developments
- How: Field Robot Design
- Who: Field Robot Design – Skills
- Where: Potential Clients
- Context: Significance of Field Robotics
- When: The Age of Robotics

Field Robotics – A New Market

- Definitions:
  - A robot moves things: Pick-and-place in factory
  - A Field Robot works in an open, unpredictable environment
    - Example: Robot vacuum cleaner vs furniture, pets and people
- Examples:
  - Robot vacuum picks up dust, places it in dust bin**
  - Lights-out warehouse forklift stores, retrieves pallets*
  - Plant nursery stock movement*
  - Delivers food, medicine in hospital*
  - Military: Autonomous trucks to deliver supplies, ammo

A New Generation - Field Robots

- Work in Home & Office
  - Changing environments + transient objects
    - People, pets and furniture move around
    - Books, toys, clothing left on floor
    - Doors to other rooms open and close
- Major Change From Factory Robots
  - Factory robots work in fixed environments

Field Robots - Basics

- Field robot “sees” environment
  - Using range sensors
- Uses sensor data to map environment
- Uses map to plan its work
- Environment constantly changing
  - Map is dynamic = continuously updated

Why Now: Recent Developments

- New: Field Robots That Work in Open Environments
- DARPA Challenge of 2005
  - Autonomous cars successfully drive 130 miles
  - Demonstrated navigation in open, unpredictable environment
  - Range sensing + heuristics + debugging => success
- Neato XV-11 of 2010 - Successful Robot Vacuum
  - "Son of DARPA" – range sensing + dynamic mapping

The DARPA Challenge Revolution

- Need: Autonomous vehicles in military
  - Gave application focus to R&D on autonomy
- Challenge: Go 100+ miles autonomous over desert
  - GPS not accurate enough to keep you on the road
- Solution: Map as you go
  - SLAM – Simultaneous Location And Mapping
- 5 cars finished: all used laser range sensors
  - LIDAR to measure range – “Time of flight”

DARPA Grand Challenge Car

DARPA - How It Worked

- Laser scanner(s) generated 3D point cloud
  - Range to objects around vehicle
- Generated dynamic map of road ahead
- Other sensors (vision, GPS) also used
  - E.g., View road near & far, compare

Lessons from DARPA

- We Have Algorithms That Work: SLAM, etc.
- The Proof of the Engineering Is in the Debugging
  - DARPA I cars = almost no desert trials
    - Result: no car finished, best was ~7 mile
  - DARPA II cars = months of desert debugging
    - 5 cars finished the 130 miles
- Laser Range Sensors Enable Mapping
  - All 5 finishers used LIDAR
- Use Multiple Sensors: LIDAR, Vision, IMU…

Field Robot Example - Neato XV-11

- Fully Automatic Robotic Vacuum Cleaner
  - Good enough to replace upright vacuum
- Uses Dynamic Mapping
  - SLAM + Laser Distance Sensor (LDS) => mapping
- Maps => Vacuums Room in One Pass
  - Assured coverage
  - Less energy than random => more power for vacuum

XV-11 – Child of DARPA

- Uses laser scanning and mapping

Neato XV-11 In Action

- Watch the movie

Neato XV-11 – How It Works

- Scans the room at start-up for initial map
- Vacuums the room in one pass
  - Mapping + Path planning + occupancy grid
- Dynamically updates internal map
  - If "obstacle" (pet, human) moves, it vacuums the freed space
- Returns to base for recharge when done
  - If charge low, goes to recharge, picks up where it left off

Advantages of Mapping

- Mapping vs bump-and-turn
  - Know when job is done
  - Gets job done in ~1/4 time
  - 4X powerful motors => professional vacuum
- Mapping vs structured environments
  - No environment modification needed
    - Saves $$ & works anywhere
  - No need to remove obstacles before run

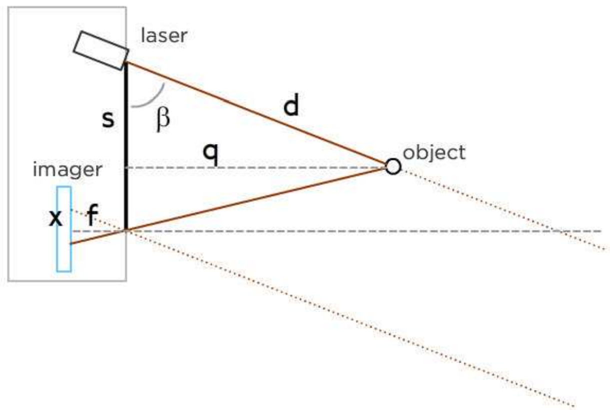
Lessons from XV-11

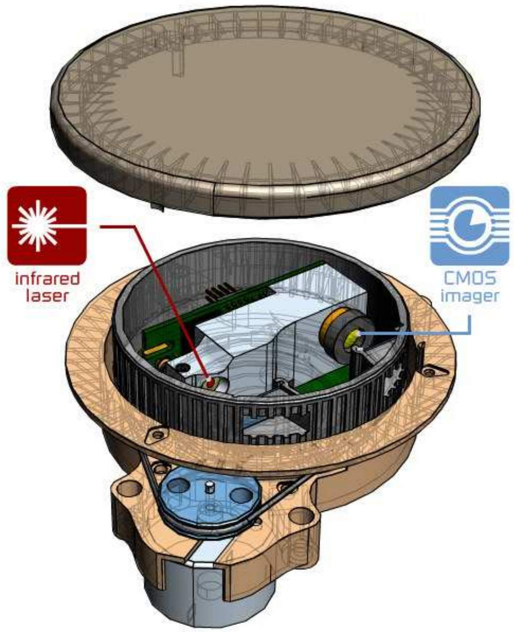
- Laser Distance Sensors Work
  - Need ~1 degree resolution
  - Laser => Small beam diameter
- But: No Single Sensor Does It All
  - Applications need proximity, collision, drop, gyro, etc. sensors
- Theory Provides Starting Point
  - Debug & heuristics = 90%+ of the work
- Application Knowledge => Success
  - Robot designs are application driven
  - E.g. Vacuum, mopping, lawn mowing, pick-up

Laser Range Sensors

- Types: LIDAR (Time of Flight) and Triangulation
- Constraint: 1 Mw Laser for Eye Safe
- Noise Limited Range
  - Photon budget: 1 mW => 25 pW @ 5 m
  - 1 nanoamp is a strong signal
- State of the Art: Velodyne LIDAR Scanner
  - 32 beams @ 1mW eye safe
  - 100 meters @ 1°, ~1 cm res @ KHz rates !

XV-11 Laser Range Sensor





Triangulation offers a simpler and cost-appealing approach to measuring distance

Field Robot Applications

- Moving Things for People Where They Live and Work
  - Pick up the kids' toys & set the table
  - Stores: restocking the shelves
- Many Tasks Are Outdoors
  - Highway and street clean-up
  - Moving materials to/from construction sites
  - Agriculture: picking, weeding
  - Remote machinery maintenance
- Robots Need Minimal Infrastructure
  - Car/Truck/Plane vs Train

Application Examples

- Delivery: Truck load/unload/transfer,warehouse
- Agriculture: Picking, weeding
- Mining and forestry/lumber
- Maintenance: Pick up trash, cleaning, store restocking
- Construction: Materials from truck to site, hold & assist
- Military: Convoy to deliver supplies and ammo; UAV's
- Remote maintenance: wilderness, sea, space
- Outpatient care: Active walker, wheelchair

Field Robot Design

- Field Robots => Autonomous Mobile Robots
- A Mobile Robot Moves in Unpredictable Environment
  - People, animals appear & disappear
- Maps Used to Make Real-time Path Planning Decisions
  - Fixed maps lose accuracy over time => dynamic mapping
  - Planning + real time decision making = autonomy
  - Path planning uses application knowledge

Field Robot Design - Elements

- Navigation: Range Sensors + SLAM + Platform
  - Simultaneous Location and Mapping (SLAM) algorithms
  - Range sensors: Laser triangulation, LIDAR
  - Support sensors: Proximity, drop, gyroscope, …
- Platform: Application Specific
  - Environment: Indoors, outdoors, remote, ocean, etc.
  - Power management: Batteries + charging, fuel cell, generator
- Arms and Grippers
  - Payload, size, speed, dexterity, degrees of freedom (DOF)
  - Electric, electro-hydraulic
  - Motion trajectory control: 5-7+ motors/arm

Field Robot Design - Consulting

- Navigation: Dynamic mapping & path planning
- Sensors: Range, proximity, motion
- Object recognition: Vision (e.g. SIFT), RFID, etc.
- Platforms: Wheels, legs
- Power: Batteries, fuel cells, power management
- Arms: conventional, delta, etc.
- Grippers & grasp planning
- Actuators: electric, hydraulic, electro-hydraulic
- Human-Machine Interface (HMI)

Field Robot Design – Skills

- Physics Driven Design:
  - Robot Platform architecture: Design for applications
  - Mechatronics: Integrated HW, SW & mech design
  - Electro-optical design: LASER range sensors
  - Sensor design: Physics => proximity, motion, location
- Real Time Algorithm Design
  - Navigation, task planning
  - Sensor integration
  - Motion control – trajectories with multiple motors
- Hacking & debugging => Application Knowledge

Robot Consulting: Why

- Robot Design Requires Many Disciplines
  - Physics: Sensors, navigation
  - Electronics: Analog, digital, FPGAs, system architecture
  - Electro-optical: Laser distance sensors, machine vision
  - Software: Navigation, object recognition
  - DSP: Real-time processing
  - Control Systems: Multiple motor trajectory control
- Many Disciplines = Many Experts
- Start-ups Cannot Afford a Big, Full-time Staff
  - Need targeted expertise until field matures => consultants

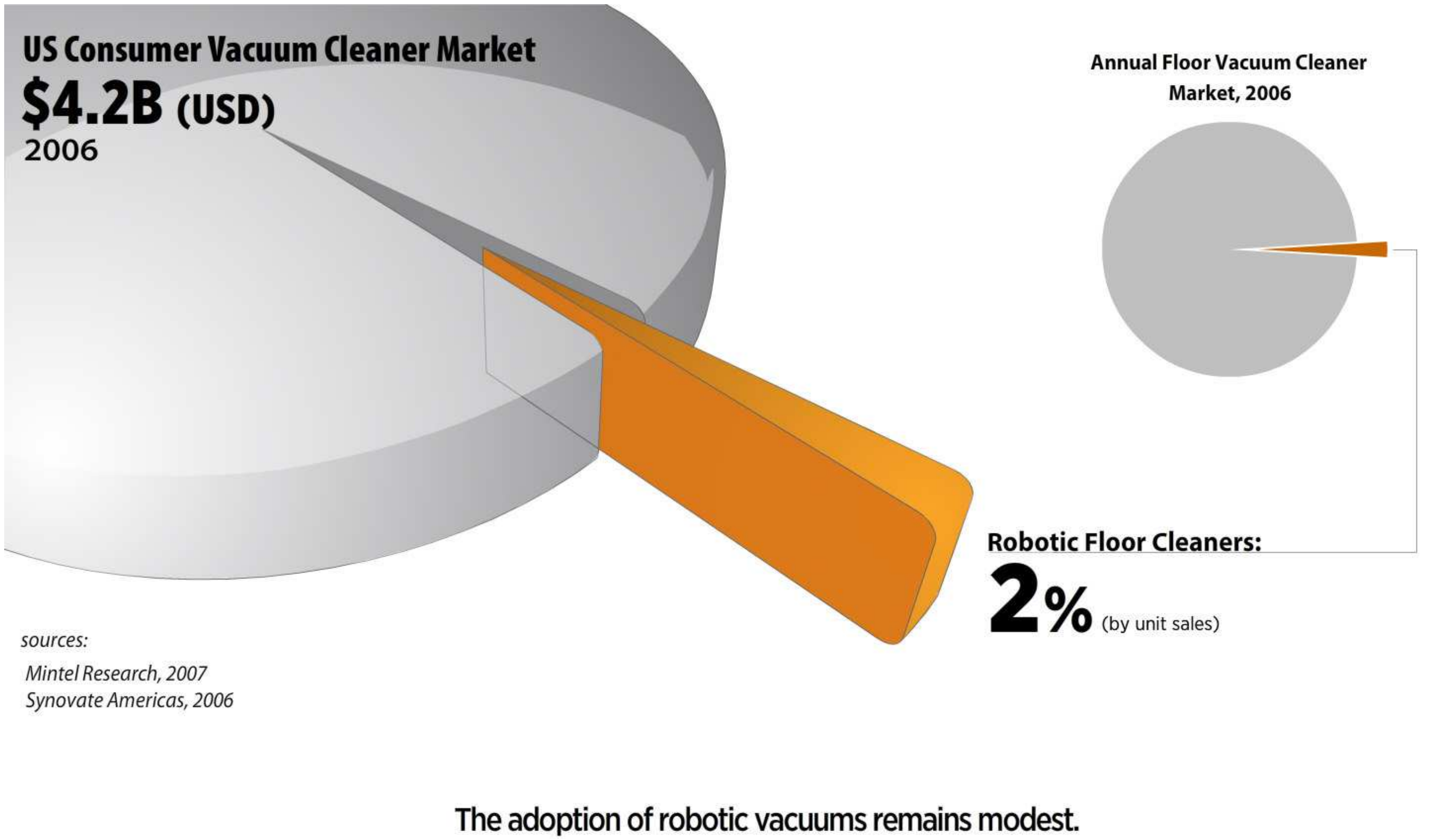
Where: Potential Clients

- Big Companies: Existing Markets
  - Agriculture - John Deere & GPS Driven Tractors
  - Automobile: Self parking cars
  - Military: Unmanned everything – trucks, planes
    - Better to lose hardware than people
- Small and Start-up Companies: Where the Action Is
  - New market ⇔ microprocessor, PC
  - Market and applications in rapid early development
  - Favors companies with new vision for new applications
  - “The Innovator’s Dilemma” New companies for new markets

Significance of Field Robots

- Major Human Inventions Moved Things
  - Wheel, cart, boat, ship, train, car, airplane
  - We spend significant time and effort moving stuff
- Factory Robots Are Successful at Moving Things
  - In fixed, structured environments
- Field Robots Move Things in Open Environments
  - Where people live: unpredictable but familiar
- Field Robot Use Will Be a Major Social Innovation
  - Comparable to the automobile, airplane

Market Example - Vacuums



When: The Age of Robotics

- Typical Invention Timeline:
  - 5 years from lab to viable product introduction
  - 25 years from introduction to market maturity
- DARPA Challenge Proof of Concept: 2005
- Neato XV-11 field Robot Introduction: 2010
  - Shipping in volume
- The Age of Robotics is Now: 2010 – 2035
  - We now have real robots

Welcome
To the
Age of Robotics!

End

Abstract

Great engineering consulting opportunities are opening up in field robotics.

- Like factory robots, these are pick-and-place machines that move things around.
- Unlike factory robots, they move things around in open, changing environments.

Robotic vacuum cleaners were the first commercial examples of field robotics.

- These were enabled by laser distance sensors and new algorithms.
- Example: Simultaneous Location and Mapping (SLAM).
- These products also made use of mechatronics, an interdisciplinary area of engineering that combines mechanical and electrical engineering with computer science.

Field robotics is a fast growing market with huge potential.

- The US military wants to have one-third of its vehicles autonomous (robotic) by 2015, and commercial applications are equally important. Instead of humanoid forms, we should expect to see a wide variety of very different machines for different environments and tasks.