Intelligent Control of Mobility Systems

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Program Funding:	$4.1 M
FTEs:	13.5

Program Goal

Provide architectures and interface standards, performance test methods and data, and infrastructure technology needed by U.S. manufacturing industry and government agencies in developing and applying intelligent control technology to mobility systems to reduce operational costs, improve performance and safety, and save lives.

Problem

As mobile systems become more intelligent, their use in the field increases. Material handling systems could be used for loading and unloading of trucks, autonomous vehicles can provide an unmanned ground force for the Army, and on-vehicle crash avoidance systems may become more effective. However, to develop and use intelligent mobile systems, industry and government agencies need architectures and interface standards to insure interoperability, real-time sensing technologies for measurement and control, and metrics for evaluating the performance of components and systems

Approach

This program will provide industry with standards, performance metrics, and infrastructure technology to broaden the use of advanced perception and autonomous navigation techniques; provide defense agencies with the control system architectures, advanced sensor systems, research services and standards to achieve efficient use of unmanned ground vehicles in the battlefield; provide the evaluation and measurement methods, testing procedures, standard reference data needed to support the deployment of advanced technology in transportation and industrial safety systems. The program will use the NIST-developed reference model architecture for intelligent unmanned ground vehicle - 4D/RCS - architecture as an example of an open system architecture for building complex autonomous robotic systems for other government agency programs. Relevant advanced robotics technology will be transferred to industrial applications.

Typical Customers and Collaborators

- Army Research Lab
- Applanix
- Robotics Technology Inc.
- University of Maryland
- DARPA
- National Highway Traffic Safety Administration (NHTSA)
- The Boeing Company
- Transbotics
- Drexel University
- Visteon & Assistware
- Bremen Univ./Germany
- DOT
- ATR
- TACOM/TARDEC
- EarthData Inc.
- University of Delaware
- OSD/JRP
- General Dynamics Robotic Systems

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mobility systems

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13.5

Annual Program Funds:
$4.1 M

Industrial Material Handling & Other Industrial Applications

Reduce costs and improve efficiency in industrial material handling by providing to the industrial autonomous guided vehicle (AGV) industry advanced technology and performance tests to support the use of non-contact safety sensors and appropriate control systems architectures and standards to enable the use of advanced navigation techniques based on such non-contact sensors;

Department of Defense (DOD) Unmanned Ground Vehicles

Save lives and improve national defense capabilities by providing agencies of the Department of Defense (DOD) with control systems architectures, advanced sensor systems, research services, and standards to achieve autonomous mobility for unmanned ground vehicles (UGVs);

Performance Measures for Mobile Robots

Improve vehicle safety, transportation system capacity, and accelerate advancement of mobile robots through the development of advanced sensors and intelligent vehicle control systems on manned and unmanned vehicles by providing performance metrics (i.e., objective evaluation and measurement methods, testing procedures, and standard reference data) needed to analyze sensor and control system effectiveness; and

Knowledge Engineering for Intelligent Control of Mobility Systems

Improve interoperability, enable knowledge reuse, and improve functionality and traceability of knowledge-based mobility systems through the development, implementation, and dissemination of rigorous knowledge capture methodologies, standardized data structures and common knowledge bases.

Customer Need & Intended Impact

To develop and use intelligent mobile systems, industry and government agencies need architectures and interface standards to ensure interoperability, real-time sensing and measurement for control systems, and metrics for evaluating performance of components and systems.

Industrial Material Handling

Discrete part manufacturing customers require material handling systems that can be changed to meet any handling and movement requirements without the need for redesign and manual rearrangement. They also would like a material handling control system that can seamlessly integrate with multiple complex handling systems and one that would self-adapt to changes in handling system configuration or processing requirements. Advanced mobile robot technology is needed in manufacturing enterprises for plant physical security, hazard detection, inventory control, and cleaning. Other industries such as agriculture, construction, postal service and service robots have similar needs. The Integrated Manufacturing Technology Roadmap (IMTR), industry representatives at workshops, conferences, and personal contacts identified the customer needs that this program will address.

Accomplishments from our Intelligent Autonomous Vehicle (IAV) project and our advanced work in autonomous vehicles technology for the military, AGV developers look to us for help in developing and demonstrating advanced capabilities for autonomous loading and unloading of trucks for the warehousing industry. AGVs currently do not provide this capability and the warehousing industry sees this as a high-risk area for vendors to address. There are several strategic advantages of automating this task: gaining a competitive advantage (i.e., performance vs. time); supplementing the workforce since the industry expects to lose between 50% to 60% of their labor in the next five years due to aging workers; decreasing by as much as 30% the warehousing and distribution costs currently incurred through manual loading and unloading of trucks. To perform automated material handling tasks reliably and efficiently with robots, a new generation of advanced, high performance, but low cost imaging sensors are needed by the UGV and other industries. We believe that a new generation of scannerless Focal Plane Array (FPA) LADARs (Laser Detection and Ranging or Laser Radar) will be able to provide this capability.

In addition to advanced technology, the UGV industry needs changes in safety standards to include non-contact bumpers and obstacle detection sensors on their vehicles. Without these changes, AGV users and vendors will be unsure who is liable during vehicle collisions. Although steps have been take to include non-contact bumpers in UGV vehicle standards, a need remains for developing standards for the evaluation of safety system object detection and localization capabilities. Standards will provide the vendors with metrics to develop and users to select systems and system components with certain specified capabilities.

Because of over thirty years of experience in development of technology for intelligent systems, MEL is well positioned to work with the material handling industry and other industries to improve performance, competitiveness and standards to help expand markets.

DOD Unmanned Ground Vehicles

Because of the technological progress in the development and demonstration of autonomous mobility for unmanned ground vehicles in the past decade, the DOD decided to proceed with plans for the deployment of intelligent robotic vehicle platforms in the battlefield by 2010. This program is called the Future Combat Systems program and is jointly managed by the U.S. Army and Defense Advanced Research Projects Agency (DARPA). Standardized architectures and interfaces encourage the use of commercially available "plug-and-play" components and provide reusability and interoperability on a variety of robotic vehicle platforms.

Autonomous tactical behaviors for UGVs are of tremendous interest to the military. With the successful development and demonstration of autonomous driving in the Army's Demo III program, it is now possible to envision the use of these vehicles in tactical situations. However, to implement autonomous tactical behavior functionality successfully in robots, it requires the development of the design methodology, architectural framework, knowledge representation and sensing requirements that support those behaviors. The Army Research Laboratory (ARL) requested that NIST/MEL focus its research to support the need for tactical behaviors for a multi-vehicle route reconnaissance mission.

It is envisioned that a single manned control vehicle could control many autonomous ground and air vehicles to accomplish reconnaissance missions. Successful development of these technologies would result in removing soldiers from performing hazardous missions, multiply the effectiveness of military personnel, help reduce combat casualties, and reduce annual operating costs.

Performance Measures

Companies developing advanced components and system technologies, and government users of such technologies, need objective metrics to evaluate and specify technology elements, products, and intelligent behaviors of complete systems. Such performance metrics improve the efficiency of the development efforts, provide the basis for an equitable and competitive marketplace, and provide the basis of legal and regulatory decisions. The National Highway Traffic Safety Administration (NHTSA) asked NIST/MEL to develop next generation real-time measurement methods, testing procedures, and roadway calibration systems to evaluate the effectiveness of on-vehicle crash avoidance systems for highways. A NHTSA analysis showed that widespread deployment of integrated advanced driver assistance systems addressing rear-end, road departure and lane change collisions could reduce motor vehicle collisions by 17%. The results from the performance tests will provide the Department of Transportation (DOT) with naturalistic-driving data that will allow them to determine the effectiveness of these systems in preventing crashes, which could save lives and reduce cost.

The DOD needs to conduct Technology Readiness Level (TRL) experiments to determine maturity of military systems and system components in preparation for deployment. In response to Congressional guidance, the Joint Robotics Program (JRP) at the Office of the Under Secretary of Defense (OUSD) initiated plans for developing and fielding a family of mobile ground robot systems for insertion into the military force structure. The JRP organized a collaborative effort to establish a National Unmanned Systems Experimentation Environment (NUSE2) to provide developers and acquirers of unmanned systems with dedicated experimentation facilities, ranges and airspace that is easily accessible. The JRP believes that NIST/MEL has the capability and experience to provide the metrology service for this initiative. If this work is successful, the NUSE2 effort has the potential to provide military service men and women with leap-ahead war-fighting capability, which will also reduce risk levels to military personnel.

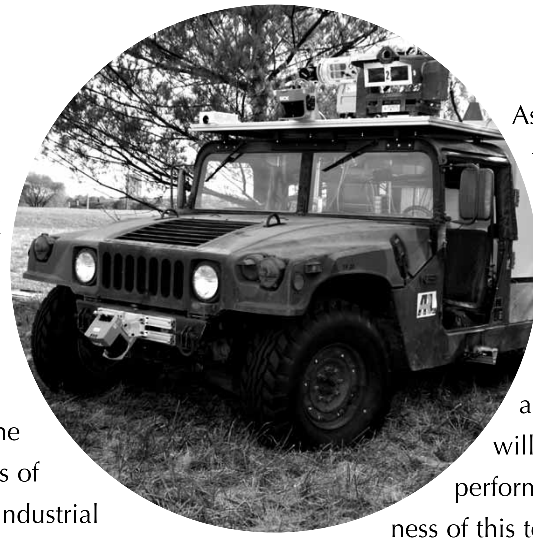
Knowledge Engineering for Intelligent Control of Mobility Systems (ICMS)

The development of intelligent ground vehicles (IGV) for the Army objective force requires a thorough understanding of all of the intelligent behavior that needs to be exhibited by the system so that designers can allocate functionality to humans and/or machines. The Army requested NIST to develop an intelligent ground vehicle ontology to capture information about tactical behaviors to enable intelligent behaviors by autonomous systems. The existence of such an ontology is essential to accomplish the level of automation that the community is demanding, which in turn will serve to offload dangerous, human-performed tasks to autonomous systems, thus removing them from harms way. In addition, a fundamental need of mobility systems, in performance of intelligent behaviors, is the ability to have a thorough understanding of the environment. Knowledge representation techniques are needed to capture information that the sensor system perceives, organize that knowledge in a fashion that makes it easy to retrieve, and process.

Technical Approach & Program Objectives

Robotics industry leaders point out that advances in military, transportation, medical, and other non-manufacturing robotics applications, where research and development investments are justified by dramatic potential benefits, will provide the technologies to advance future generations of robots for applications in manufacturing. Industrial robots trail in technology development, thus adopting advanced technology developed under military projects is proven to be reliable and cost effective; autonomous mobile systems for military applications represent the forefront of robotics research.

Thus, to achieve the program objectives, the primary technical approach is to use the NIST Real-time Control System (RCS) architecture as an example of an open system architecture for building complex autonomous robotic systems for other government agency programs (i.e., military and transportation), and then transfer relevant advanced robotic technology to industrial applications. The RCS architecture provides a systematic analysis, design, hierarchical framework, and implementation methodology for developing real-time sensor-based control systems. The control system uses sensory information to guide the intelligent vehicle in the execution of complex tasks. Planning for task execution, coordinated activities between vehicles, and for adaptation to changes in the environment are also parts of the total hierarchy.



As intelligent vehicle technology matures and our other agency customers consider deploying intelligent robots for their program tasks and missions, they will want to evaluate the performance and effectiveness of this technology as it applies to their requirements and expectations. Based on our history, NIST is in a unique position to fulfill this need for them. However since this is a new emerging metrology field, NIST/MEL will need to put more emphasis on establishing technical strength in performance measures, reference/standards and test facilities that support evaluating the performance of intelligent vehicle systems. Many of the potential sponsors and customers view that measurements and standards are part of NIST's mission. Therefore, some cost sharing for metrology sensors and equipment may increase the likelihood of attracting other agency funds and in establishing long term collaborative relationships. The reference/standard test facilities and measurement equipment are expected to remain at NIST, but could be duplicated at customer experimentation sites.

Objective #1: Industrial Material Handling

Provide industries with the necessary standards, performance metrics, and infrastructure technology to support the use of non-contact safety sensors and control system architectures that enable broader use of advanced perception and autonomous navigation techniques in the AGV, and other industries.

Objective #2: DOD Unmanned Ground Vehicles

Provide DOD agencies with the control system architectures, advanced sensor systems, research services, and standards to achieve next generation autonomous mobility and tactical behaviors for unmanned ground vehicles.

Objective #3: Performance Measures for Mobile Robots

Provide the evaluation and measurement methods, testing procedures and standard reference data for performance analysis and deployment of advanced sensors, and intelligent vehicle control systems on manned and unmanned vehicles used in next generation transportation safety/driver assist systems and in UGVs for the military.

Objective #4: Knowledge Engineering for Intelligent Control of Mobility Systems

Provide rigorous knowledge capture methodologies, standard data structures and common knowledge bases to mobility system researchers and developers to enable improved interoperability, greater knowledge reuse, and increased functionality and traceability of knowledge-based mobility systems.

Major Accomplishments

Advanced Sensing and Control Applied for Industrial AGVs

- We work with a Cooperative Research and Development Agreement (CRADA) partner to develop and demonstrate an autonomous AGV, which uses a LADAR sensor, to locate pallets, pick them up and deliver them into a truck. NIST tested several commercially available LADARs for this application and generated algorithms for detection and localization of pallets.
- We evaluated the performance of prototype next generation FPA LADAR. Developers of these systems project a factor of 10 drop in cost for a LADAR.
- Together with the NIST Building and Fire Research Laboratory, we published a NIST Internal Report (NISTIR 7117) titled "Performance Analysis of Next-Generation LADAR for Manufacturing, Construction and Mobility.". The construction industry recognized the value of this report by announcing its release in a SparView article and in a FIATECH (non-profit consortium focused on development and deployment of technologies in the construction industry) newsletter.

Unmanned Ground Vehicles

NIST Completes Technology Readiness Level Assessment of UGV Performance for the Army Research Laboratory

In the spring of 2003, personnel from the NIST MEL, BFRL and the Information Technology Laboratory (ITL) completed a Technology Readiness Level (TRL) 6 assessment for the ARL autonomous UGV program. The effort used Experimental Unmanned Vehicles (XUVs) developed by General Dynamics Robotic Systems (GDRS). Three similar assessment exercises were conducted in arid, rolling/vegetated, and urban environments. The test vehicles successfully completed over 500 km of autonomous driving. The results show the DOD that the UGV technology developed under the ARL Demo III program is sufficiently mature and reliable to be considered for a variety of tactical missions. The Future Combat Systems (FCS) program considered this when they decided to proceed with the development of an Autonomous Navigation Systems for robotic vehicles.

Adjusted Research and Upgraded Test Vehicles and Mobility Lab Facilities to Support the Next Phase of ARL and Other Agency Mobility Work

Autonomous tactical behaviors for UGVs are of tremendous interest to the military. With the success of the autonomous mobility technology, which was evaluated in the TRL 6 experiments, it is now possible to consider the use of robotic vehicles in tactical situations. Therefore, adjustments and improvements have been made by this program to better support this very demanding new initiative.

- Emphasis has been placed on conducting research to implement autonomous tactical behavior functionalities successfully into robots
- The NIST HMMWV (High Mobility Multipurpose Wheeled Vehicle) testbed vehicle has been upgraded to support research, testing and evaluation of advanced sensors, world modeling, planning and control technology that is needed to demonstrate autonomous performance in tactical behaviors.
- The Mobility Lab has been expanded to accommodate test vehicles for the new DOD and DOT (Intelligent Transportation) research and testing requirements. The lab now accommodates the NIST HMMWV, the GDRS Experimental UGV, and the DOT/NHTSA instrumented test vehicle.

Autonomy Levels for Unmanned Systems (ALFUS) Terminology Document Published

A document defining basic terminology pertaining to autonomous unmanned systems was published by NIST: "Federal Agencies Ad Hoc Autonomy Levels for Unmanned Systems Working Group, *Terminology for Specifying the Autonomy Levels for Unmanned Systems, Version 1.0."* External groups and committees, including the American Institute of Aeronautics and Astronautics, NASA, NATO and the Canadian Forces requested copies of the report. The seventh autonomy level workshop took place in mid-October 2004.

Performance Measures for Mobile Robots

Road Departure Crash Warning System (RDCWS) Metrics Project Drives On

The DOT/NHTSA funded NIST to provide continued independent measurement and data collection support for the RDCWS Field Operational Tests and to provide planning support for a new four-year initiative in Integrated Vehicle-Based Safety System (IVBSS) program. The IVBSS is a new program to develop and evaluate a multi-function warning system (i.e., road departure, rear-end and lane-change) on multiple vehicle classes (i.e., cars, trucks, and buses).

FY2005 Projects

Industrial Autonomous Vehicles (IAV) Technology Transfer (Objective #1)

This project team will work with key industry AGV developers and user partners to advance the state of autonomous robotic technology.

Deliverable for FY2005:

Demonstration of the autonomous truck loading and unloading with NIST CRADA partner, applying advanced range imaging sensors technology and perception algorithms transferred from DOD and DOT projects.

Deliverable for FY2006:

Collection of data, advance processing algorithms, and design implementation toward integration of advanced 3D sensors onto industrial AGVs and other mobile robots.

ARL Tactical Behaviors (Objective #2)

This project team will support the Army Research Laboratory (ARL) program in tactical behaviors.

Deliverable for FY2005:

A demonstration of next generation perception, planning and autonomous mobility that supports multiple vehicle tactical behaviors using real/virtual simulation environments.

Deliverable for early FY2006:

UGV intelligent tactical behaviors for route reconnaissance available to ARL for Field Operational tests.

NIST Mobility Testbed Vehicle (Objective #2)

This project team will provide DOD agencies with the control system architectures, advanced sensor systems, research services, and standards to achieve next generation autonomous mobility and tactical behaviors for unmanned ground vehicles.

Deliverable for FY2005:

The NIST mobility testbed vehicle upgraded to evaluate and refine next generation perception, learning, planning, and multi-vehicle behaviors for a reconnaissance mission.

Deliverable for FY2006:

A demonstration of next generation autonomous technology and tactical behaviors at NIST.

Military UGV & US Standards (Objective #2)

This project team will support relevant military standards activities.

Deliverable for FY2005 and beyond:

Working with standards groups on standards for the deployment of UGVs in the battlefield.

NHTSA Integrated Vehicle Safety Systems (Objective #3)

The project team will support the NHTSA Intelligent Transportation Systems (ITS) program initiative in Integrated Vehicle Based Safety Systems.

Deliverable for FY2005:

A NHTSA new program plan and Field Operational Tests in Integrated Vehicle Based Safety Systems developed to prevent highway crashes.

Deliverable for FY2008:

Development of the Next Generation baseline measurement system and test method concepts for measuring performance of Integrated Vehicle Based Safety Systems in preventing highway crashes.

Reference/Standards and Metrics for NUSE2 (Objective #3)

The project team will support the OSD Joint Robotics Program office by developing references and standards, and metrics for evaluating the performance of intelligent systems.

Deliverable for FY2006:

Assuming funding becomes available–
An initial baseline reference test facility for small autonomous robots at NIST.

Deliverable for FY2007:

Assuming funding becomes available–
Transition of reference/standard assessment technology to the NUSE2 experimentation sites

DOD/DOT Intelligent Vehicle Technology Transfer (Objective #3)

This project team will conduct a workshop and initiate a process for intelligent vehicle technology transfer between the DOD Joint Robotics Program, the DOT Intelligent Transportation Systems program, and their associated industry and research partners.

Deliverable for FY2005:

Assuming funding becomes available - a workshop and a final report to DOD and DOT describing the results of the workshop.

TARDEC Intelligent Ground Vehicle Ontology Program (Objective #4)

This project team will support the U.S. Army's Tank and Automotive Research, Development and Engineering Center (TARDEC) office in the development of a neutral Intelligent Ground Vehicle Ontology for representing tactical behaviors for unmanned ground vehicles.

Deliverable for FY2005:

An initial version of the Intelligent Ground Vehicle Ontology that focuses on scenarios identified by the TARDEC STOs (Science and Technology Objectives).

Knowledge-based Representations for Mobility Systems (Objective #4)

This project team will develop data structures and knowledge bases that will allow an autonomous mobility system to better understand itself and the environment.

Deliverables for FY2005:

1. Representations for moving objects that include the ability to predict their future location probabilistically.
2. Exploration of tools to aid in knowledge entering, reasoning, and visualization.

Typical Customers and Collaborators

Government:

- Army Research Lab: Tactical Behaviors for Unmanned Vehicles
- DARPA: Future Combat Systems Technology Development
- DOT/NHSA: Metrics for Vehicle-based Safety Systems
- TACOM/TARDEC: Intelligent Vehicle Ontology for Tactical Behaviors
- OSD/JRP: National Experimentation Sites for Unmanned Robotic Systems

Industry:

- Applanix: Integrated (INS/GPS) Position and Orientation Systems
- ATR: Advanced Computing and Simulation
- Transbotics: Automated Loading and Unloading of Trucks
- Visteon & Assistware: Road Departure Crash Warning Systems
- Robotic Technology Inc.: Military and Transportation Robotics
- Advanced Scientific Concepts, Coherent Technologies: Next Generation LADAR
- Lockheed Martin, Raytheon: Next Generation LADAR
- Aeolean: Advanced Computing
- EarthData Inc.: High Resolution Ground Truth
- Automated Material Handling Association: Automated AGVs

Universities:

- University of Delaware: Dynamic Modeling of Vehicles, Path Planning
- Drexel University: Real-time Hierarchical Control Architectures
- University of Maryland: Gesture Recognition, Hyper-spectral Imaging
- Bremen University/Germany: Research in Next Generation Planners
- MIT/Lincoln Labs: Next Generation Solid State LADAR

FY 2005 Standards Participation:

- American Society of Mechanical Engineers (ASME) B56.5 AGV Bumper Standards Committee – participate in committee activities
- ISO Technical Committee 204, Working Group 14 – Standards for Lane Departure Warning Systems – participant
- DOD Joint Architecture for Unmanned Systems – participant
- DOD Weapon System Technical Architecture Working Group – participant
- DOD Vetronic Architecture Standards for Unmanned Ground Vehicles – participant
- Autonomy Levels for Unmanned Systems (ALFUS) – facilitator and participant
- Infrastructure & Standards Committee for Unmanned Systems - participant

Intelligent Control of Mobility Systems

2002 | 2003 | 2004 | 2005 | 2006 | 2007

Themes

- Build technical strength in robotics (2002–2006)
- Transfer adv. intelligent vehicle technology to industry (2003–2006)
- Establish technical strength in Performance Measures (PM) & reference/standards (2003–2007)

Principal Activities

- Develop PM for Autonomous Mobility (AM) technology (ARL Demo III UGV program) (2002–2004)
- Develop PM for next generation AM technology (ARL) (2004–2006)
- Support Army/DARPA FCS Program Architectures & Autonomous Navigation System (2002–2004)
- Develop PM & Ref/Stds for intelligent vehicles (OSD/JRP) (2005–2007)
- Develop PM for Road Departure Crash Warning Systems (DOT/IVI) (2002–2004)
- Transfer intelligent vehicle technology (2005–2007)
- Develop PM for DOT/IVI Integrated Vehicle Based Safety Systems (2005–2007)
- Transfer advanced technology to AGV – Material Handling and other industries (2003–2006)

Deliverables

- ARL: AM technology & architecture for UGVs (2002–2003)
- ARL: TRL assessment (2003)
- ARL: Next gen. AM algorithms for tactical behaviors (2004–2005)
- PM for tactical behaviors (2006–2007)
- FCS: Boeing received 4D/RCS architecture & design specs. of ANS (2002–2003)
- OSD/JRP & FCS: Ref/Stds and PM for unmanned systems (2004–2007)
- DOT: PM validation for crash warning systems in Field Operational Tests (2002–2004)
- DOT: PM validation for Integrated Vehicle Based Safety Systems (2005–2007)
- NISTIR on non-contact sensors for safety and autonomous navigation (2002–2003)
- Autonomous loading & unloading of trucks for warehousing industry (2004–2005)
- Increased collaboration with other industries (2005–2006)

Impacts

- 4D/RCS draft standard for military UGVs
- FCS develops ANS based on results of TRL-6
- ANSI/ASME stds. allow use of non-contact safety sensors
- Reduced annual operating cost savings and casualties
- Cost savings and lives saved on highways
- Cost savings and increased productivity in industry