TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Robotics Collaborative Technology Alliance – Foundations of Autonomy for Ground Robotics

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26 April 2012

A Vision of the Future

Robots as Teammates

From this…

…to this

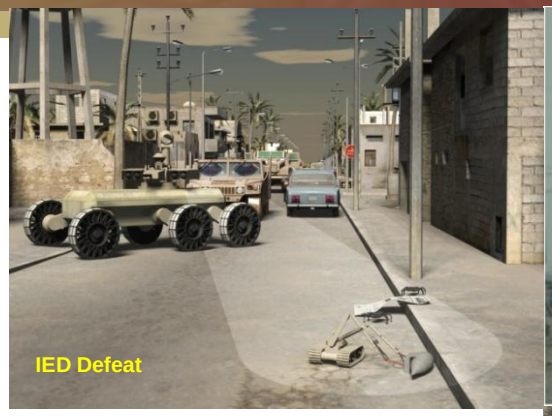
A Paradigm shift -
from Tool to Team Member

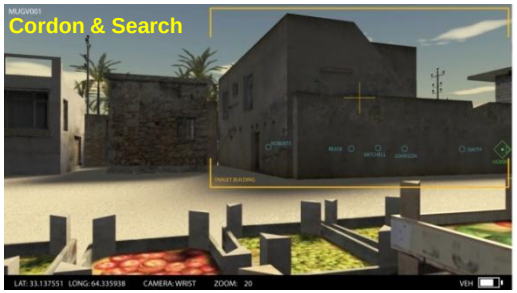
An Unmanned System that

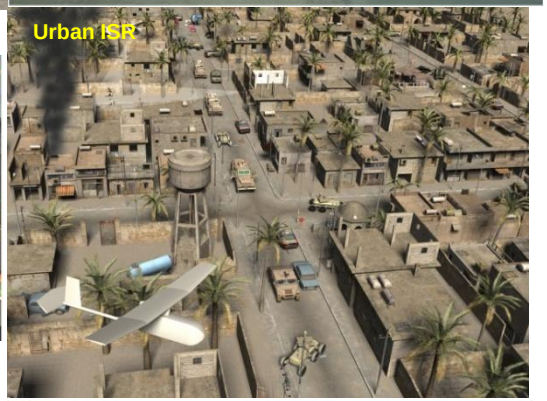
- ***Understands its environment***
- ***Conducts useful activity***
- ***Acts independently, but…***
- ***Acts within prescribed bounds***
- ***Learns from experience***
- ***Adapts to dynamic situations***
- ***Possesses a shared mental model***
- ***Communicates naturally***

Expands the bubble of influence for a military unit

Multiple Missions Share Common Requirements

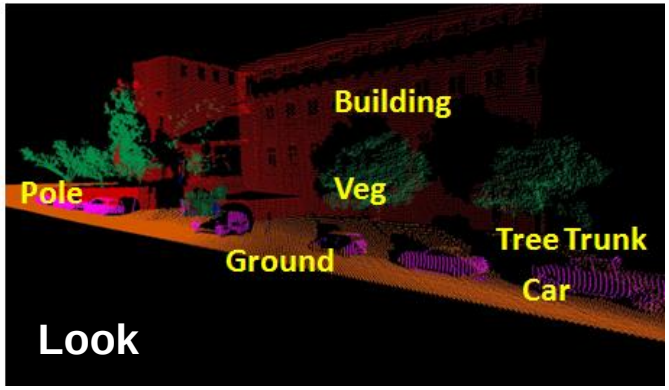






- ***Understand the mission***
  - Receive/interpret orders
  - React to changing situations
- ***Understand the environment***
  - Recognize “rubble pile by lamppost”
  - Observe person fleeing checkpoint
- ***Move in a tactically correct way***
  - Move downrange to IED – and return
  - Check intersection before manned units pass through it
- ***Communicate clearly & efficiently***
  - Ask for assistance when needed
  - Report salient activity – e.g., insurgent entering building, fleeing checkpoint
- ***Perform missions***
  - Monitor activity at checkpoint
  - Resupply combat outpost
  - Inspect and neutralize IED
  - Perform ISR in urban setting

Basic Skills Are Necessary to Address these Requirements



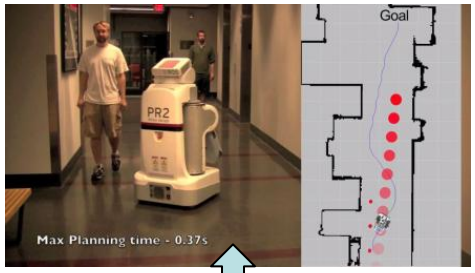
- **Focused Situational Awareness**
  - **Semantic labeling of objects & behaviors**
  - **Relationships**
- **Adaptive Tactical Reasoning**
  - **Learning**
  - **Mission & Task Knowledge**
- **Efficient Proactive Interaction with Humans**
  - **Shared mental model**
- **Safe Secure and Adaptive Movement**
  - **Adaptive behavior**
  - **Cognizance of mission & environment**
- **Interaction with the Physical World**
  - **Move & manipulate**

Five Technical Barriers Must Be Overcome to Attain These Skills

Skills	Barriers	Simplistic, Shallow World Model	Mobility Focused Perception	Scripted Planning or Tele-operation	Lack shared understanding of missions & roles	Missing or shallow learning capabilities
Think	Adaptive Tactical Reasoning	Represent complex concepts, e.g., METT-TC		Generate appropriate behaviors & adapt to dynamic situations	Follow instructions given at the cognitive or semantic level	
Look	Focused Situational Awareness	Represent, monitor, & correct people, objects, & behaviors	Contribute to the general SA of the unit - make salient observations		Report salient observations to other members of the unit	Compare observations & actions to human teammates
Move	Safe, Secure, and Adaptive Movement	Correctly represent constraints to movement	Perceive entities & terrain impacting mobility	Tactically correct maneuver, adapting to changing circumstances		Learn from prior experience
Talk	Efficient Interactive Communication	Shared mental model as basis for human-robot interaction	Transmit relevant information		Receive and acknowledge cognitive level instructions & explain its behavior	Learn through cognitive level interaction with human teammates
Work	Interaction with the Physical World	Represent a wide variety of objects for manipulation	Enable interaction in a 3-D environment			Learn through interaction with the physical world

Five Foundational Thrusts Address These Technical Barriers

Adaptive Behavior Generation



task/mission knowledge

outcome/status

Hybrid World Model

WORLD MODEL

Cognitive Level	Context Guides Perception	Activities – run, enter, throw, flee, fight, drive, … Missions – logistics, ISR,… Orders, chain of command,… Mental models
Relational Level		Statistical classification with uncertainty
Metric Level		Metric Objects – appearance features, tracks, kinematics, obstacles

design for learnability

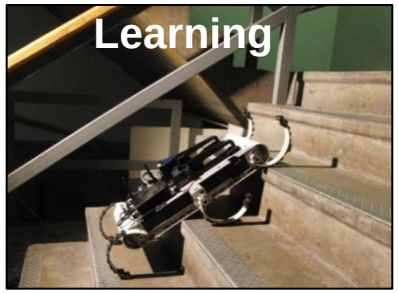
updated skills

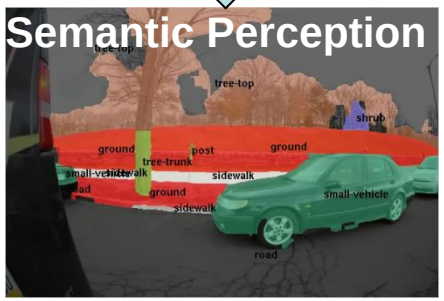
shared mental model

situational awareness

context

semantic labeling



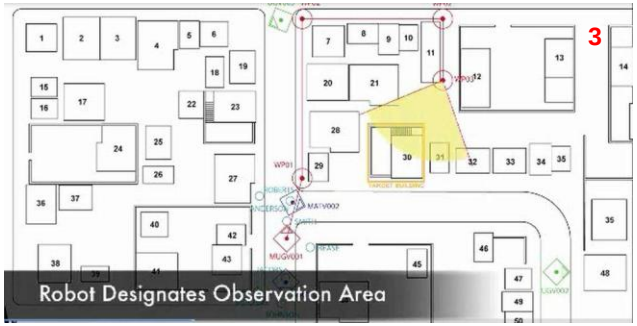


Proposed Capstone Experiment – A Vision for Autonomous UGVs

Mission order: "Watch the back of that building and report suspicious activity"

- Understand command
- Relate to perceived environment ("that building")
- Demonstrate understanding (e.g., lase building)

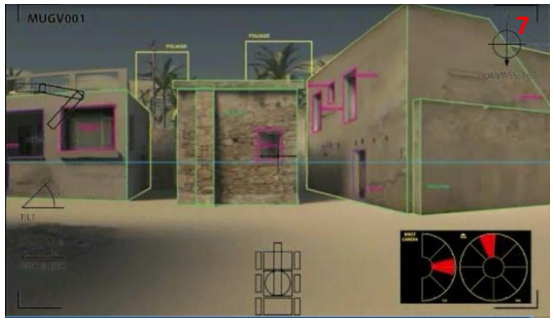
- Figure out where to go to surveil building
- Plan/execute path to move safely & securely
- Establish initial shared SA and Common Ground



- Move through cluttered environment to reach OP, overcome mobility challenges

- Approach OP cautiously -- along wall of building

- As needed, clear obstacles and get in advantageous position for surveillance



- Assess egress points, detect humans, update status

Upon mission completion, rejoin unit, maintain SA, accept new missions

Planned Capstone Experiment

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Current Assessment Plan Provides a Pathway to Future Capabilities

IRA ID	Integrated Research Assessment Name	Timeframe	Think	Look	Move	Talk	Work
0	2011 Baseline: Small Robot Autonomous Navigation	Aug. 2011	Legacy Waypoint Planning Algorithms	Hokoyu LADAR	Stationary & Moving Obstacle Avoidance		
1	2011A: Recognition of Salient Behavior	Dec. 2011	Cognitive Architecture (ACT-R) on Small Robotic Platform	Stereo Tracking on Small Robot Feeds Cognitive Reasoning			
2	2011B: Physical Interaction Baseline	Apr. 2012	Include WM Entities/Descriptors to Enable Interaction	Close-in 3D Sensing for Manipulation	Autonomous Stair/Hill Climbing, Crawling		Simple Autonomous Trenching, Caging & Manipulation
3	2012A: Intelligent Navigation	Oct. 2012	World Model with Short/Long-Term Memory Linked to ACT-R	Semantic Labels and Tracked Movers to WM, Using Stereo & LADAR	Intelligent Movement to Described Locations	Accept & Understand Movement Orders, Provide Status	
4	2012B: Physical Interaction	Apr. 2013	Reason about Moveable Objects	Perceive Wide Range of Mobility Challenges	Adaptive Locomotion, Quadruped & Hexapod Mobility, Snakes	Supervisory Communication for Manipulation	Complex Autonomous Trenching, Caging & Manipulation
5	2013A: Autonomous ISR	Oct. 2013	Reason about Adversary Actions to Provide Prediction & Context	Perceive Apertures, Transit Routes for Fugitives	Move to Good Vantage Point(s) for Observation	Update Teammate(s) wrt Ongoing Mission	Recognize & Report Salient Events
6	2013B: Tactical Team Movement	Apr. 2014	Reason about Troop, Adversary and Neutral Movement	Maintain SA and Common Ground with Soldiers	Move with Soldiers in Correct Tactical Positions	Communicate only as Needed, Accept New Orders	Move with Team, Accept New Mission on the Fly ("Follow that Guy!")
7	2014A: Capstone Assessment	Oct. 2014	Reason and Adapt through Stages of Mission	Monitor Egress Points and Recognize Mission Relevant Activity	Move Adaptively to Evolving Mission and Mobility Challenges	Update Status & Communicate Salient Information	Report Events, Move Obstacles, Track Fugitives, Seek Guidance

The Players & Their Objectives

Alliance

- General Dynamics Robotic Systems
- Carnegie Mellon University
- Florida A&M University
- University of Central Florida
- University of PA
- Boston Dynamics
- QinetiQ North America
- Cal Tech/Jet Propulsion Lab
- Subawardees
  - Brigham Young University
  - iRobot
  - Massachusetts Institute of Technology
  - Robotics Research
  - Stanford University
  - University of California at Berkeley
  - University of Colorado
  - University of Washington

Objectives

Make the research investments that support the Army's robotic system development goals:

- *Perceive and understand dynamic & unknown environments, including creation of a comprehensive model of the surrounding world*
- *Autonomously plan and execute military missions; readily adapt to changing environments and scenarios; learn from prior experience; share common understanding with team members*
- *Seamlessly integrate unmanned systems into military and civilian society*
- *Manipulate objects with near-human dexterity and maneuver through three-dimensional environments*

Technical Leads

- **Perception**
  - Dr. Raghuveer Rao, ARL
  - Dr. Martial Hebert, CMU
- **Intelligence**
  - Stuart Young, ARL
  - Dr. Tony Stentz, CMU
- **Human-Robot Interaction**
  - Dr. Susan Hill, ARL
  - Dr. Randy Shumaker, UCF
- **Manipulation & Mobility**
  - Harris Edge, ARL
  - Dr. Al Rizzi, Boston Dynamics

- Program Director:
  Dr. Robert Mitchell, GDRS
- Deputy CAM:
  Dr. Purush Iyer, ARO

Summary

ARL Robotics Collaborative Technology Alliance:

- **A cooperative agreement between ARL & 8 Partners+**
- **Conducts fundamental research to create autonomous robots that can effectively team with Soldiers in small units**
- **It conducts research in four technical domains:**

  Perception - Intelligence - Human-robot interaction - Manipulation & Mobility

- **Five multi-disciplinary thrusts to achieve greater levels of autonomy**
  - **Hybrid cognitive/metric world models**
  - **Learning**
  - **Semantic Perception**
  - **Adaptive Behavior Generation**
  - **Meta-cognition**
- **Alliance conducts periodic technology assessments to assess progress and fac transition**

Further information can be found at

http://www.arl.army.mil/www/default.cfm?page=392