Robot-Assisted Search and Rescue at the WTC: Why Partnerships are Needed

Robin R. Murphy, PhD, murphy@csee.usf.edu
Jenn Casper, Mark Micire, Jenny Burke, Carson McCoy, John Blitch, Justin Reuter
Director, Center for Robot-Assisted Search and Rescue (CRASAR)
University of South Florida
ONR Grants: N00173-99P1543, CDMHA subcontract

Outline

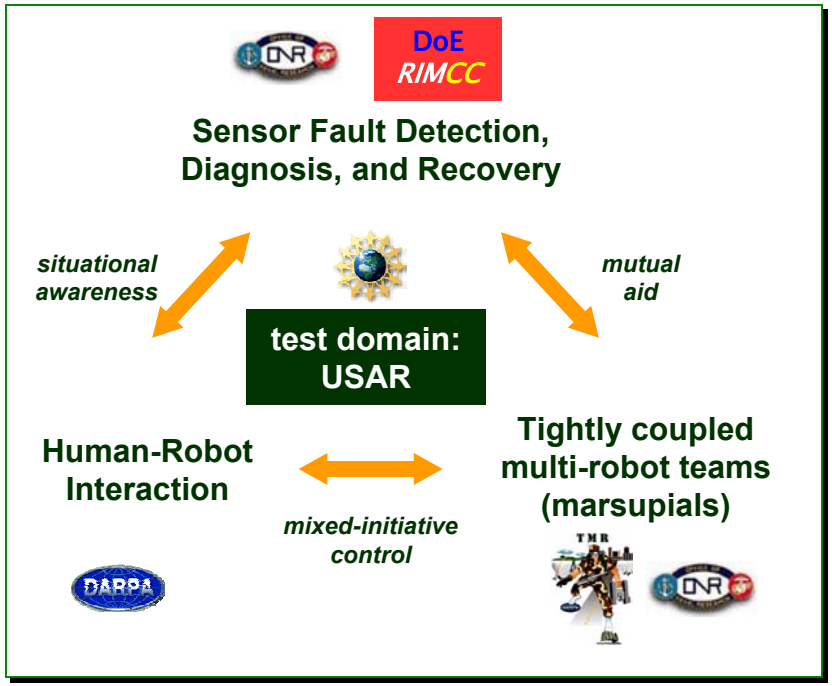
- The "business" of USAR
  - ESF 9, transportation, task expectations and task pace
- The key skills needed by a robot in the Hot Zone and how skillful the WTC robots were
  - mobility, perception, usability
- Is the WTC incident a reasonable indicator?
  - Would we see same failures, problems in more typical situations?
- Conclusions
  - WTC is a good indicator of the nascent state of robotics
  - The Navy can/should play a major role

USF Studies of Robot-Assisted USAR

Outline
Business
Skills
WTC v. reality
Conclusions

- Prior to WTC
  - Field evolutions Florida Task Force 3 (Casper et al 02)
- WTC
  - ***Data collected and archived from all teams***
    - 10 hours of tapes, mostly robot's eye view from 9/11-22
    - daily outbriefings, field journals (Casper and Murphy)
  - **Analysis: 2 M.S. Theses**
    - human-robot interaction (Casper 02)
    - failures and operator errors (Micire 02)
- Post-WTC
  - Night field evolution RTA
- Related Studies
  - Failure statistics of 14 robots, in field and lab, since 1998

USF Basic & Applied Research Triangle



www.csee.usf.edu/robotics
www.crasar.org

Why Use Robots for USAR?

- Things that humans can't do or can't do safely
  - **"the human use of humans"** Norbert Wiener
  - *and that applies to dogs*
- 135 rescuers died Mexico City, 65 in confined spaces
- Not enough trained people
  - 1 survivor, entombed: 10 rescuers, 4 hours
  - 1 survivor, trapped/crushed: 10 rescuers, 10 hours

Lost at WTC:
12 Father-son pairs, 15 pairs of brothers

ESF9 Tasks: Search, Assessment, Medical

Outline
Business
-ESF9
-niche
-pace
-enterprise
Skills
WTC v. reality
Conclusions

FEMA Task Force Organizational Chart

- Local Jurisdiction
  - FEMA
    - DoD Liaison
    - Task Force Leader
      - Plan/Ops
      - Safety
      - Search Team
        - 2 Canine Search Spec.
          - Tech Search
          - Haz Mat
      - Rescue Team
        - 2 Rescue Squads 12 Rescue Spec.
      - Medical Team
        - 2 Medical Specialists
      - Logistics Team
        - Structure Specialist
          - Rigging
          - PIO
          - Comm. Spec.
          - Logs Spec.

photo courtesy of Justin Reuter

The Search Team "Market Niche"

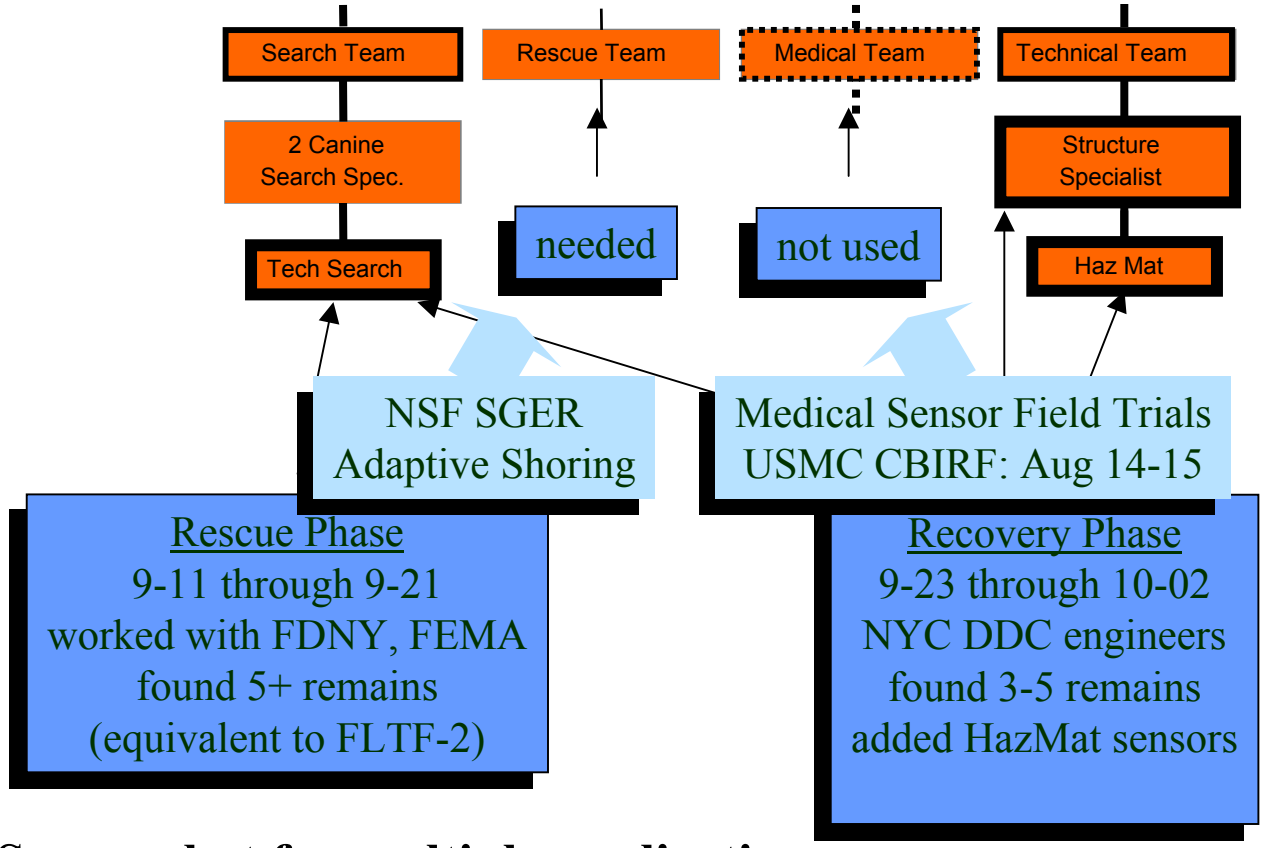
- **Typical resources**
  - ***dogs, search cams, acoustics, sledgehammers***
  - ***30 minutes a month refresher***

camera with zoom, lights couldn't do this

dogs:
injured by sharp metal, smell only 0.3m due to rain on 2nd day, lack of circulating air

SearchCam:
camera on a pole

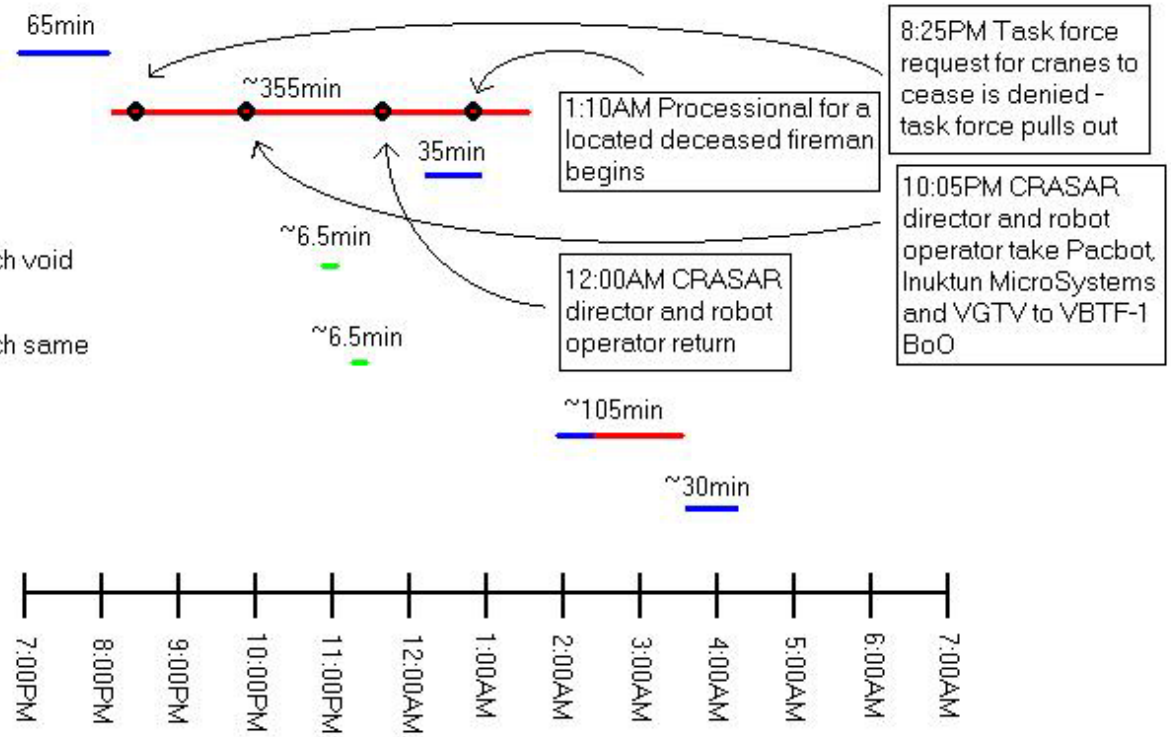
Robots Can Be Used Across all Tasks



- **Same robot for multiple applications**
  - Robots used for unimagined applications
    - how to speed this up? cross-fertilize?
- **Anticipating the need for adaptation**

Pace is "Hurry Up and Wait": Representative 12-hour shift

1. Drive to Ground Zero from Javits Center
2. Wait near parked vehicles
3. 2 CRASAR members retrieve parts robot from Javits center
4. CRASAR director, robot operator and VBTF-1 search void with Inuktun MicroSystems until bulb burns out
5. CRASAR director, robot operator and VBTF-1 search same void with Inuktun VGTV unti track is thrown
6. Move to new location and wait or walk around
7. Return to Javits Center from Ground Zero

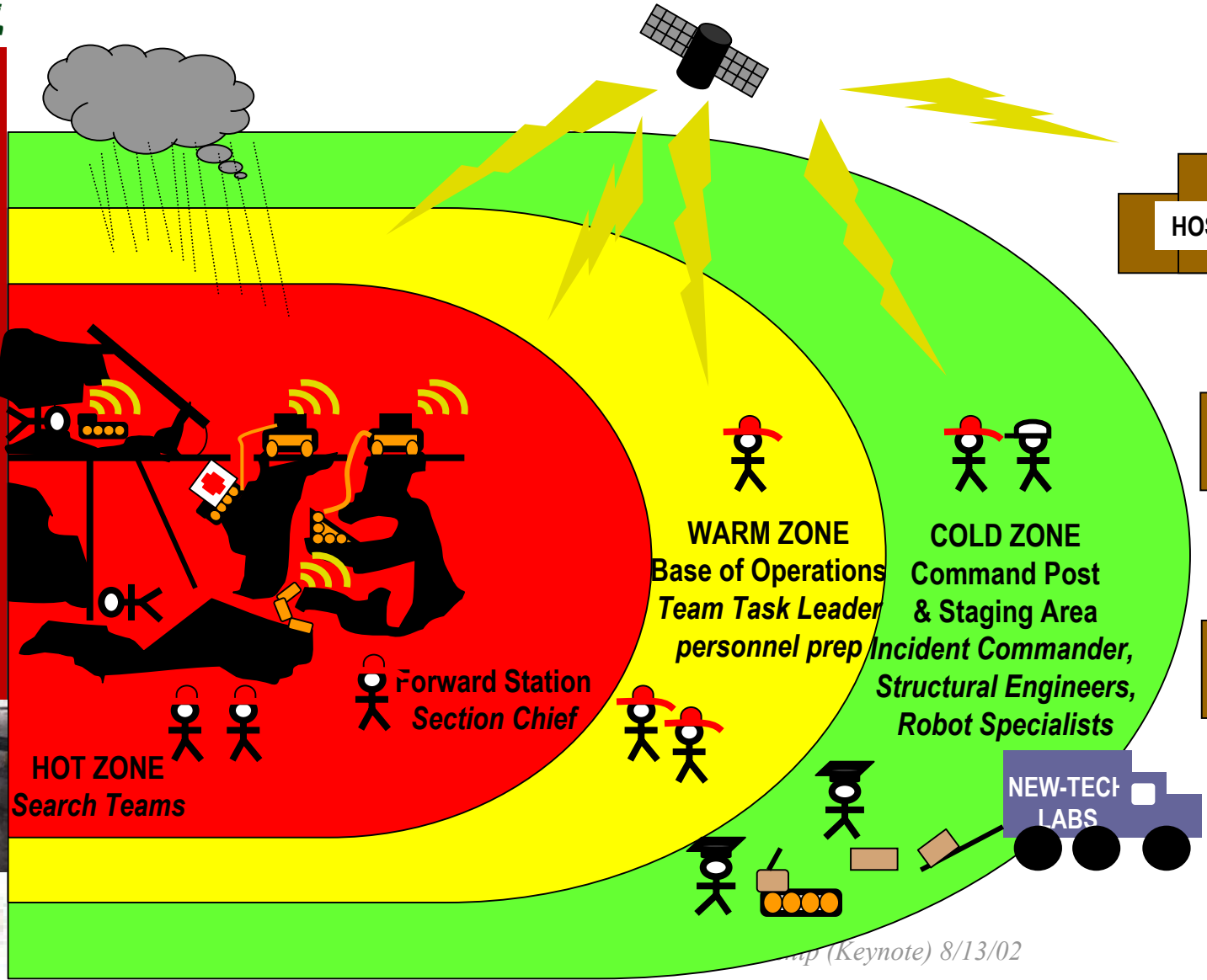


Timeline of Shift with VBTF-1 (7:00PM 9/18/01 - 7:00AM 9/19/01)

- ***Less than 15 minutes for entire shift, found 3+ victims***
- ***Average run 7 minutes***
- <1.5 minute set up time or rescuers walk away

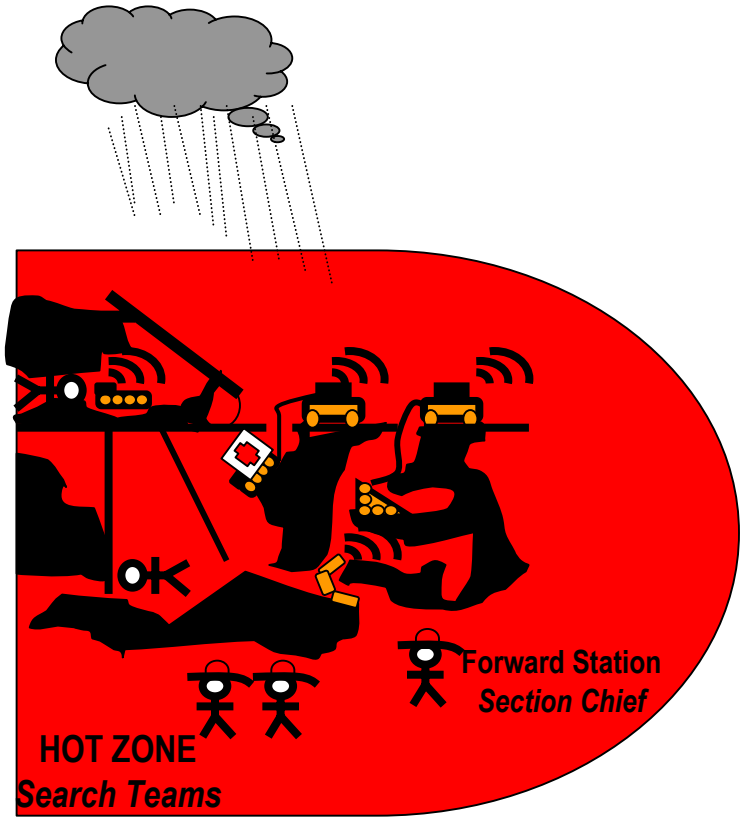
It's not the robot, it's the task!

Outline
Business
-ESF9
-niche
-pace
-enterprise
Skills
WTC v. reality
Conclusions



Skills in the Hot Zone

Outline
Business
Skills
-mobility
-perceptibility
-usability
WTC v. reality
Conclusions



- **mobility and manipulation**
  - "right" size and weight
  - navigate
  - adapt to terrain, weather
- **perceptibility**
  - supports navigation AND tasks (search, assess, medical)
  - "plug and perceive"
- **usability**
  - minimize personnel
  - reduces fatigue, errors
  - can insert information into the "stream"

Mobility: Getting from Forward Station to the Void

Outline
Business
Skills
-mobility
-perceptibility
-usability
WTC v. reality
Conclusions

WTC Mobility & Hardware Failures

- **Lost 1 Solem robot**
  - **lost wireless comms**, left in hole, wasn't there later (WTC 4)
  - **1:40 min drop out in 7:00 min run before loss**
- **Field Repairable**
  - **"impaled" micro-tracks (WTC 1)**
  - **detracked micro-VGTV (WTC 2)**
  - **blew out lights (WTC 2)**

Foster-Miller Solem at WTC 4

Inuktun micro-Tracks damaged in WTC 1

WTC Mobility & Hardware Problems

Outline
Business
Skills
-mobility
-perceptibility
-usability
WTC v. reality
Conclusions

- Tethers tangle
  - only twice not immediately recoverable
    - 7.75 "stuck assists" per drop (or once a minute)
  - but *tether handling is significant*
    - 9.25 "gravity assists" per drop
- Safety rope
  - still have tie a rope around the wireless 'bots

micro-Tracks insertion at Liberty St. 9/12

Hidden Cost-Human:Robot Ratios

"Only takes 1 person to operate"

Transportation **Operations**

Inuktun microTracks **1:1** → Inuktun microTracks **2:1**

½ iRobot PackBot **2:1**

"tether wrangler"
>2 times a minute

operator

Perceptibility Failures and Problems

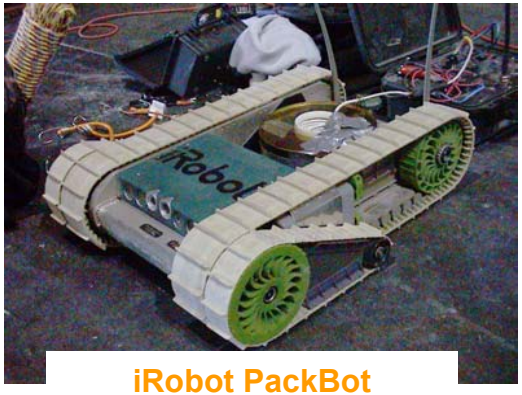
- **Missed victim remains**
  - no ground truth
- **Operator errors**
  - Mistakes *(Norman '91)*
    - 2 out of 7 drops: wrong robot, had to remove and try another
    - ***10% of duration*** of Inuktun runs spent significant time adjusting lights despite auto gain optimization
  - Slips *(Norman '91)*
    - 0.25 collisions per drop (oversteer)
    - ***8.9% of duration***, robot was high centered, wrong configuration

view from Inuktun microVTGV
WTC 2, 9/12/01

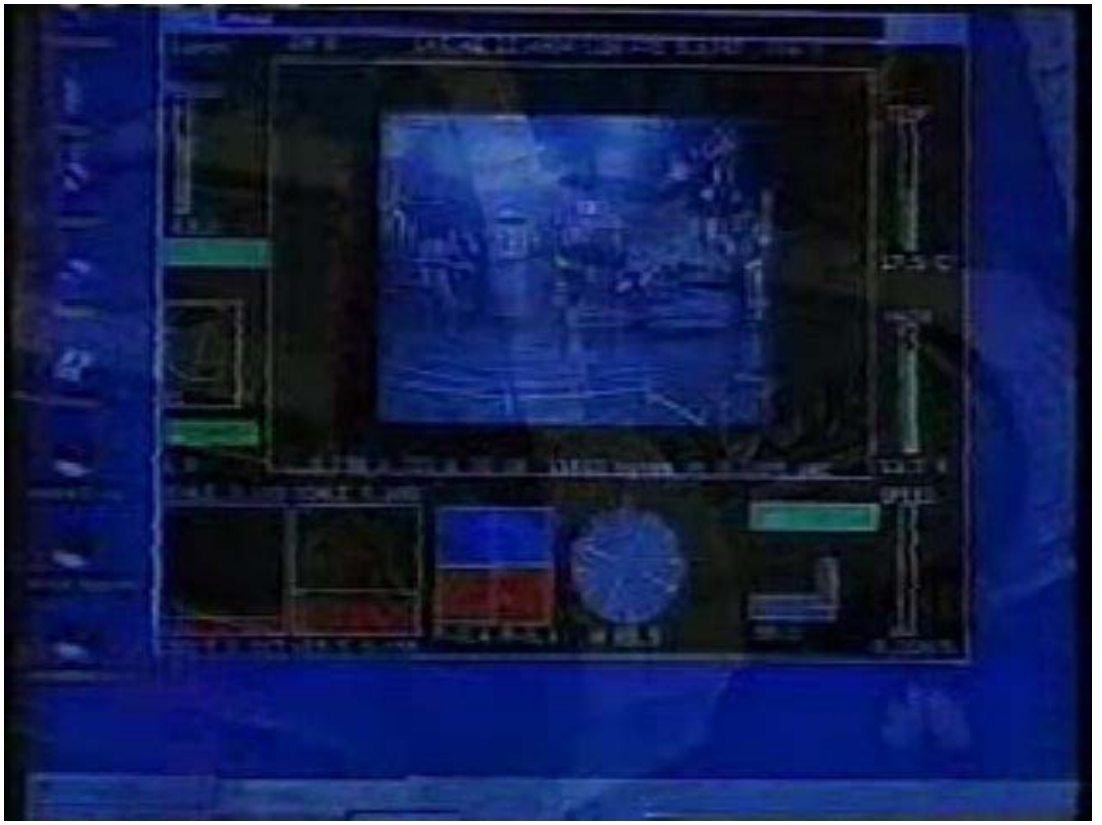
Inuktun microVGTV,
Inuktun pipe crawler
video, 2 way audio

Usability and HCI

Outline
Business
Skills
-mobility
-perceptibility
-usability
WTC v. reality
Conclusions



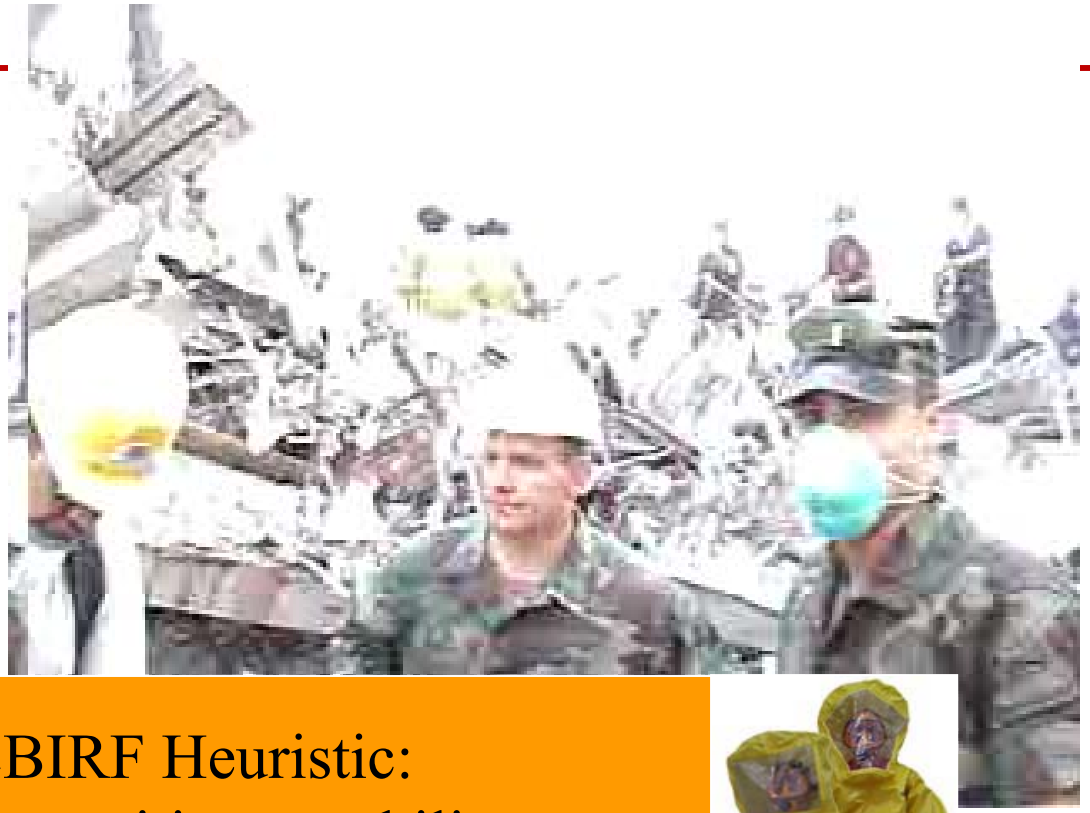
iRobot PackBot
video, FLIR, 2 way audio



- gamer joystick plus laptop with video & audio
- robot state: battery, comms, orientation, camera, encoders
- scared off rescuers: too complicated, too long to boot, too toy
  - *now integrated with Land Warrior– used in Afghanistan*

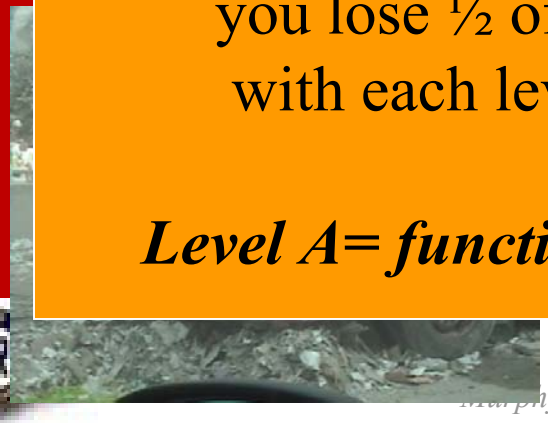
Environment at Ground Zero

Personal Safety:
-Thick dust for days
  - asbestos, glass
-Rubble largely stable, but if fall, could be impaled
Weather:
-45-70 deg F
-rain 2 days, making rubble slick, s



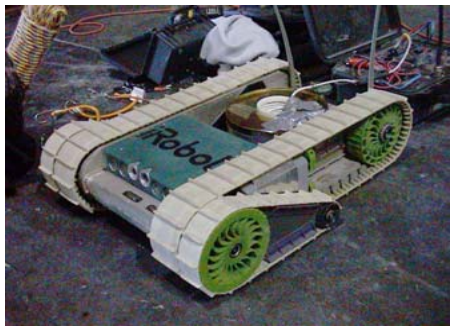
USMC CBIRF Heuristic:
you lose ½ of cognitive capability
with each level of protective gear

Level A= functioning at 1/8th capability



WTC Performance Reasonable Indicator?

- NASA Technical Readiness Levels
  - Level 9: fielded, mature device
  - Level 6: tested in laboratory
  - Level 1: concept
- WTC: Most Level 9 robots were really Level 6/7
  - Inuktun microTracks, microVGTV *for HVAC, chemical, oil pipes*
  - Foster-Miller Solem and Talon *for explosive ordinance*
- Manufacturers small, custom-build houses



Failures by Component

Analysis of failure logs since Sept., 1998, except WTC. Field robots are used in field conditions ~30%

Manufacturer	Effector	Control System	Power	Sensing	Wireless
A (4 bots: 2 models, 3 generations; tethered)	47%	34%	8%	11%	
B (8 bots: 4 models, 2 generations, wireless)	37%	33%	15%	9%	7%
average failures field robots	42%	33%	12%	10%	3%
C (2 bots: research robot, wireless)	0%	13%	25%	13%	50%

- **Effectors (platform mobility) fails the most: 42%**
  - not surprising since most platforms are at TRL 6/7 for terrain
  - *but still flawed designs & not improving with new generations*
- **Manufacturer-supplied control circuit/sw is close second: 33%**
  - hardware guys driving very demanding software development
- **Wireless at WTC was worse than wireless in exercises (*duh*!)**
  - Industry/research may be being lulled into false sense of capability

Impact of Failures: Field-Repairable v. Terminal

- Field-repairable failures
  - terminate mission, but can be fixed on-site, mission resumed

7.2 MIN downtime

- MTF for field-repairable

EVERY 27 DAYS

Impact of Failures: Field-Repairable v. Terminal cont.

- Field-repairable failures
  - terminate mission, but can be fixed on-site (assuming tools, expertise)

7.2 MIN downtime

- MTF for field-repairable

every 27 DAYS

- Terminal failures
  - require offsite repair

22 DAYS downtime

- MTF for terminal
  - *8d for the most hardened model*

EVERY 15 DAYS

Cognitive Impacts

- Two high fidelity exercises confirmed WTC
- Findings from Jul 01 (FL-TF-3)
  - tech search specialists had trouble switching between FLIR and video; *asked for software to assist perception*
- Preliminary findings from Nov 01 (RTA)
  - avg. ***33 times*** focused on establishing ***situational awareness*** (where the robot is, what is being observed, where had the robot been)
  - avg. ***22 team communication events*** (asking for help, advice)
  - avg. ***7.6 times on task*** (victim or structural notes)

Operator needs augmentation!

Cognitive Impacts cont.

- Two high fidelity exercises confirmed WTC
- Findings from Jul 01 (FL-TF-3)
  - tech search specialists had trouble switching between FLIR and video; asked for software to assist perception
- Preliminary findings Nov 01 (RTA)
  - avg. *33 times* focused on establishing *situational awareness* (where the robot is, what is being observed, where had the robot been)
  - avg. *22 team communication events* (asking for help, advice)
  - avg. *7.6 times on task* (victim or structural notes)
  - **avg run: 51% Navigating, 49% Stationary**

It may not all be about mobility and platforms!

Where Was the Software?

- Back at the lab or discarded
  - computer interface to Inuktuns thrown away
  - comms relay package for robots left on West Coast
- On the "other" robot
  - newest model not backwardly compatible on software
  - victim affordance detectors wouldn't run on Inuktuns, Packbot
  - self-righting not available
- Focusing on the "fun" problems
  - "Roboticists automate what is easy to automate, then leave the rest to the human"- Norman
  - platforms v. navigation v. perception
- Packaged within unacceptably complex systems

Conclusions

- **The problems are systemic and broadly applicable**
  - tasks with unpredictable terrain, elements
  - tasks with high attention demands but repetitive, fatiguing
  - tasks with high human interaction, need for human acceptance of the technology
  - tasks where tactics are coevolving with the technology
- **Capability can be doubled in 18 months**
  - Manufacturing is the *immediate problem*
  - Perception (and usability) is the *real key to productivity*
  - *Integration will reduce failures*
- **The Moore's Law curve can continue**
  - Harvest ONR's base of long-term, basic research
  - Balance the robotics research portfolio of mobility with perception, HRI, et.
- **The Navy can, and should, guide this**
  - Continue doing what it's doing
    - ONR research, NR-STAT, Tech Solutions
  - Create and support industry-university-research partnerships
    - Provide continuity, sustainable technology insertion

How Can Academe Help with Naval Industry-Research Partnerships

- **Document the field**
  - conduct ethnographic studies, beta-testing, field trials
- **Provide incubator support**
  - Business plans, industrial design teams, general infrastructure
- **Facilitate the transfer of research**
  - industry-oriented workshops, cooperative R&D, SBIR
- **Fill in the gaps**
  - "spot market" research and development
- **Supply superbly trained people**
  - Co-ops, interns, graduates
  - visiting scientists and engineers
- **Certify products to increase user acceptance**
  - Neutral party: act as a Underwriter's Laboratories
  - Encourage interoperability
- **Educate partners**
  - exposure to latest software practices, quality control techniques

Outline
Business Skills
WTC v. reality
Conclusions

Tell Us How We Can Be of Use

- Publications, datasets, video and stills
  - www.crasar.org
  - www.csee.usf.edu/robotics
- contact: Dr. Robin Murphy, murphy@csee.usf.edu