

Overview: Robotics Alliance to  
National Defense Industrial  
Association-Robotics Panel

13 December 07

# Robotics CTA Members and Objectives

## Consortium Members

- General Dynamics Robotic Systems (Lead Industrial Partner)
- Carnegie Mellon University
- Applied Systems Intelligence
- Jet Propulsion Laboratory
- Alion Science & Technology
- BAE Systems
- Sarnoff Corporation
- SRI International
- Florida A&M University
- University of Maryland
- PercepTek
- Robotic Research
- Signal Systems Corp
- Howard University
- NC A&T University
- University of Pennsylvania
- Skeyes Unlimited

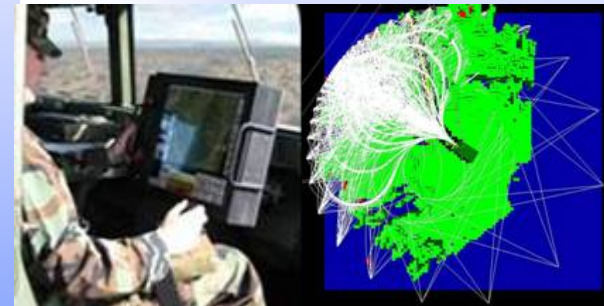
## Objectives

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

- *Develop perception technologies that allow robotic vehicles to sense and understand their environment;*
- *Develop intelligent control technologies and architectures enabling robotic systems to autonomously plan, execute, and monitor operational tasks undertaken in complex, tactical environments;*
- *Develop human-machine interfaces that allow soldiers to effectively task robotic systems and minimize operator workload.*

## Technical Areas

- Advanced Perception
- Intelligent Control & Behavior Development
- Human / Machine Interfaces



# Robotics CTA Task Areas

## CTA Inception

- Terrain Based Preplanning
- Fixed Behaviors with Fragile Performance
- Limited Replanning Under Failure Conditions
- Extensive Human Interaction Required

## Required

- Automatic Planning & Replanning with Limited Human Interaction
- Dynamic Replanning Based on Perception, Tactical Information, & Frag Orders
- Robust Behaviors to Operate Over a Wide Range of Situations

## Human Machine Interface

## Required

- Decision Aids for Offloading Operator
- Rapid Context Switching Between Multiple Platforms
- Robotic Platform Supervision & Tasking
- Multi-Model Input/Output
- Multi-Platform & Mixed Asset Tasking

## CTA Inception

- Human Intensive Planning
- Extensive Teleoperation Required
- Operator Saturation

## CURRENT

- Program making steady progress toward required capabilities

## Intelligent Control

## Perception

## CTA Inception

- Road Following on Well Defined Surfaces
- Slow Cross-Country Navigation in Relatively Benign Terrain
- Highly Sensitive to Environmental Effects
- Vulnerability while Platform is in Motion

## Required

- All Weather, Day/Night
- Complex Environments
- Recognition of Tactical Situations
- Speed Commensurate with OPTEMPO
- Perception for Mid-Range Planning
- Understanding of Moving Agents while Platform is in Motion
- Perception to enable Vehicle Safeguarding

*Requires advancing the state of the art in three critical areas:*

- *Perception*
- *Intelligent Control*
- *Human Machine Interface*

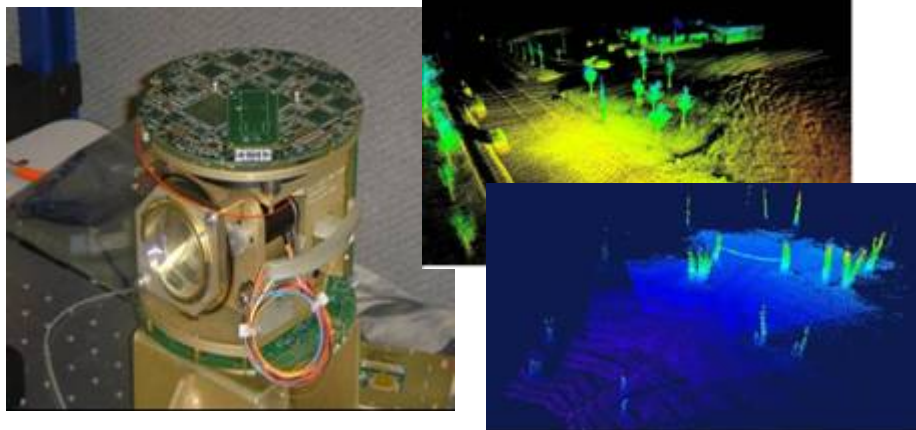
*Requires integrating research advances from all three areas using a system-level approach to provide a mechanism for:*

- *Field experimentation and research validation*
- *User input*

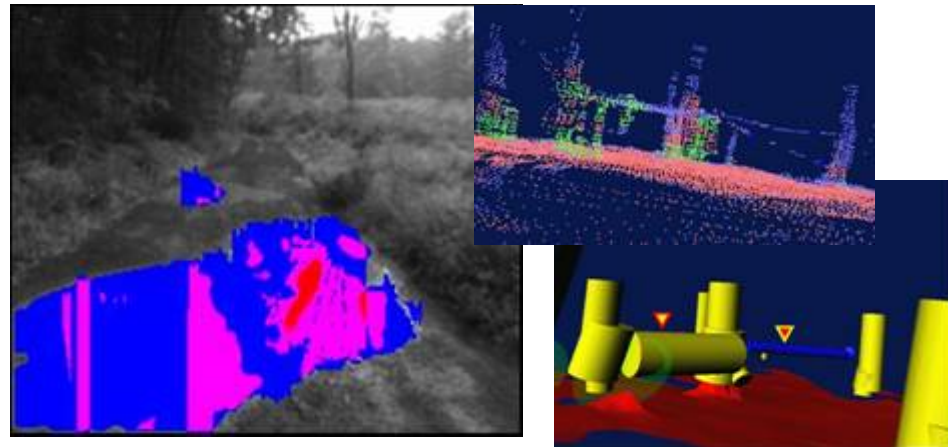


# Advances in Sensors and Perception

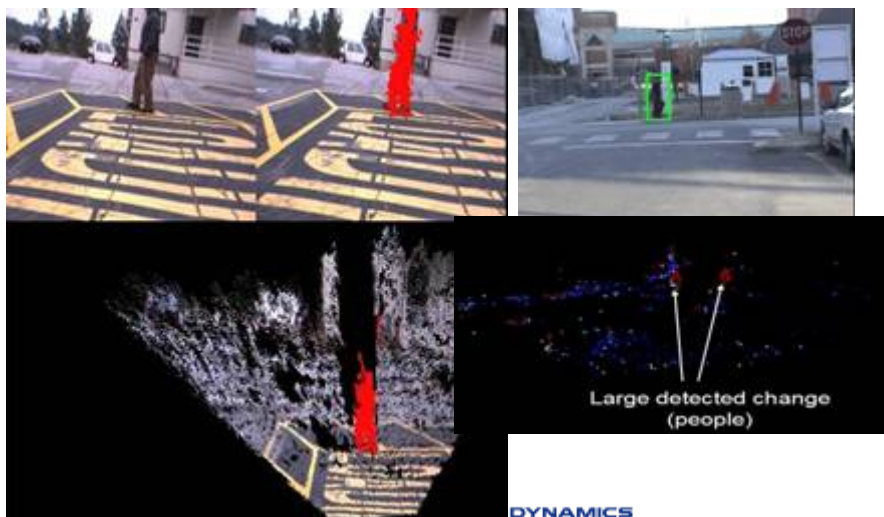
## LADAR Development & Processing Algorithms



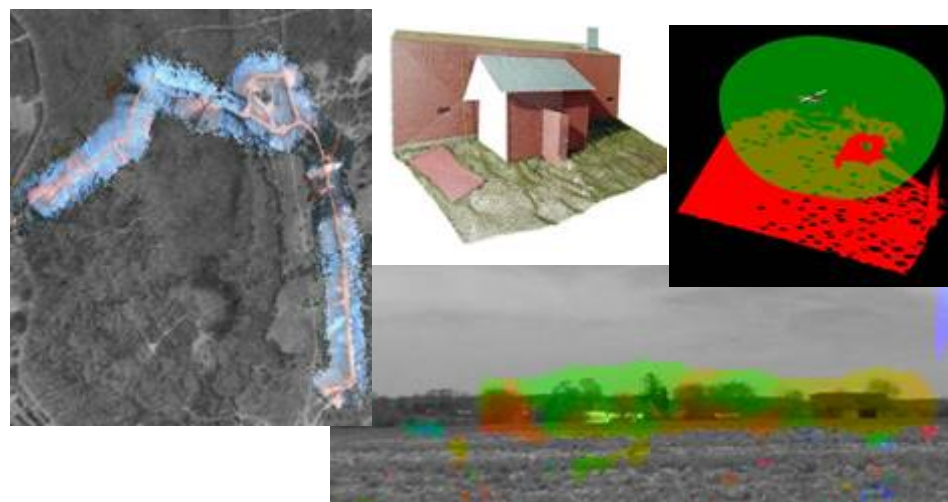
## Terrain Classification



## Moving Agent Understanding



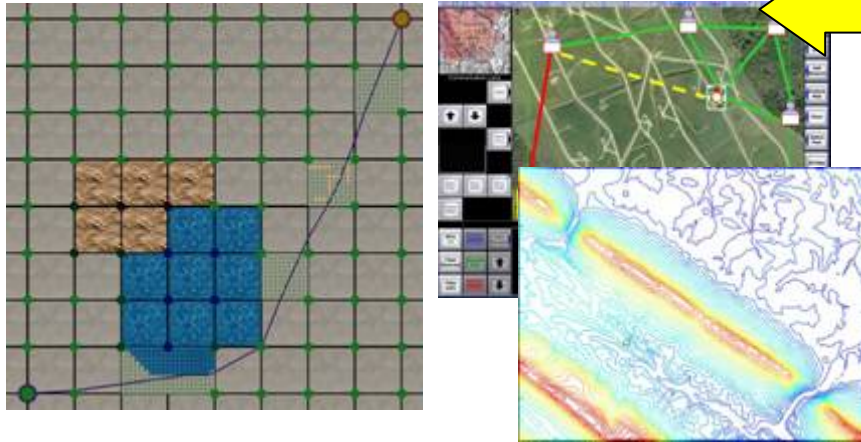
## Air / Ground & Mid-Range Sensing



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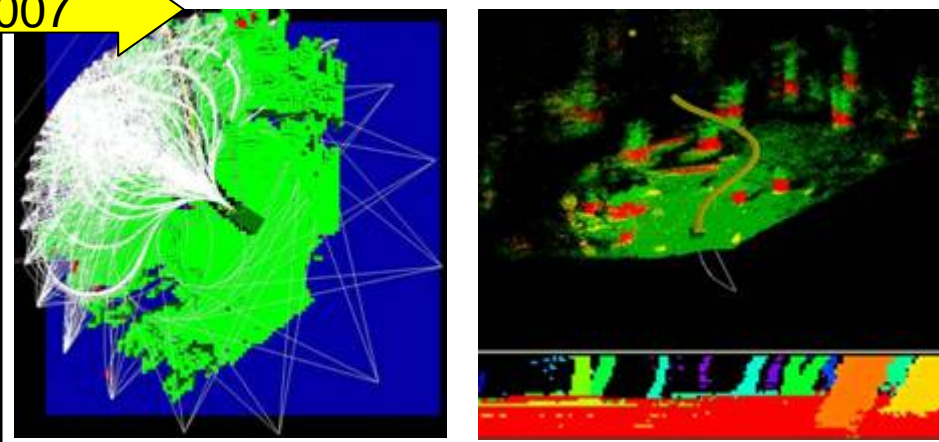
# Advances in Control Architectures

## Global Planning for Robotic Vehicles



2007

## Local Planning for Robotic Vehicles



## Tactical Behaviors

**ARV Tactical Engagement Behaviors- MOUT**

Time: 055hr, Dawn

**Scenario 1: ARV-A Counter-Strike**

- With support from UAV 1, ARV-A autonomously moves into MOUT site.
- UAV 1 spots movement in building, sends signals to ARV.
- ARV-A determines threat to be a suspect.
- ARV-A counter-attacks suspect contained to ARV-A.
- UAV 1 moves in closer to gain target acquisition. ARV-A moves into open and destroys suspect.

**Scenario 2: ARV-A Recon Placement**

- With support from UAV 1, ARV-A determines in-hole position outside urban environment, maneuvering EPW to entry point in MOUT site.
- ARV-A spots enemy troops in the East of EPW.
- ARV-A engages troops with RL05, neutralizing enemy.

**Scenario 3: ARV-A Visual Monitoring**

- With support from UAV 1, ARV-A, during reconnaissance becomes engaged by enemy personnel.
- ARV-A employs smoke and retreats from position available route.

**Scenario 4: ARV-A Visual Monitoring**

- With support from UAV 1, ARV-A, provides lead cover for maneuvering EPW into MOUT site.
- ARV-A gives ARV-A target to create an opening in objective building.
- ARV-A creates opening in wall of building.
- ARV-A stacks against building and enters control system.
- ARV-A moves into position, along wall and becomes a natural branching point for EPW to climb and enter 2nd floor.

**Legend:**

- Troop Movement
- ARV-Retreat Path
- ARV-Path
- Sensors

**General Dynamics Robotic Systems**

## Collaborative Operations



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Robotic Systems

# Advances in Human Machine Interface

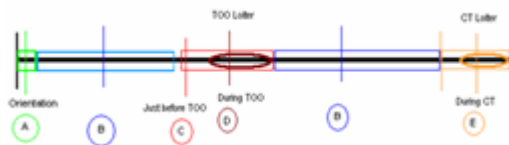
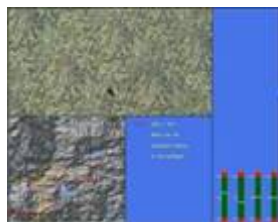
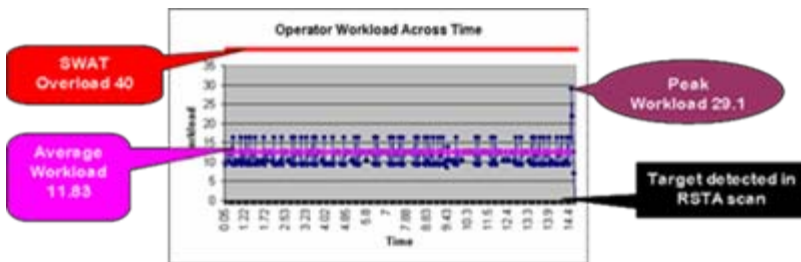
## Scalable Human Machine Interfaces



## Multi-Modal Input



## Workload / Trust in Automation



## HMI Interface Extensions



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# Evaluation and Experimentation Overview

## Stages of Experimentation and Integration

### Proof of Concept Testing with COTS Hardware

Researchers test proof of concept in their own labs with commercial off-the-shelf (COTS) hardware. The image at right is from the Carnegie Mellon Robotics Institute Laboratory.



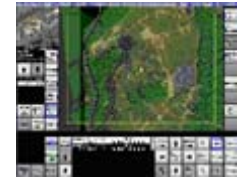
### Perception and Autonomous Navigation Testing with GDRS Standardized Test Facilities

GDRS facilities are used to test perception and autonomous navigation tasks. Data is analyzed against the ground truth of known obstacles. ARL and NIST design quantitative experiments.



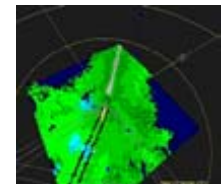
### Simulation Testing with RCTA SIL

The RCTA Systems Integration Lab (SIL) at GDRS provides a hardware-in-the loop simulation testbed for Advanced Perception, Intelligent Control Architecture (ICA) and Human Machine Interface (HMI) technologies.



### Integration and Testing in Realistic Environments

New technology is integrated and tested on the Demo III XUV and commercial vehicles in various terrains including rolling and forested terrain, as well as a MOUT environment at Fort Indiantown Gap.



# Fort Indiantown Gap, Pennsylvania

## Robotics Lab and Test Facility

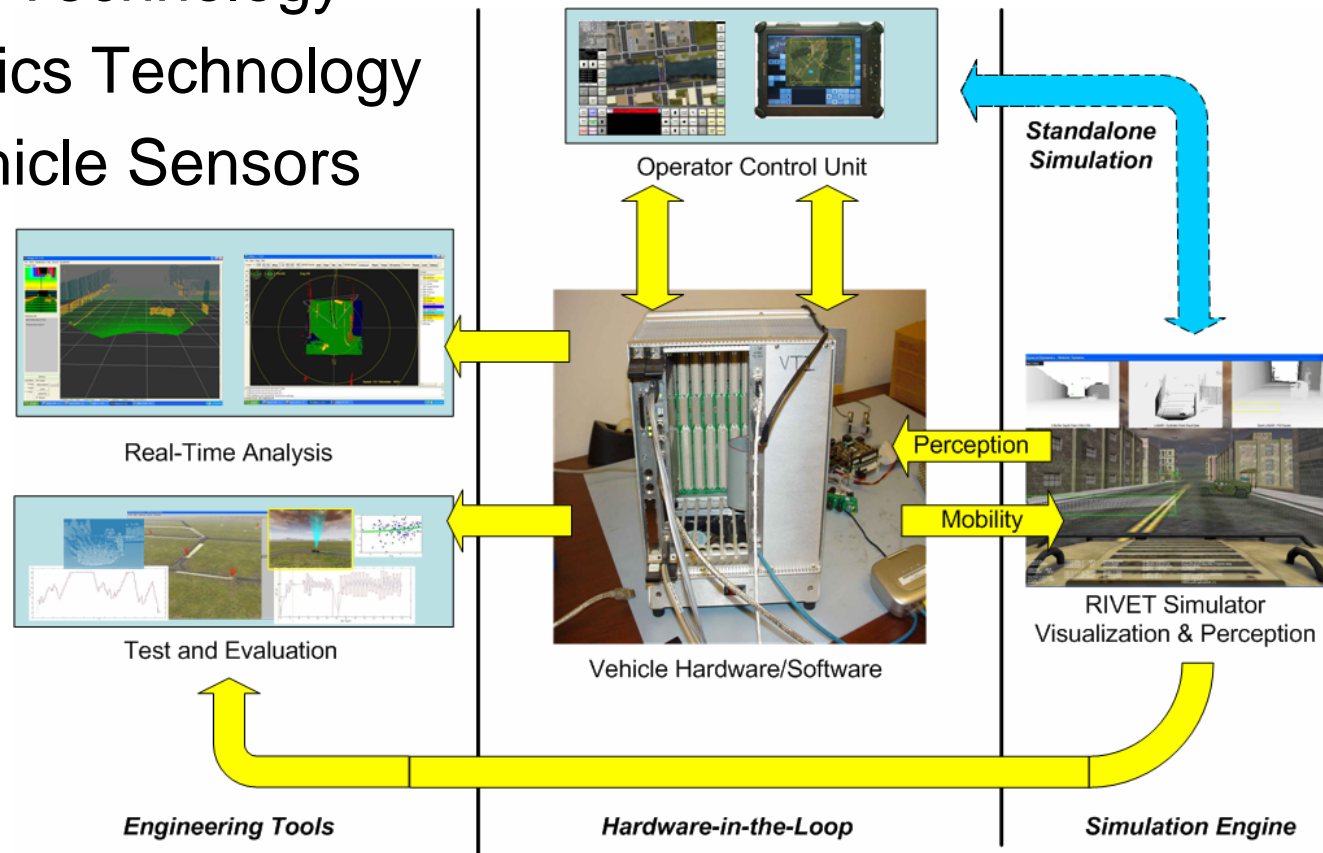


- State-of-the-art Robotics Facility located at Ft. Indiantown Gap, PA.
- Realistic environment for Field Experimentation currently used as a training facility
  - 10<sup>th</sup> Mtn. Division Exercises
  - 20<sup>th</sup> ID Training prior to deployment in Iraq
  - Stryker Brigade
- Facility Statistics
  - 5,000 sq. ft. Office / Lab Space
  - 3,500 sq. ft. High Bay
  - Floor capable of supporting large vehicles such as Stryker
  - TVMA-B Range 4km x 1.5 km



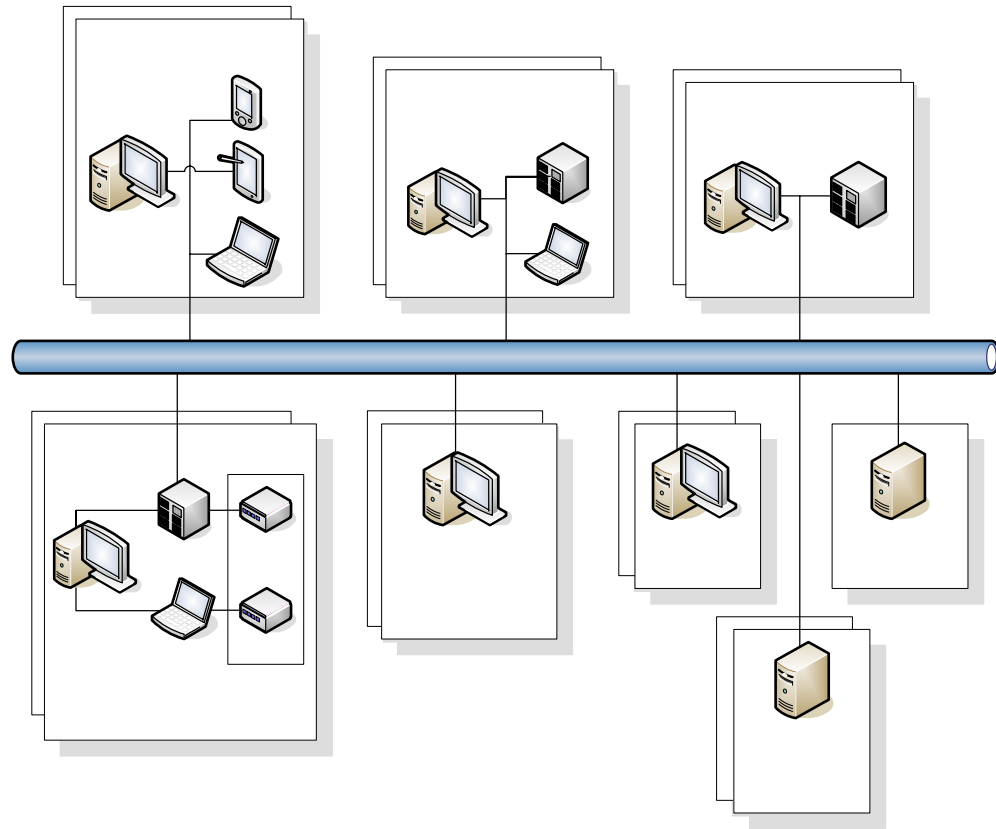
# Hardware-in-the-Loop Simulation

- Capability Developed in FY 2007
- Leverages Visualization Technology from COTS Gaming Technology
- Exploits Graphics Technology to Emulate Vehicle Sensors

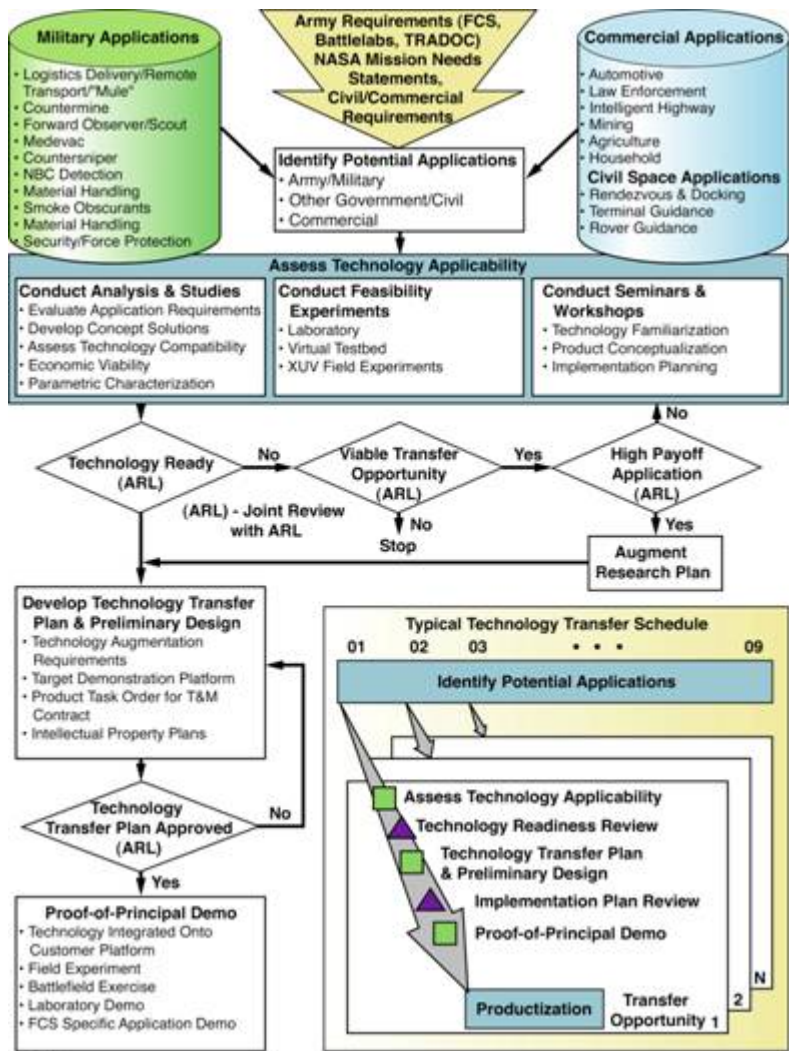


# Hardware-in-the-Loop Simulation: Benefits and Uses

- Benefits
  - Engineers: Closed-Loop Desktop Test Environment
  - Soldiers: Scalable, Coherent Evaluation Environment
- Uses
  - Exercise Perception Algorithms
  - Exercise ICA & Tactical Behavior Algorithms
  - HRI Development
  - Workload Theory Data Collection
  - Soldier Training



# Robotics CTA Technology Transfer



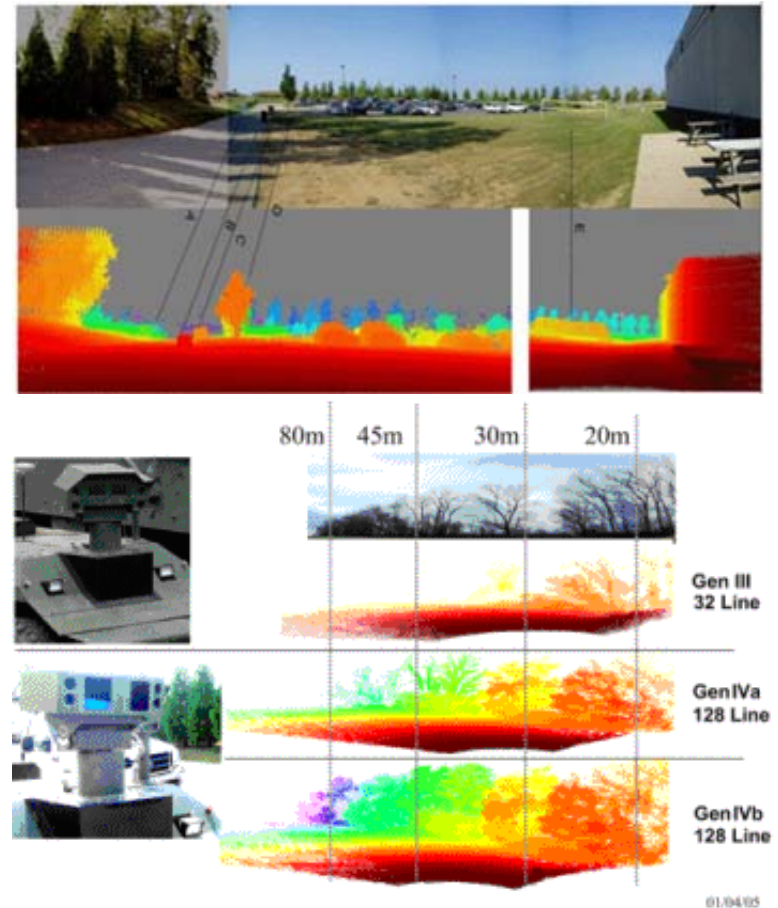
**DEVELOP** technologies to meet current and anticipated military needs.....

**ASSESS** applicability of developed technologies to new applications as they arise through interaction, analysis and integrated field experimentation.....

**TRANSFER** technologies to maximize investment and advance the state-of-the-art!!!

# RCTA Transitions to FCS ANS

- Provided the technical foundation for FCS-ANS and the demonstration in 2003 that was instrumental in funding FCS unmanned ground systems
  - Field-tested LADAR hardware
  - LADAR processing algorithms for obstacle detection, classification algorithms for obstacle detection, and terrain classification
  - Engineering visualization tools for LADAR and vehicle planner development
  - Field-tested robotic testbed platforms (with interfaces to navigation sensors), capable of data collection and archiving in realistic tactical environments
  - LADAR optics, TX/RX electronics and processing firmware (FFT, multi-pulse, ranging, etc.)
  - Passive perception system algorithms; stereo correlator, rectification and pyramid algorithms



# *RCTA Transitions to TARDEC's VTI RF and CAT STO*

- All hardware and software perception sensors
- Sensor processing algorithms
- Vehicle planners
- Planning algorithms via Terrain Reasoner
- Selected tactical and cooperative behavior algorithms
- Perception technologies from the 3500-pound XUV testbed to the 18-ton Stryker vehicle
- SMI related components



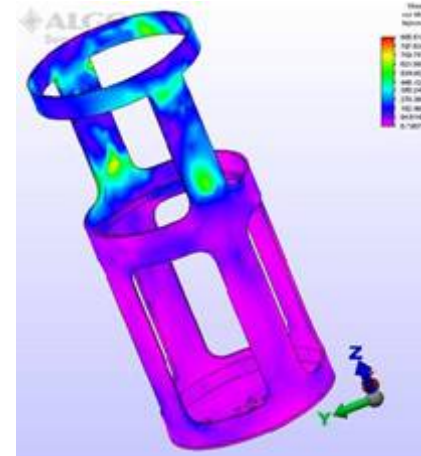
# RCTA Transitions to PM-FPS MDARS

- Perception Sensors (LADAR and EO/IR)
- Sensor processing algorithms
- Vehicle planners and OA Planning algorithms
- LADAR optics and TX/RX electronics
- LADAR processing firmware (FFT, multi-pulse, ranging, etc.)
- Acadia Vision Processor



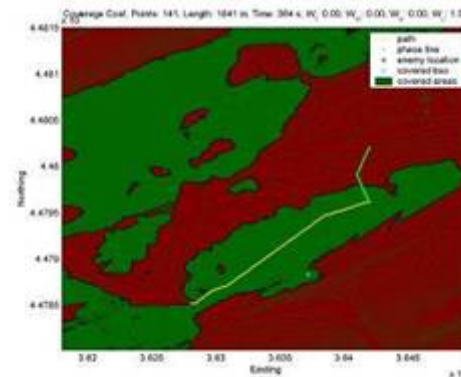
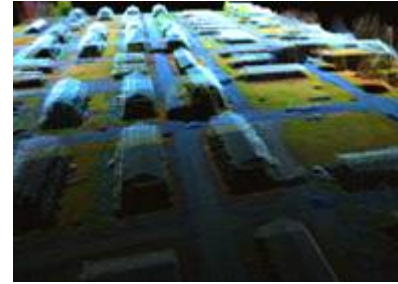
# RCTA Transitions to DARPA OAV-II

- LADAR Core Sensor Technology
- Sensor Processing and Obstacle Avoidance/Path Planning Algorithms
- Human-Robotic Interface and Command and Control Technologies



# RCTA Transitions to AATD UACO

- UGV Perception Sensors and Demonstration Platforms
- UGV and LADAR Sensor Processing Algorithms
- Vehicle planners and OA planning algorithms
- Market-Based Collaborative Tasking Algorithms
- SMI Interface, Decision Support System, and Terrain Reasoner
- Air / Ground Cooperative C2
- Test and Demo Facilities



# Transitions to Other Government Programs

- TARDEC
- DARPA
- Robotic Systems JPO
- NASA

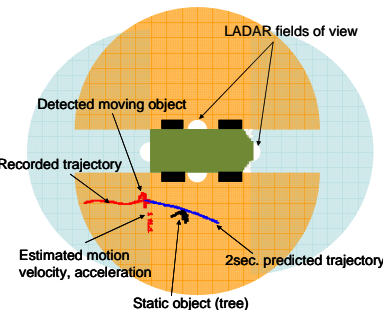
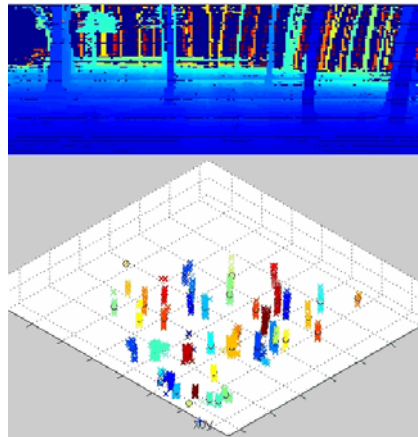
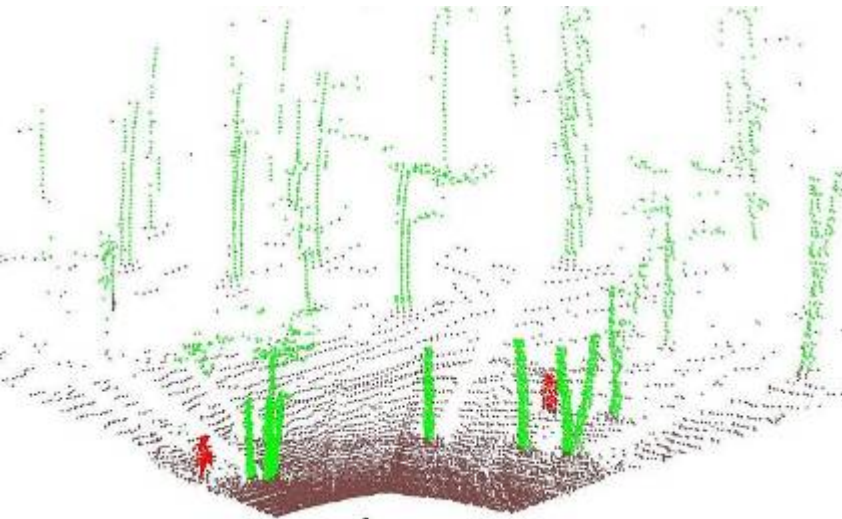
## Summary of RCTA Transitions to Other Government Programs

DARPA Robotic Vision 2020 (RV2020) Program	<ul style="list-style-type: none"> <li>• Real-time optical flow algorithm that runs in parallel with stereo ranging to develop a moving obstacle detection on-the-move capability</li> <li>• Run-time stereo algorithms on a compact smart camera board</li> </ul>
DARPA Perception for Off-road Robotics (PerceptOR) Program, and Unmanned Ground Combat Vehicle (UGCV)	<ul style="list-style-type: none"> <li>• Visual pose estimation capability to provide accurate autonomous vehicle position estimation during extended GPS-denied operation</li> <li>• Stereo bilateral pre-filter</li> </ul>
DARPA Multi-Spectral Adaptive Networked Tactical Imaging System (MANTIS) Program	<ul style="list-style-type: none"> <li>• Pose and 3D estimation capabilities to provide accurate position and orientation estimation based on visual inputs from helmet mounted VNIR and SWIR sensors</li> </ul>
DARPA Learning Applied to Ground Robots (LAGR) Program	<ul style="list-style-type: none"> <li>• Large-baseline stereo analysis</li> </ul>
USMC Self Mobile Trailer (SMT) Program	<ul style="list-style-type: none"> <li>• Perception Sensors and Processing Algorithms</li> <li>• Vehicle Path Planning &amp; Control</li> </ul>
Robotic Systems JPO – Ground Standoff Mine Detection System (GSTAMIDS) Program	<ul style="list-style-type: none"> <li>• Actuation and low-level vehicle control</li> </ul>
TARDEC Safe Operations Program	<ul style="list-style-type: none"> <li>• Perception, Planning &amp; Tactical Behaviors</li> </ul>
TARDEC Near-Autonomous Unmanned System STO (formerly ARV Robotics Technology STO)	<ul style="list-style-type: none"> <li>• Perception, Planning &amp; Tactical Behaviors</li> </ul>
NASA Mars Technology Program	<ul style="list-style-type: none"> <li>• Run-time stereo algorithms and 3D stereo range visualization and diagnostic tools for integration into future Mars Rovers</li> </ul>



# FCS Risk Mitigation Accomplishments

- FCS Risk 213 – Safe Operations
- 11 Research Tasks, 4 Sensor Modalities
  - Assessments Designed by ARL & NIST
  - Approval for Live Human Experimentation
  - Common Evaluation Platform
  - 3 Quantitative Assessments in 2007
  - Additional Assessments in 2008



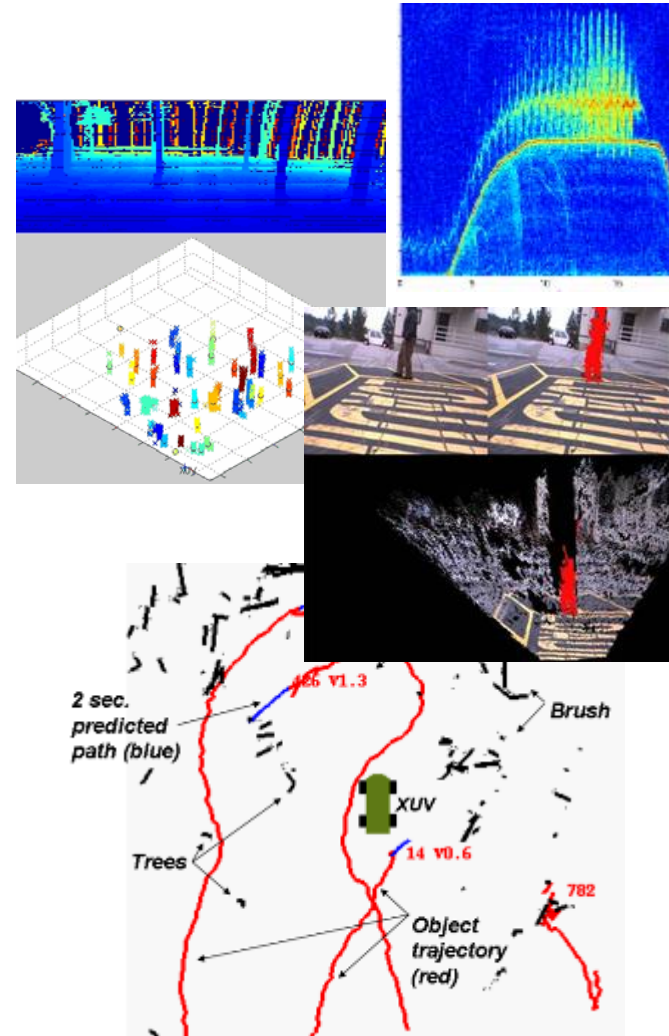
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# RCTA Focus Going Forward

## Advanced Perception

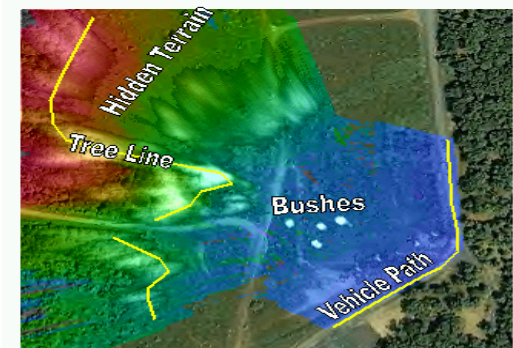
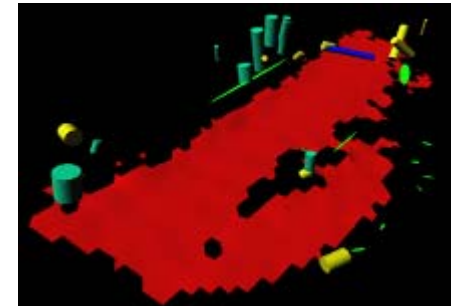
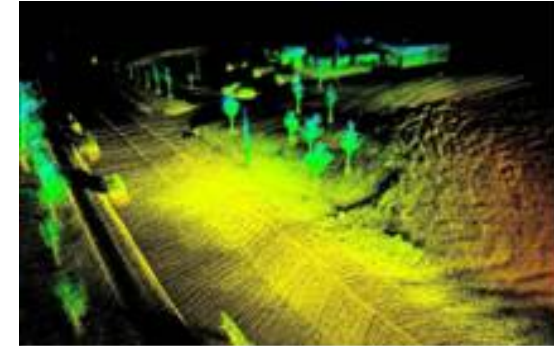
- **Continued Emphasis on Safe Operations**
  - Focus future research on detecting and tracking of **humans** to meet FCS criteria for safe operations
  - In any and all terrain types
  - Upright, crouched, prone
  - Occluded, emerging from occlusions
  - Fast detection, accurate tracking
  - Long ranges (100 m), varying speeds (up to 40 mph)
  - Anytime, anyplace, anywhere



# RCTA Focus Going Forward

## Advanced Perception

- Develop better/faster **obstacle detection and classification** algorithms to improve speed in open/rolling terrain and urban environments
- Emphasize **local situational awareness and scene understanding** to address the development and maintenance of an operational picture
- Advance **perception algorithms for mid-range planning** in order to enhance planning for safe operations, effective reconnaissance and tactical behaviors
- Advance **cooperative perception and planning** among heterogeneous assets including airborne perception for use as a planning aid



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BAE SYSTEMS

Carnegie Mellon

Florida A&M



JPL



PERCEPT



Sarnoff

SFU

Signal Systems Corporation

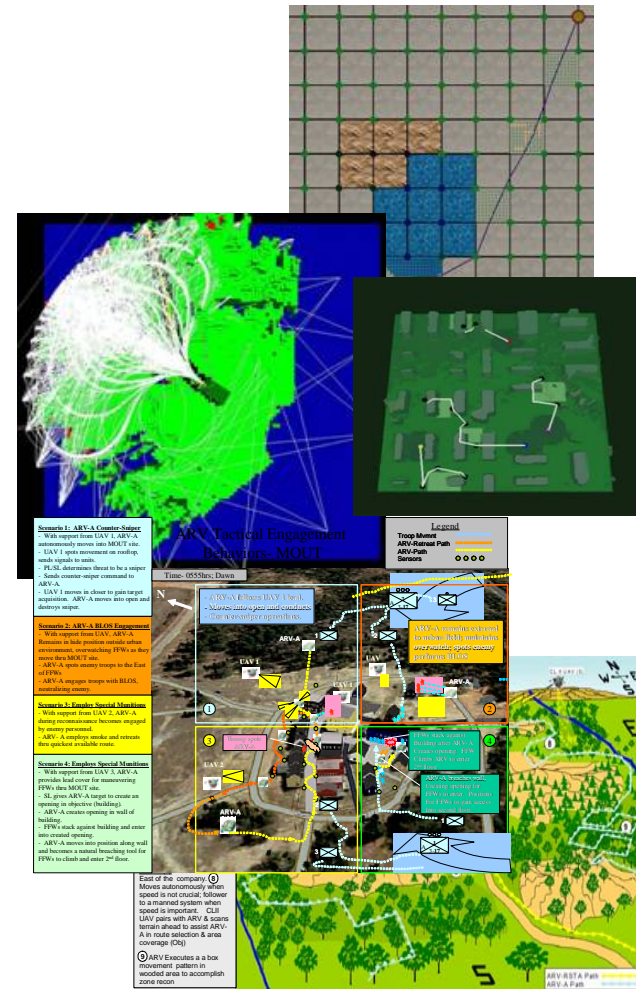
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# RCTA Focus Going Forward

## Intelligent Control Architectures

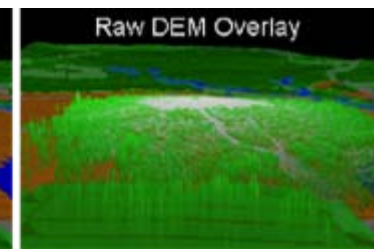
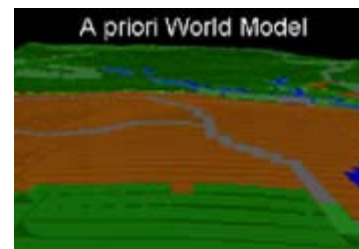
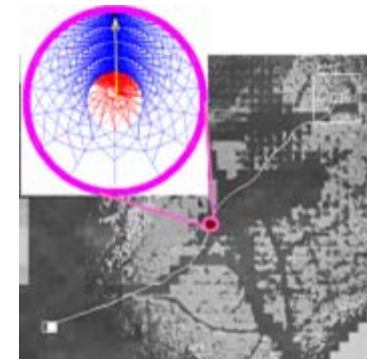
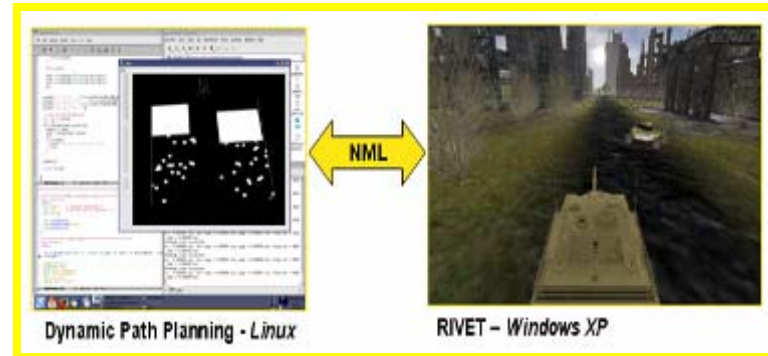
- Develop technologies to support FCS Requirements for **Deliberative Planning** in support of safe operations in dynamic environments
  - GPP planner, multi-resolution planning, planning with uncertainty
  - Collaborative planning for heterogeneous robots
- Enable **Local Planning for Autonomous Safe Operations**
  - Incorporate vehicle dynamics
  - (x,y,t) planning, etc.
- **Combining Global and Local Planners**
  - Field Interface at the cost level
  - AM data used by the global planner



# RCTA Focus Going Forward

## Intelligent Control Architectures

- Develop **Supporting Tools** to enhance Algorithm Development
  - Visualization for planning algorithms
  - Hardware-in-the-loop sensor simulation
  - Simulated data to test new approaches
- Integrate **Perception-Based Feedback** into Tactical Behaviors
  - Bowls, tree lines, urban sight lines, intervisibility, etc.
- Enable **Best-Information Planning** for robotic command and control
  - Ingest real-time data from aerial sensors, a-priori maps, AM sensors



# RCTA Focus Going Forward

## Human Machine Interface

- Develop **HMI Extensions** to support increased situational awareness and operator control in cluttered environments
  - Support human detection for safe operations
  - Enhance visualization for situational awareness
  - Enhance simulation tools
  - Improve Spoken Language Interface
- Quantify **Human Performance and Cognitive Capability** during control of multiple heterogeneous robots
  - Data collection with UAMBL to support FCS concept development
  - ARL data collection to support AM / Reconnaissance workload

