National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

RESPONSE ROBOTS

DHS/NIST Sponsored Evaluation Exercises

Pocket Guide
Version
2010.2

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Albert Wavering
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Elena Messina
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Ann Marie Virts
Editor/Developer

Hui-Min Huang
Test Method Developer

Anthony Downs
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Futher Information:
http://www.isd.mel.nist.gov/US&R_Robot_Standards/

Intelligent Systems Division
Engineering Laboratory
National Institute of Standards and Technology
100 Bureau Drive, MS8230
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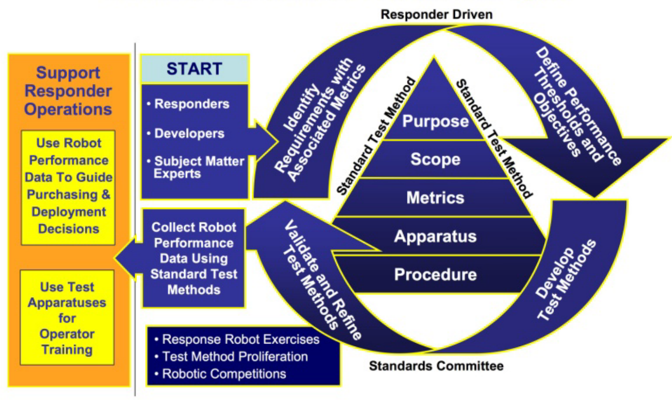
Program Overview

The Intelligent Systems Division of the National Institute of Standards and Technology is conducting an ongoing project, sponsored by the Department of Homeland Security Science and Technology Directorate and the National Institute of Justice, to produce a comprehensive set of standard test methods and associated performance metrics to quantify key capabilities of emergency response robots. These test methods address responder-defined requirements for **robot mobility**, **manipulation**, **sensors**, **energy**, **communications**, **human-robot interfaces**, **logistics** and **safety** for remotely operated ground vehicles, aquatic vehicles, and micro/mini aerial vehicles (under 2 kg/5 lbs) for urban environments. The goal is to facilitate emergency responder comparisons of different robot models based on statistically significant robot performance data captured within the standard test methods to help guide purchasing decisions and understand deployment capabilities. The test methods also support operator proficiency training and foster development and hardening of advanced mobile robot capabilities.

Standard Test Method Developmental Cycle



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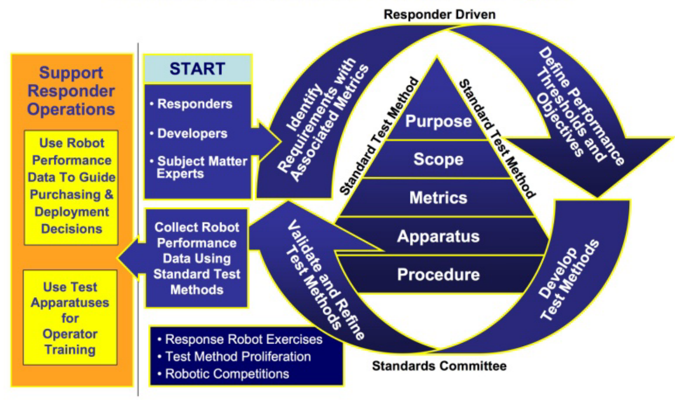

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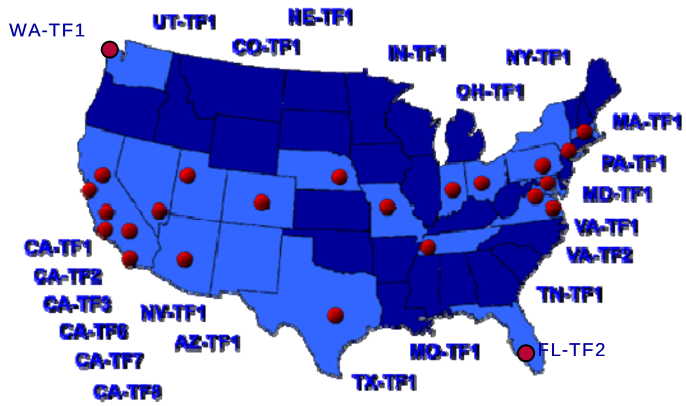
These response robot evaluation exercises for FEMA urban search and rescue teams; federal, state and local bomb squads; and police/SWAT teams to introduce emerging robotic capabilities to emergency responders within their own training facilities, while educating robot developers regarding the necessary performance requirements and operational constraints to be effective. Emerging standard test methods and usage guides for robot performance are under development within the ASTM International Committee on Homeland Security, Operational Equipment (E54.08.01). These events help refine the proposed standard test methods and fixtures/props that developers can use to practice critical capabilities and measure performance in ways that are relevant to emergency responders. These events are conducted in US&R training scenarios to help correlate the proposed standard test methods with envisioned deployment tasks and to lay the foundation for usage guides identifying a robot's applicability to particular response scenarios.

TASK FORCE PARTICIPATION



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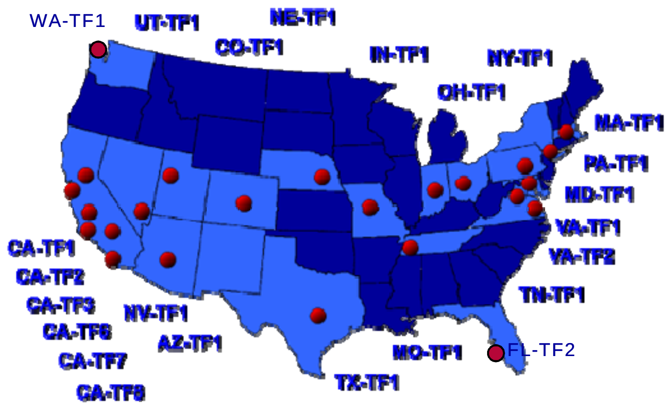

Disaster City
March 8-12, 2010

Disaster City
March 8-12, 2010

Event Introduction

The sixth in a series of DHS/NIST response robot evaluation exercises will be hosted at the emergency responder training facility known as Disaster City in College Station, TX. Thirty emergency responders from across the country will participate, including FEMA urban search and rescue teams; federal, state and local bomb squads; and police/SWAT teams, to help validate emerging standard robot test methods, become familiar with available robot capabilities, and advise robot developers regarding operational requirements. All applicable robots are invited to take part in this exercise including ground, aquatic, and VTOL aerials under 5 lbs. Robots will capture performance data within emerging standard test methods developed to evaluate Logistics, Mobility, Manipulation, Sensors, Radio Communications, Energy, Human-System Interaction, and Localization/Mapping capabilities. Robots may then be deployed with responders to perform operational tasks in practice scenarios, for example:

•searching and mapping (2D, 3D) test methods for operational tasks in building interiors and exteriors, partially collapsed structures, and confined spaces in rubble piles

•mobile manipulation test methods for operational tasks in EOD scenarios

•endurance, radio communications, sensor acuity, and decontamination/washdown test methods for operational tasks in down-range reconnaissance of a hazardous materials train wreck from an stand-off greater than 150m/500ft

•towing test methods (trailers, gripper-drag) for operational tasks in EOD and US&R scenarios

•underwater test methods for navigation and sensor acuity for operational tasks in the on-sight pond

•aerial test methods for air-worthiness, station-keeping, and sensor acuity for operational tasks supporting scenarios noted above



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•aerial test methods for air-worthiness, station-keeping, and sensor acuity for operational tasks supporting scenarios noted above



Event Robots - 2010

Robot Name (by size)	Company
Ground Robots	
Scout	ReconRobotics, Inc.
ActiveScopeCamera	Tohoku University
Pointman	Applied Research Associates, Inc.
VGTV-Extreme	Inuktun
Dragon Runner	Qinetiq N. America / Foster-Miller Inc.
Versatrax	Inuktun
Souryu IV	International Rescue Systems Institute
G2Bot	Mesa Robotics, Inc.
Element	Mesa Robotics, Inc.
UMRS 2009	International Rescue Systems Institute
Kenaf	International Rescue Systems Institute
Quince	International Rescue Systems Institute
Digital Vanguard ROV	Allen Vanguard Corp.
Matilda II	Mesa Robotics, Inc.
PackBot 510 CAM, SAM, EAP	iRobot Corp.
NuTech-R4	Nagaoka University of Technology
Helios IX	International Rescue Systems Institute
KOHGA	International Rescue Systems Institute
Talon GenIV	Qinetiq N. America / Foster-Miller Inc.
Talon GenIV Hazmat	Qinetiq N. America / Foster-Miller Inc.
Talon GenIV Shoulder	Qinetiq N. America / Foster-Miller Inc.
TeleMAX	Telerob, GmbH
Caliber MK3 EOD	ICOR Technologies
Andros HD-1J	Northrop Grumman Remotec
Andros Mini	Northrop Grumman Remotec
RMP 400-INL	Segway, Inc.
Centaur	The MITRE Corporation

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TeleMAX	Telerob, GmbH
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Event Robots - 2010

Robot Name (by size)	Company
Aerial Robots	
sUAS VTOL (FAA ARC Group I under 2kg, 30knots, frangible)	
AirRobot	**AirRobot GmbH**
Aquatic Robots	
LBV200L2	SeaBotix
LBV150SE-5	SeaBotix

Event Robots - 2010

Robot Name (by size)	Company
Aerial Robots	
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Aquatic Robots	
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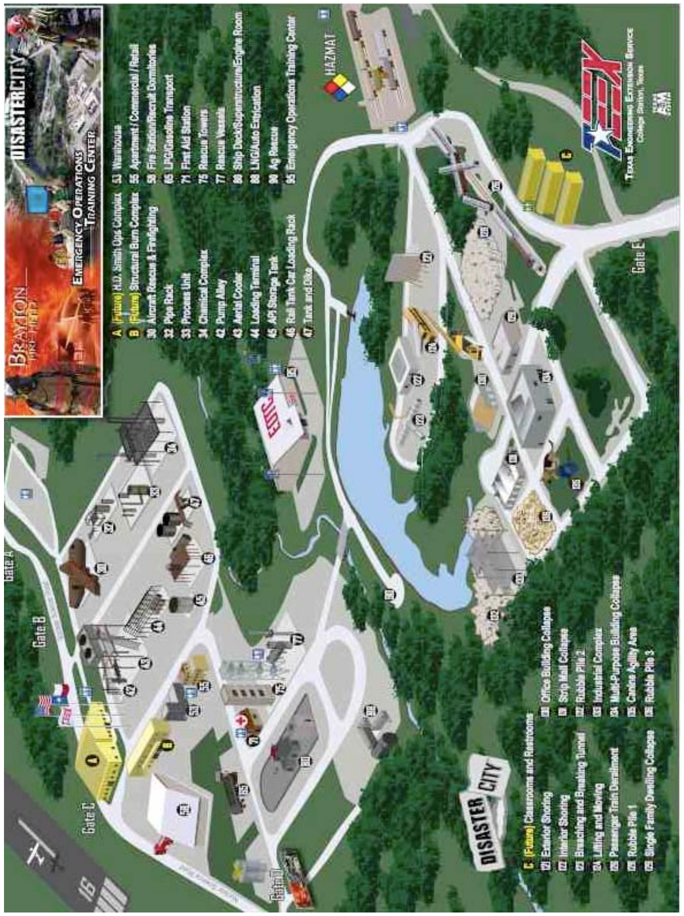
Site Map



Site Map

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#134
Multi-Purpose Building Collapse/Theater Building

Dispatch Station/Robot Picture/Cache Packaging

Robot Navigation During Teleoperation (Random Maze)

#134
Multi-Purpose Building Collapse/Theater Building

Dispatch Station/Robot Picture/Cache Packaging

Robot Navigation During Teleoperation (Random Maze)

Main Street

 

Visual Acuity/Field Of View/Spatial Awareness Test Method

#130 Annex
Covered Vehicle Port

 

Endurance Test Method

Main Street

 

Visual Acuity/Field Of View/Spatial Awareness Test Method

#130 Annex
Covered Vehicle Port

 

Endurance Test Method

#129
Dwelling Collapse


The House of Pancakes collapse scenario

#130
House of Pancakes


Dwelling collapse scenario

#129
Dwelling Collapse


The House of Pancakes collapse scenario

#130
House of Pancakes


Dwelling collapse scenario

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#133
Municipal Building
Industrial Complex


Confined Space Test Method **Incline Plane Test Method**


Stairs


Step Gap Test Method

#133
Municipal Building
Industrial Complex


Confined Space Test Method Incline Plane Test Method


Stairs


Step Gap Test Method

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#131
Strip Mall Collapse


Directed Perception and Grasping Dexterity Test Method

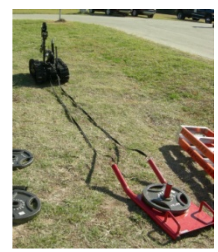
Near Hazmat Train Derailment


Towing Test Method

#131
Strip Mall Collapse

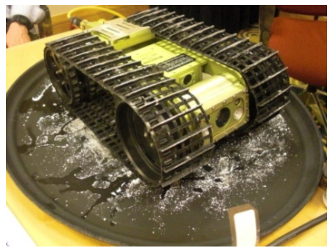

Directed Perception and Grasping Dexterity Test Method

Near Hazmat Train Derailment

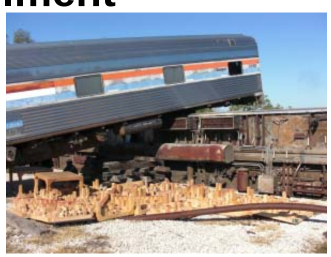
Towing Test Method

Hazmat Train Derailment

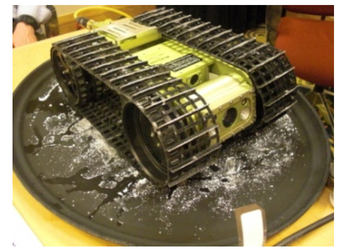
Decontamination Test Method

#128 Passenger Train Derailment

Passenger train derailment scenario

Hazmat Train Derailment

Decontamination Test Method

#128 Passenger Train Derailment


Passenger train derailment scenario

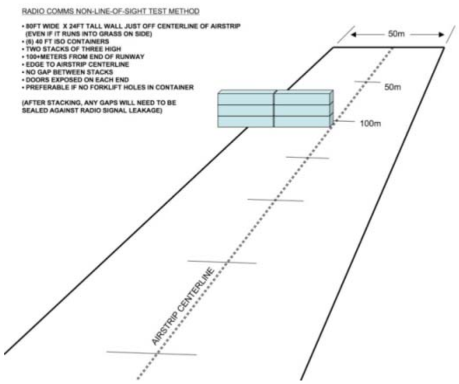
Lake / Dock

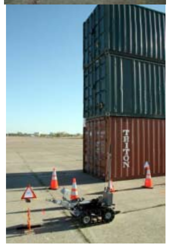
Underwater Scenario

Lake / Dock

Underwater Scenario

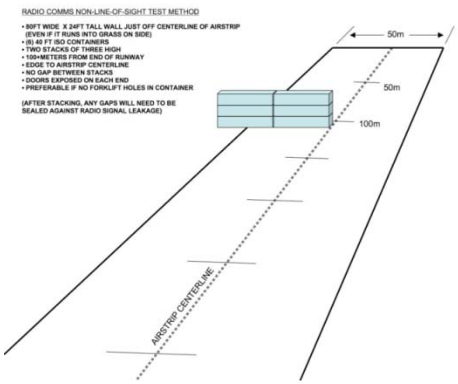
Off-Site
Riverside Airstrip



Radio Comms Non-line of Sight Test Method

Off-Site
Riverside Airstrip



Radio Comms Non-line of Sight Test Method

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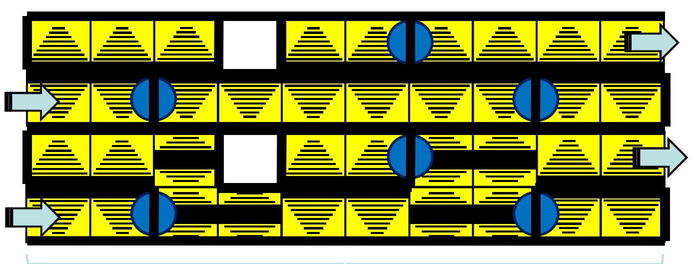
Mapping in Scenarios

#134 Theater Building:
This building showcases two emerging test methods used to evaluate the performance of robotic mapping technologies. The Random Maze and the Sparse Feature Maze are testing apparatuses designed to challenge mapping technologies over potential failure conditions.

#130 Pancake House:
This building embeds the Hallway Labyrinth to create a scenario that evaluates a robots ability to map three-dimensional space in environments that may not contain distinguishable features.



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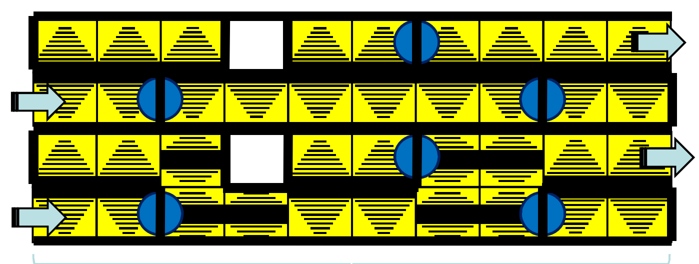

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Mapping in Scenarios Cont.

#128 Passenger Train Derailment
The scenario combines emerging test methods used to evaluate the mobility of robotic platforms to assess how complex terrain in variable environmental conditions (indoor and outdoor) will impact the ability of a robot to make maps

Passenger Train Derailment

Inside Passenger Train

#129 The Dwelling:
This building houses partial mazes in operationally relevant environments to create a scenario that explores the ability of a robot to create maps in unknown environments.

The Dwelling

Partial Mazes in Scenario

Mapping in Scenarios Cont.

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Passenger Train Derailment

Inside Passenger Train

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The Dwelling

Partial Mazes in Scenarios

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Disaster City
November 17 - 21, 2008

Disaster City
November 17 - 21, 2008


Homeland Security
NIST
Response Robot Evaluation Exercise
FEMA US&R Task Force Training Facility (TX-TF1)
Disaster City, College Station, TX
November 17-21, 2008
(including an ASTM E54.08.01 standards committee meeting Friday morning)
Sponsor: Bert Coursey, Science &Technology Directorate, DHS www.isd.mel.nist.gov/us&r_robot_standards
Test Director: Adam Jacoff, Intelligent Systems Division, NIST usar.robots@nist.gov

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Event Introduction

The fifth in a series of DHS/NIST Response Robot Evaluation Exercises for FEMA urban search and rescue (US&R) teams is hosted at the Texas Task Force 1 (TX-TF1) training facility known as **Disaster City** located at Texas A&M University, College Station, TX. All applicable robots were invited to take part in this exercise, which will capture robot performance data within emerging standard robot test methods and operationally relevant practice scenarios. Practice scenarios feature ground robots working in confined spaces within a partially collapsed structure along with down-range reconnaissance of two train wrecks; one a hazardous materials train and the other a passenger train from an operational stand-off greater than 150m/500ft. Other practice scenarios will also be available.

The robots used in these scenarios should deploy any or all appropriate sensors such as: color cameras, two-way audio, thermal imagers, chemical sensors, 3D mapping, GPS/GIS location, and/or other useful capabilities such as payloads, manipulators, etc. General descriptions of the robots that were sought are as follows, but are not limited to:

– Ground based portable robots that can circumnavigate large unknown situations
– Highly agile, man-packable robots that can lead responders through complex environments
– Confined space accessible robots for deployment into sub-human size voids or be thrown into/over inaccessible area
– Aquatic vehicles with sonar and/or other sensors to search and identify underwater environments
– Quad-rotor aerial vehicles (under 2kg/4.4lbs) deploying sensors to perform horizontal and vertical station keeping in front of windows.



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Event Robots - 2008

Robot Name (by size)	Company
Ground Robots	
Active Scope Camera	Tohoku University
Pointman (LRV)	ARA
VGTV	Inuktun
Dragon Runner SUGV	Foster-Miller/Automatika
Versatrax 100	Inuktun
Marv	Mesa Robotics
G2Bot	Mesa Robotics
Jacobs Rugg.Robot	Jacobs University
Hero	First-Response Robotics
Super Kenaf	IRS
PackBot EOD	iRobot
PackBot Explorer	iRobot
Robbie 6	University Koblenz-Landau
Matilda	Mesa Robotics
Matilda II	Mesa Robotics
NuTech-R4	Nagaoka Univ. Tech.
Versatrax 150	Inuktun
Modular Log. Platform	Segway
Talon Gen IV	Foster-Miller/Qinetiq
Talon Hazmat	Foster-Miller/Qinetiq
TeleMAX	TeleRob
HD-1	Remotec
RMP 400	Segway
Aerial Robots	
AirRobot	AirRobot

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Talon Hazmat	Foster-Miller/Qinetiq
TeleMAX	TeleRob
HD-1	Remotec
RMP 400	Segway
Aerial Robots	
AirRobot	AirRobot

Event Robots - 2008

Robot Name (by size)	Company
Aquatic Robots	
VideoRay Pro 3	VideoRay
LBV200L2	SeaBotix
LBV150SE-5	SeaBotix
Sensors	
dcMap	University of Freiburg
High Speed 3D Scanner	Tohoku University
Multibeam Imaging Sonar	
MBI350-45	BlueView Tech.
P450E-15	BlueView Tech.
P900E-20	BlueView Tech.
Multibeam Imaging Sonar	BlueView Tech.
Swiss Ranger 4000	Mesa Imaging

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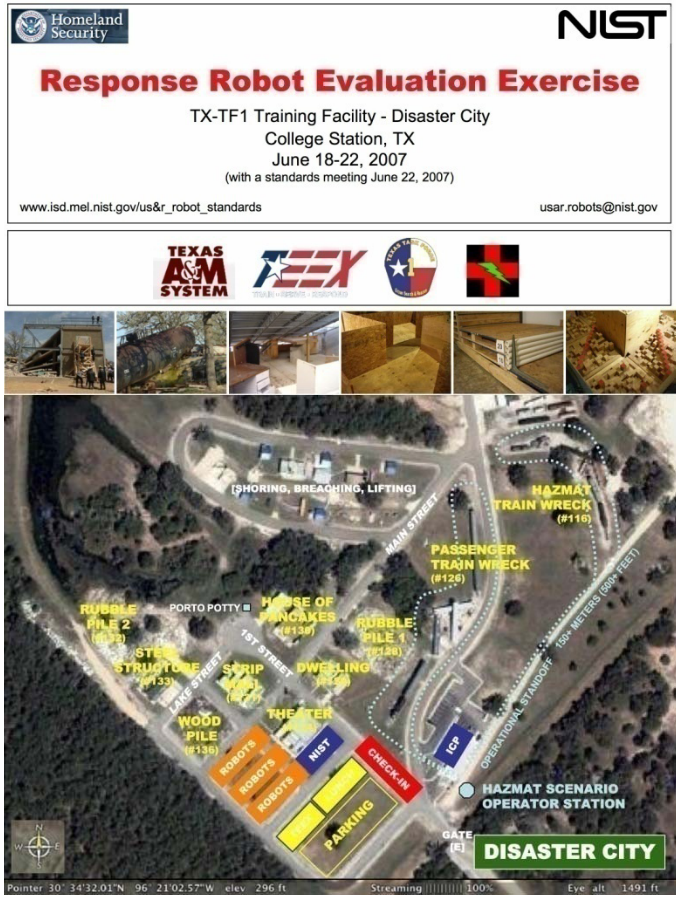
Disaster City
June 18-22, 2007



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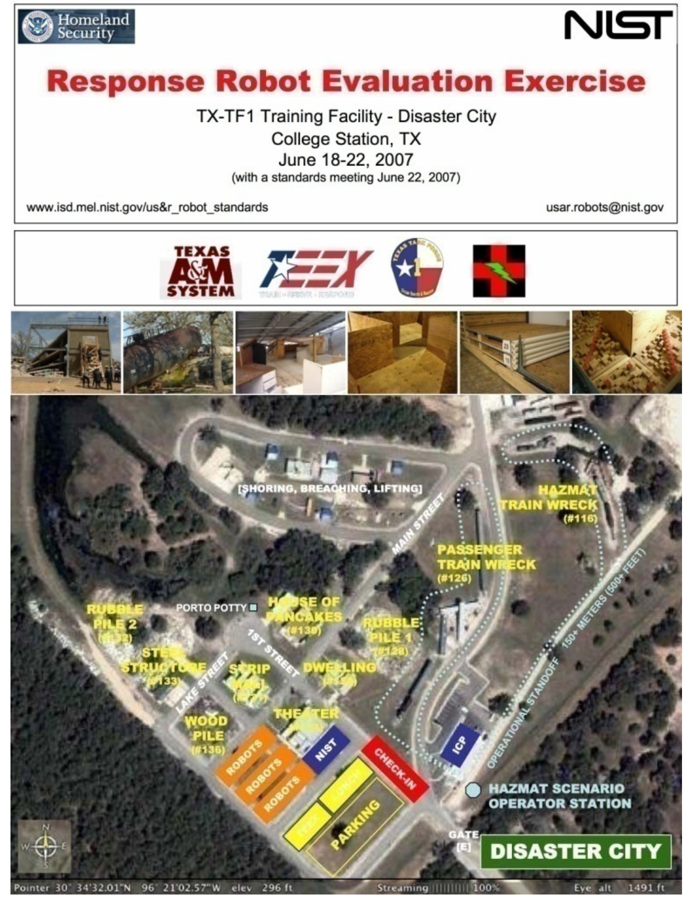

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The robots used in these scenarios should deploy any or all appropriate sensors such as: color cameras, two-way audio, thermal imagers, chemical sensors, 3D mapping, GPS/GIS location, and/or other useful capabilities such as payloads, manipulators, etc. General descriptions of the robots that were sought are as follows, but are not limited to:

- Ground based portable robots that can circumnavigate large unknown situations (i.e. around the train derailments).
- Highly agile, man-packable robots that can lead responders through complex environments (i.e. the buildings and rubble piles).
- Confined space accessible robots for deployment into sub-human size voids or be thrown into/over inaccessible area
- Wall climbing robots for surveillance from elevated vantage points

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- Highly agile, man-packable robots that can lead responders through complex environments (i.e. the buildings and rubble piles).
- Confined space accessible robots for deployment into sub-human size voids or be thrown into/over inaccessible area
- Wall climbing robots for surveillance from elevated vantage points

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Event Robots - 2007

Robot Name (by size)	Company
Ground Robots	
Eyeball	Remington Tech
ToughBot	Omnitech Robotics
Active Scope Camera	Tohoku University
Dragon Runner	Automatika
BomBot	WVHTC
BomBot 2	WVHTC
Marv	Mesa Robotics
Hero	First-Response Robotics
PackBot EOD	iRobot
PackBot Explorer	iRobot
Matilda	Mesa Robotics
Modular Log. Platform	Segway
Talon	Foster-Miller
Talon Hazmat	Foster-Miller
RMP 200	Segway
RMP 400	Segway
TeleMax	TeleRob
Wall Climbers	
VMRP	Vortex
Aerial Robots	
AirRobot	AirRobot

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Wall Climbers	
VMRP	Vortex
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AirRobot	AirRobot

Site Map

Site Map

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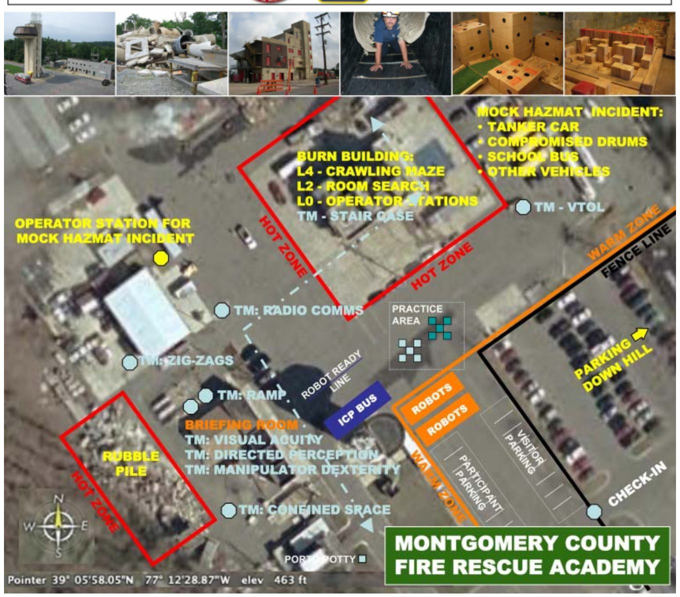
Maryland TF-1
August 19-21, 2006

Response Robot Evaluation Exercise

MD-TF1 Training Academy
Rockville, MD
August 19-21, 2006
(with a standards meeting August 21, 2006)

www.isd.mel.nist.gov/us&r_robot_standards
usar.robots@nist.gov



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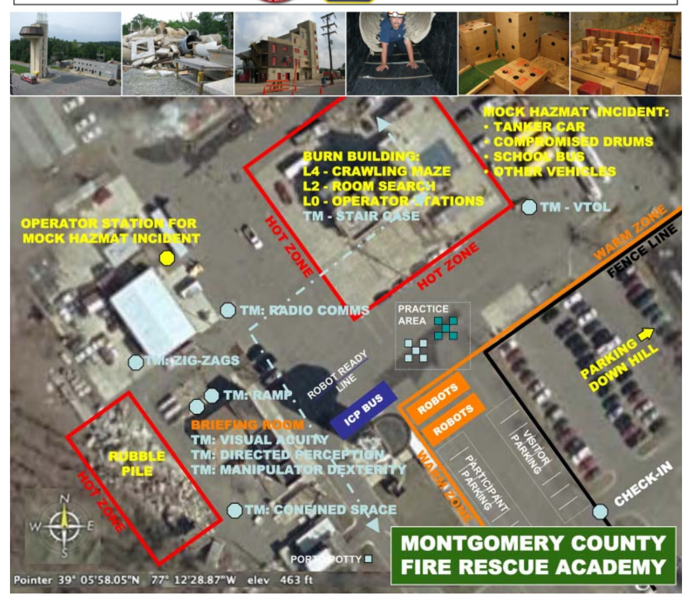

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Event Introduction

The third in a series of response robot informal evaluation exercises for DHS/FEMA US&R teams was hosted at the Montgomery County Fire Rescue Training Academy in Rockville, Maryland (near Washington DC). This event finalized the test methods targeted for the initial (Wave 1) set of standards as well as initiated experimentation with onboard payloads, especially for Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE) sensing. Therefore, emphasis was on (a) robots that could address the deployment categories relevant to Wave 1 standards and (b) deploying CBRNE sensors on these robots. The three robot deployment categories selected by responders to be emphasized in Wave 1 are: ground peek robots that are small and throwable, ground wide-area survey robots that can traverse non-collapsed structures or areas external to the collapse, and aerial survey or loiter robots. Manufacturers of robots, purchasable and/or developmental, that can address these areas, were invited to take part in this exercise, which will highlight operationally relevant US&R scenarios.

Maryland Task Force 1 Training Facility

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Maryland Task Force 1 Training Facility

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Event Robots - 2006

Robot Name (by size)	Company
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Eyeball	Remington Tech
ToughBot	Omnitech Robotics
Iris	Toin
LRV	Applied Research Assoc.
VGTV-Extreme	Inuktun
Dragon Runner	Automatika
BomBot	WVHTC
Marv	Mesa Robotics
Soryu	IRS
Soryu V	IRS
PackBot EOD	iRobot
PackBot Explorer	iRobot
Hibiscus	Toin
Cphea	Toin
Shinobi	Univer. Electro Comm.
Matilda	Mesa Robotics
ATRV mini	Idaho National Lab
Talon	Foster-Miller
Mini-Andros II	Remotec
Andros F6A	Remotec
Boz I	BOZ Robotics
Wall Climbers	
VMRP	Vortex
NanoMag	Inuktun
Aerial Robots	
Blimp	ARACAR
AirRobot	AirRobot
Yamaha Heliocoper	Skeyes Unlimited

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Site Overview

Site Overview

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Disaster City
April 4-6, 2006

Homeland Security NIST

Response Robot Evaluation Exercise

TX-TF1 Training Facility - Disaster City
College Station, TX
April 4-6, 2006
(with a standards meeting April 7, 2006)

www.isd.mel.nist.gov/us&r_robot_standards usar.robots@nist.gov

TEXAS A&M SYSTEM TEEX

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April 4-6, 2006

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TEXAS A&M SYSTEM TEEX

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The second in a series of response robot evaluation exercises for DHS/FEMA US&R teams was hosted at the TX-TF1 training facility known as Disaster City located at Texas A&M University, College Station, TX. All applicable robots and supporting technologies (e.g., sensors), purchasable and/or developmental, were invited to take part in this exercise, which highlighted operationally relevant US&R scenarios specifically devised for ground, aerial, and underwater response robots. Based on their experiences deploying robots within the training scenarios, responders selected three robot categories as being the focus deployment types for the development of the Wave 1 standards. These are small throw-able "peek bots;" wide-area ground survey robots; and aerial loiter/survey robots.

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TeleMax	TeleRob
PackBot Scout	iRobot
Sneaky	M-Bots
Wall Climbers	
VMRP	Vortex
NanoMag	Inuktun
Aerial Robots	
Blimp	ARACAR
Nighthawk	Applied Research Assoc.
Dragon Eye	AeroVironment, Inc.
CyberBug	Cyber Defense Systems, Inc.
Raven	AeroVironment, Inc.
Evolution-XTS	L-3 BAI Aerosystems, Inc
Flying Bassett	Univ. of AL – Huntsville
Wasp	AeroVironment, Inc.
Aquatic Robots	
Pro III	VideoRay, LLC

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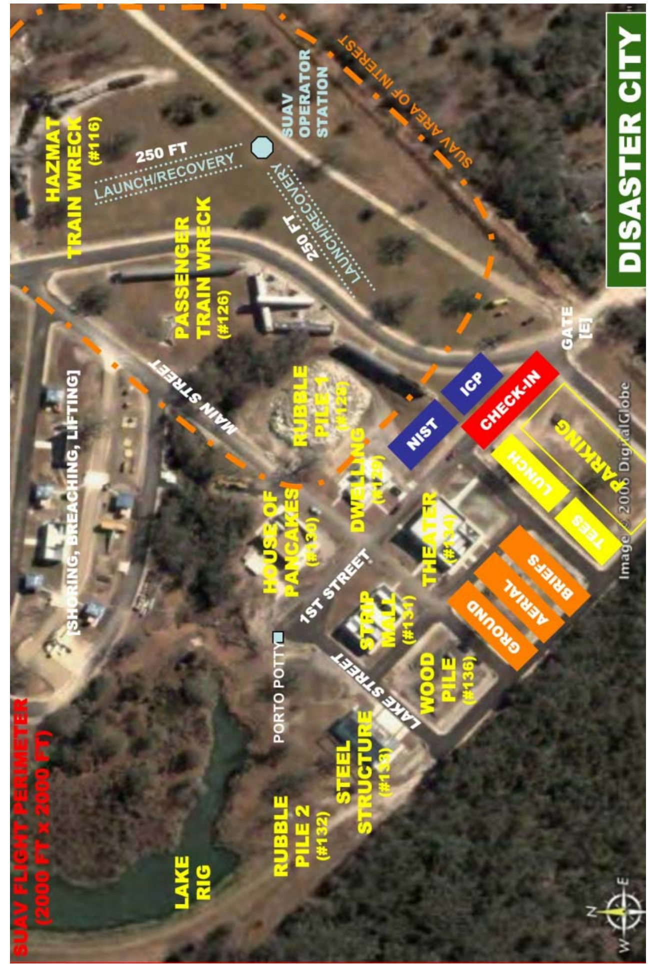
Site Map

Site Map



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Safety

Safety

Safety of all personnel participating in this event is our first concern. The fact that we have robotics personnel generally unaccustomed to working within the hazardous environments at these US&R training sites is particularly problematic. Having emergency responders generally unaccustomed to working with robots is also a concern. Please follow these simple guidelines:

• Appropriate personal protective equipment (PPE) must be worn at all times while on site (see associated page on PPE). Compliance with PPE rules are mandatory.

• Rubble piles and other difficult scenarios present the most risk to novices. If your robot needs to be extracted, please ask your associated emergency responder to retrieve it.

• Always maintain awareness of others working within your scenario and communicate your intentions *before* doing whatever you have in mind.

• Robots can do unpredictable things; the bigger/heavier the robot the more space you should allow it when operating. Always verify that the robot is powered off before interacting with it. Never stick your fingers into wheels, tracks, manipulator pinch points, etc. while the robot is powered on. Remotely teleoperated robots may be the most dangerous because the remote operator may not know you decided to perform on-the-spot maintenance! Always familiarize yourself with the EMERGENCY STOP procedures first -- and last -- before interacting with or operating robots. Some implementations are more predictable than others.

• If you see anything you consider unsafe in our environment, please inform the Test Director or any emergency responder on site, and let's discuss it at the daily after action briefing to be sure every potential hazard is addressed.

• **Everybody on site is a safety officer!**

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Personal Protective Equipment

Personal protective equipment (PPE) is required for working within any US&R scenario at the site. People in street clothes or without helmets/gloves/etc as shown below are limited to paved roads only. If you are working within a scenario, you must wear ALL the equipment shown below. Compliance with these personal protective equipment rules are mandatory - it is standard practice for US&R environments.

- **Helmet**
  Hard hats are okay. We have some to borrow or you can purchase at www.thefirestore.com for $75 and up.
- **Ear protection**
  We'll supply these.
- **Eye protection**
  Sunglasses are okay.
- **Long sleeve shirt**
- **Work gloves**
- **Long pants**
  Army surplus stores sell typical BDU and EMT pants.
- **Boots**
  Preferably steel toe.

Additional protective padding for knees and elbows is optional, but good for rubble piles.

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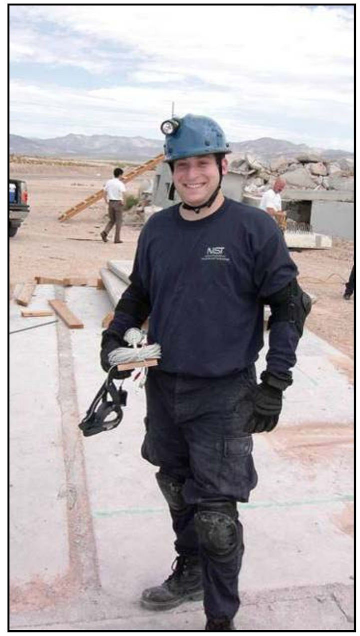

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Test Methods

Test Methods

Test Methods

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Status Indicators:
Standard (ASTM ####-##), Validating (V), Prototyping (P)

Standard Terminology for Emergency Response Robots (ASTM E2521-07A)

Standard Practice for Establishing the Test Configuration and Associated Cache Packaged Weight and Volume of Emergency Response Robots (ASTM E2592-07)

Energy/Power

- Endurance Tasks: Terrains: Continuous Pitch/Roll Ramps (V)

Mobility

- Terrains: Flat/Paved Surfaces (V)
- Terrains: Continuous Pitch/Roll Ramps (V)
- Terrains: Crossing Pitch/Roll Ramps (V)
- Terrains: Symmetric Stepfields (V)
- Terrains: Sand (P)
- Terrains: Gravel (P)
- Terrains: Mud (P)
- Obstacles: Inclined Planes (V)
- Obstacles: Gap Crossings: Static, Dynamic (V)
- Obstacles: Pipe Steps (V)
- Obstacles: Stair/Landings (V)
- Obstacles: Confined Space (P)
- Towing: Grasped Sleds (V)
- Towing: Hitched Sleds (P)
- Towing: Hitched Trailers (P)

Radio Communications

- Control and Perception Tasks: Line-of-Sight (V)
- Control and Perception Tasks: Non-Line-of-Sight (V)
- Control and Perception Tasks: Structure Penetration (P)

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Manipulation

- Directed Perception Tasks: Open Access (V)
- Directed Perception Tasks: Reach-Over Access (P)
- Directed Perception Tasks: Reach-Under Access (P)
- Gasping Dexterity Tasks : Open Access (V)
- Gasping Dexterity Tasks : Reach-Over Access (P)
- Gasping Dexterity Tasks : Reach-Under Access (P)
- Gasping Dexterity Tasks : Weighted Payloads (P)
- Door Opening and Traversal Tasks (V)

Human-System Interaction

- Navigation Tasks: Random Mazes with Complex Terrain (V)
- Navigation Tasks: Outdoor Navigation for Large UGV (P)
- Search Tasks: Random Mazes with Complex Terrain (V)
- Search Tasks: Under-Body Voids with Complex Terrain (V)
- Operator Interface Constraints: PPE; Posture; Lighting (P)
- Operator Interface Indicators: Low Battery; Robot Tilt (P)

Sensor

- **Video Acuity Charts/Field of View Measures (ASTM E2566-08)**
- Video Directed Search Tasks: Detailed (V)
- Video Directed Search Tasks: Rapid (P)
- Audio Speech Intelligibility Rhyming Words (2-Way) (V)
- Audio Spectrum Response Tones (P)
- Ranging Targets and Spatial Resolution Measures (P)
- Localization/Mapping Tasks: Hallway Labyrinths with Complex Terrain (P)
- Localization/Mapping Tasks: Wall Mazes with Complex Terrain (P)
- Localization and Mapping Tasks: Sparse Feature Environments (P)
- Localization and Mapping Tasks: Tunnel Mazes (P)

Manipulation

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Test Methods

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Washdown/Decontamination Capabilities of Emergency Response Robots (V)

Aerial

- sUAS (Group I) VTOL Endurance
- sUAS (Group I) VTOL Station-Keeping

Operational Task: Radio Comms: Nike Siite

Operational Task: Metrobus Package Removal/Disruption

Operational Task: sUAS (Group I) VTOL Exterior Building Reconnaissance

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Test Methods

Test Methods

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Development Process

The process used to develop standard test methods begins with specific requirements defined by emergency responders for robotic capabilities that could make their operational deployments more effective, efficient, or safe. Each requirement must have an associated metric along with thresholds of performance below which the responders will not accept. Where such robot requirements already exist, for example bomb squad applications, they may have been used directly. Other responder communities, for example technical search specialists from FEMA urban search and rescue teams, were solicited during the course of this program and have provided over 100 such requirements for 13 different categories of robots.

The requirements are prioritized by responders and prototype test apparatuses are generated to isolate and repeatably test and measure robot performance. Response robot evaluation exercises are hosted in responder training facilities to allow responders to validate the test methods and learn about emerging robotic capabilities. International robot competitions featuring the prototype test apparatuses and tasks are used to leverage robot traffic (over 100 missions per competition) to refine apparatus designs and inspire robot innovations. They also support proliferation of the test methods for practice and provide benchmark comparisons for qualification. Once the apparatus is validated, it is balloted through the ASTM Standards Committee on Homeland Security Applications; Operational Equipment; Robots (E54.08.01).

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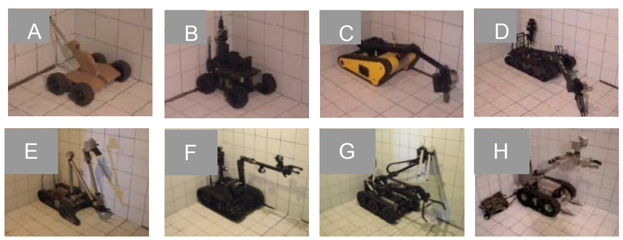
Test Methods

General Scope

This suite of test methods characterize the capabilities of robots intended to operate in human-scale, complex environments with variable terrains, lighting, temperature, etc. Robots under test shall be teleoperated via a remote operator control unit (OCU), out of sight and sound of the test apparatuses but within communications range (except for the radio communications test methods). The robot configuration as tested shall be specified in detail (manipulators, payloads, batteries, communications, etc) and subjected to the entire suite of test methods. Any variation in robot configuration must be retested across the entire suite of test methods to provide a comprehensive overview of performance characteristics for that particular robot variant. Systems with assistive capabilities or autonomous behaviors should demonstrate improved remote operator/robot performance, efficiency, or survivability of the robot under test. Although these test methods were developed specifically for emergency response robots, they may be applicable to other application domains with modest variations in terrains, targets, or tasks.



Robots shown above are typical of the size robot these test methods are intended to evaluate. They are shown in front of a 20 cm (8 inch) metered backdrop used in the *Standard Practice for Establishing the Test Configuration and Associated Cache Packaged Weight and Volume of Emergency Response Robots.* These eight robots provided the first ten robot configurations to be subjected to the entire suite of emerging standard test methods to determine test method “repeatability” within a single apparatus and test method “reproducibility” across different test facilities. Two of the robots also tested either without their manipulator or with an extended manipulator making them new configuration subject to testing across the entire suite of test methods to capture trade-offs in capabilities

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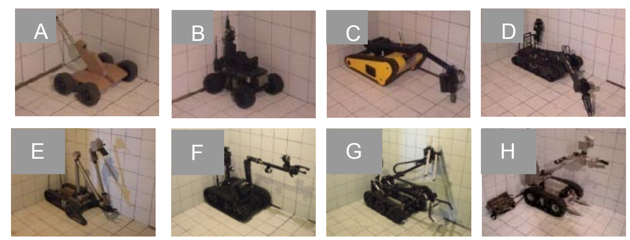

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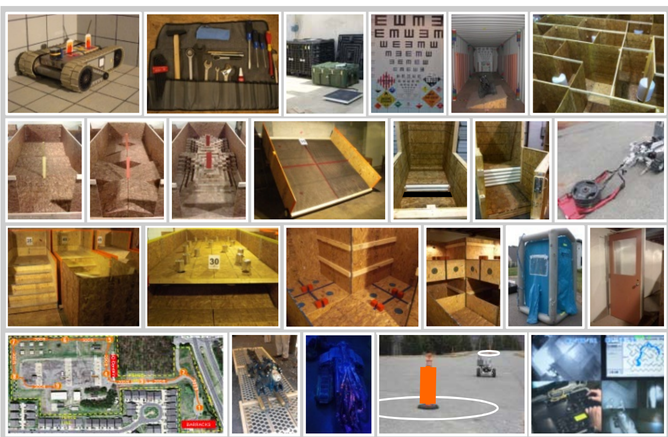
Apparatuses

The apparatuses associated with these test methods challenge specific robot capabilities in repeatable ways to facilitate direct comparisons of different robot models and particular configurations of similar robot models. Many of the test apparatuses use terrains, targets, and tasks that are intentionally abstract to facilitate the standardization process which requires capture of repeatable results within a specific test apparatus and reproducible results across different test facilities with replica test apparatuses. They are generally fabricated using readily available materials to facilitate fabrication by robot developers to support system innovation refinement, and hardening, and for emergency responder organizations to support evaluation and training. For example, many test apparatuses are constructed with oriented strand board (OSB) plywood to provide a common friction surface similar to dust covered concrete. The specific terrains, targets, and tasks used can be modified or replaced with more operationally representative examples while using the same apparatuses and procedures to further support training, practice, and comparison of specific system capabilities. These test methods should be considered baseline evaluations and performed prior to more relevant Operational Tasks as defined by responders, although Operational Tasks should leverage a specific set of test methods to pre-qualify particular robot capabilities.



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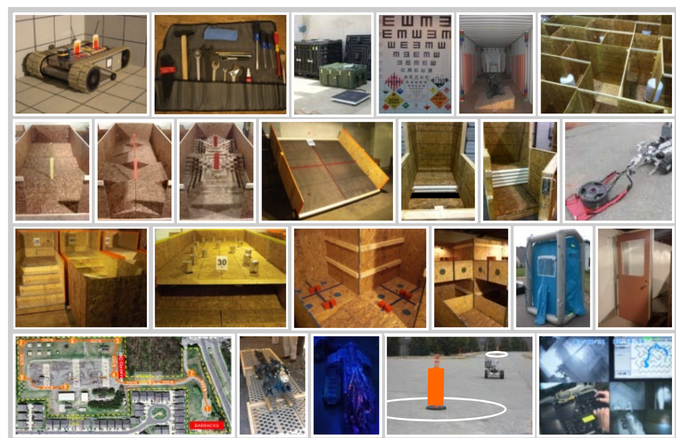

50

Performance Data Collections

Performance data collections are conducted using the described test methods to capture robot and remote operator performance across a statistically significant number of repetitions. Robots are tested to completion of certain tasks with "expert" operators, as designated by the developer, to capture a task-based capability for a given robot in a given apparatus. The number of repetitions for each test method is determined by ASTM with input from standards committee participants and uses statistical principles while considering test administration practicalities for longer tests, such as the Endurance test method. The duration of each test is typically not included as a metric in the standard test method to de-emphasize speed in favor of task completeness, though the test duration is typically captured secondarily for comparison purposes. Test durations are reported as an average time to perform each repetition, or as an average time to perform a particular sub-task within a test method that can produce varying levels of completeness. For example, in the Manipulation test methods the durations are reported as an average time per task value so that novice operators can quantitatively establish their proficiency as a percentage of "expert" performance within the same test method. The test method forms use graphical representations of the data to provide an intuitive understanding of the test results to facilitate comparisons across different robot configurations.

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Test Methods

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Presentation of Robot Performance Data

Each robot configuration shall be tested in all applicable test methods and may attempt each test as many times as necessary to attain a satisfactory result. Robots may abstain from a particular test method when not applicable or when they may not successfully complete the set of continuous repetitions necessary to get reported in the data. In either instance, the page will be marked as “ABSTAINED” to indicate that the test method was available at test time and the manufacturer acknowledges the omission of performance data. Although some robot implementations are not designed or equipped for particular test methods, (e.g. robots without manipulators in the manipulator test methods) this testing methodology makes no assumptions regarding capabilities. Specifics of particular robot configurations should be considered when the robot has abstained from a given test method. Prototype test methods may be used to capture practice data while the apparatuses are under development. Data for these test methods are clearly marked and not released, but may be used to help refine the apparatus or procedure.

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Test Methods

53

Terminology

Purpose

The purpose of this standard is to identify and standardize the terms necessary to facilitate communication between emergency responders, robot developers, and robot researchers.

Metrics

- Number and weight of Consistency of term definitions among communities.

E2521-07A

Terminology

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Metrics

- Number and weight of Consistency of term definitions among communities.

E2521-07A

Apparatus

None

Procedure

1. Identify terms used in the standard test methods, operational tasks, an emergency response operations.
2. Standardize their definitions through literature search and consensus building, including discussions in the standards committee meetings. Pay particular attention to current emergency response field practices.
3. Publish or reference robot related terms within the ASTM International Committee on Homeland Security Applications; Operational Equipment; Robots (E54.08.01) terminology standard.
4. Forward terms that are applicable wider than robotics to E54.92.
5. Identify and define additional, keywords used in the standard test methods to facilitate standardization process (listed in the next page).

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None

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5. Identify and define additional, keywords used in the standard test methods to facilitate standardization process (listed in the next page).

Test Methods

55

Key Words: Apparatuses

Expert operator: All robot performance data is collected with operators designated by the developer to achieve the best possible performance within a given test method.

Flat terrain element: A flat surface using oriented strand board (OSB) plywood surface with overall dimensions of 1200 cm x 1200 cm (48 in x 48 in) elevated using 10 cm x 10 cm (4 in x 4 in) solid wood posts to form a 10 cm (4 in) thick pallet.

Full ramp terrain element: A ramped OSB surface with overall dimensions of 1200 cm x 1200 cm (48 in x 48 in) typically angled at 15 degree using 10 cm x 10 cm (4 in x 4 in) solid wood posts with angle cuts. These provide some complexity of robot orientation and traction in continuous or crossing configurations.

Half ramp terrain element: A ramped OSB surface with overall dimensions of 600 cm x 1200 cm (24 in x 48 in) typically angled at 15 degree using 10 cm x 10 cm (4 in x 4 in) solid wood posts with angle cuts. These provide some complexity of robot orientation and traction in continuous or crossing configurations.

Operator station: An apparatus set up out of sight and sound of the test apparatuses, but within communications range (except for the radio communications test methods). The robots will be teleoperated via a remote operator control unit (OCU) from this apparatus.

Oriented strand board (OSB) plywood: Readily available building product which provides a frictional surface similar to dust covered concrete. It is commonly available in U.S. in the size of 1200 cm x 2400 cm (48 in x 96 in).

Pick and place object: A 10 cm x 10 cm (4 in x 4 in) blocks or cylinders made from 0.5 kg (1 lb) wood, 3.5 kg (7 lbs) aluminum, or 7 kg (14 lbs) steel embedded into mobile manipulation apparatuses to provide pick and place tasks. The key considerations are:

- **Size:** Fill the gripper to possibly obstruct camera and lighting views
- **Shape:** Require precision placement of gripper for grasping
- **Weight:** Require sufficient gripper force to hold and possibly challenge arm strength and center of gravity at maximum reach

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Stepfield terrain element: A discontinuous terrain type using 10 x 10 cm (4 x 4 in) solid wood posts cut to cubic unit lengths of 10 cm, 20 cm, 30 cm, 40 cm, and 50 cm (4 in, 8 in, 12 in, 16 in, 20 in) and arranged in prescribed topologies. These provide continuous terrain complexity for highly mobile robots.

Sensory Identification Target: A feature embedded within the test apparatus used for identification and measurement of capabilities. They may or may not be operationally relevant but could be replaced to support specific operational tasks.
Examples of targets may include the following:

Visual

• Hazardous Materials (HAZMAT) Label: A standard label with four identifiable features: color, icon, number, and word identifying a particular type of hazardous material.

• Tumbling E Eye Chart: A standard language-neutral eye chart. Often called a Snellen chart.

• Shape Totem: A vertical strand of rotationally consistent spheres and cylinders which form vertical patterns in random order ("dot-dash-dot"). Four different size shapes are used: 10 cm, 5 cm, 1 cm , 1 mm (4 in, 2 in, 0.4in, 0.04) to test resolution of sensors. To test color recognition for visual sensors, colored shapes are used: red, blue, green and white. To test grey scale recognition for visual sensors, three varying shades of grey shapes are used.

Audio

• Standard rhyming words
• Full spectrum tones

Chemical trace (elements are used)
Biological (simulants may be used)
Radiological (trace elements are used)
Explosive (trace elements are used)d

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Chemical trace (elements are used)
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Test Methods

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Key Words: Procedures

Correct Identification of Target (HAZMAT Label): when three out of the four features: color, word(s), number, and icon are correctly identified by the operator.

Fault Condition: A condition where the current trial of a test method is ended as noted on each test method description. This results in a Maintenance/Repair/Other Event Report form to be filled out and a new trial to start at the operator's discretion.

Remote teleoperation: Operation of the robot through the system's communications and interface components from a location out of sight and sound of the test apparatus. All the test methods are conducted using remote teleoperation.

Repetition: Completion of the test method task from the prescribed start position and return to the original start position. Multiple repetitions establish robot performance to a predefined degree of statistical significance.

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58

General

Test Suite: A collection of test methods that are used, collectively, to evaluate the performance of robot's particular subsystem, namely, mobility, manipulation, sensors, energy, communications, HRI, logistics, safety, and aerial and aquatic maneuvering

Lux: A derived SI unit of measure based on the lumen, which in turn is based on the candela, which describes the illuminance of a scene rather than a light source. Examples include:

Illuminance	Example
0.01 lux	Quarter moon
0.27 lux	Full moon on a clear night
1.0 lux	Full moon overhead at tropical latitudes
3.4 lux	Dark limit of civil twilight for clear skies
50 lux	Family living room
80 lux	Hallway/toilet
100 lux	Dark overcast day
320–500 lux	Office lighting
400 lux	Sunrise or sunset on a clear day
1,000 lux	Overcast day/ TV studio lighting
10,000–25,000 lux	Full daylight (not direct sun)
32,000–130,000 lux	Direct sunlight

Key Words: Performance Data Collection

Position and orientation tracking: A product of the performance testing process which captures 2D position and orientation of the robot operating within a test method. This is only applicable for certain test methods and is not used in the standard metric.

Quad screen video: A product of the performance testing process which captures simultaneous video streams to help remote operators and others understand the successes and failures of different systems, capabilities, and approaches.

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Logistics: Robot Test Configuration and Cache Packaging

Purpose

The purpose of this standard practice is to quantitatively evaluate the cache packaging and setup attributes of deployable robotic systems to be compatible with transportation and storage procedures prescribed by the Federal Emergency Management Agency (FEMA) Urban Search & Rescue (US&R) Task Force Teams and other emergency response organizations.

Metrics

- Number and weight of qualified packing containers
- Setup time from packing containers to deployment
- Downrange/testing configuration of robotic system
- Weights and measurements of the robot, operator control unit (OCU), payload, and batteries
- Tools needed for repair and maintenance

E2592-07

Standard Practice for Evaluating Cache Packaged Weight and Volume of Robots for Urban Search and Rescue

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E2592-07

Standard Practice for Evaluating Cache Packaged Weight and Volume of Robots for Urban Search and Rescue

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Apparatus

- Scales to measure robotic system weights
- Tape measures to measure robotic system dimensions
- Photo backdrop with 20 cm (8 in) grid lines

Procedure

1. Note the number and type of packing containers necessary for the robot to deploy for 10 days, without re-supply for the first 72 hours or as organization requires.
2. Determine a configuration to perform the tests.
3. Time the setup process from unloading to ready to perform the tests/go down range (prior to the below measuring steps).
4. Weigh the robot and OCU.
5. Measure the robot and OCU.
6. Take pictures of the robot, including fully retracted and fully extended postures, OCU, and tool set in a metered backdrop for scale.
7. Note the tools needed to perform setup and repair.

Test Methods

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Test Methods

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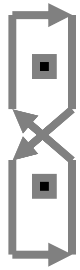
Energy/Power: Endurance:
Pitch and Roll Ramp Terrain



Purpose

The purpose of this test method is to quantitatively evaluate the battery capacity per charge cycle for a remotely teleoperated robot operating in confined areas in lighted and dark conditions. This test method can also be tested at temperature extremes.

Metrics

- Distance (m) per charge tested to inoperability (before and after benchtop cycling)
- Time (min) per charge tested to inoperability (before and after benchtop cycling)
- Change in capacity (%) after 100 benchtop battery cycles

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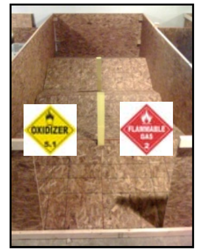

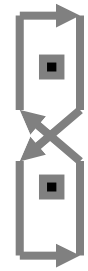

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- Change in capacity (%) after 100 benchtop battery cycles

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Apparatus

- The flooring terrain is continuous **full and half ramp flooring elements** setup according to the design.
- The apparatus includes lighting control for testing in lighted and dark conditions.
- **Targets** will be installed to provide for a periodic timed dwell task.
- A beam break sensor can be used to count laps.
- This test apparatus is intended to fit into a 12 m x 2.4 m (40 ft x 8 ft) standard ISO shipping container to allow testing in hot and cold temperature extremes . It can also be setup as a freestanding apparatus with 1.2 m (4 ft) tall walls with supports.

Procedure

1. Place the robot at starting point with newly conditioned batteries.
2. Start the timer when the robot begins and capture total elapsed time for a complete set of **repetitions.**
3. Traverse the prescribed figure-8 path around the pylons until the batteries are depleted .
4. Every 10 laps (150 m (500 ft)) the operator shall dwell at starting point of the test apparatus for 1 minute while identifying **targets** at known locations. Each set of 10 laps will be conducted alternately in lighted conditions (>100 lux) and near darkness (<1 lux).
5. Power/energy data logged over the first 20 laps (300 m (1000 ft)) will be used to perform 100 benchtop depletion cycles unless the battery fails prior to that point.
6. Benchtop cycled batteries will be re-installed into the robot to perform one final battery depletion test.
7. Maintenance and repairs of the robot are allowed, but must be done in-situ within the test apparatus. Elapsed time for the repair will be noted in an event description form and subtracted from the overall test duration. The tools used will also be noted.

Fault Conditions: (Fill out an Event Report)

- Removal of the robot from the apparatus for repair of any type

Apparatus

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- The apparatus includes lighting control for testing in lighted and dark conditions.
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- A beam break sensor can be used to count laps.
- This test apparatus is intended to fit into a 12 m x 2.4 m (40 ft x 8 ft) standard ISO shipping container to allow testing in hot and cold temperature extremes . It can also be setup as a freestanding apparatus with 1.2 m (4 ft) tall walls with supports.

Test Methods

Procedure

1. Place the robot at starting point with newly conditioned batteries.
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Fault Conditions: (Fill out an Event Report)

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Mobility: Terrain: *Flat/Paved Surfaces*

Purpose

The purpose of this test method is to quantitatively evaluate the sustained speed capabilities for a remotely teleoperated robot operating on a flat/paved surface with confined area turns.

Metrics

- Completion of 10 figure-8 **repetitions**
- Average time per **repetition**

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Metrics

- Completion of 10 figure-8 **repetitions**
- Average time per **repetition**

Apparatus

- This test apparatus is a flat/paved path of 50 m (165 ft) between two pylons.
- Each pylon has a clearly marked turning boundary with a radius of 2 m (6.5 ft) marked by a chalk or paint line.

Procedure

1. Place the robot at the starting position within a pylon turning boundary.
2. Start the timer when the robot begins and capture total elapsed time for a complete set of **repetitions**.
3. Traverse the prescribed figure-8 path around the pylons for 10 continuous **repetitions** without intervention. Maintain at least part of the robot clearly inside the marked turning boundaries.
4. Failure to stay within the turning boundary negates the current lap. Teleoperate the robot to the starting position and continue with the timer running.

Fault Conditions: (Fill out an Event Report)

- Failure to complete 10 continuous **repetitions**

Test Methods

Apparatus

- This test apparatus is a flat/paved path of 50 m (165 ft) between two pylons.
- Each pylon has a clearly marked turning boundary with a radius of 2 m (6.5 ft) marked by a chalk or paint line.

Procedure

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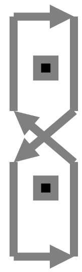
Fault Conditions: (Fill out an Event Report)

- Failure to complete 10 continuous **repetitions**

Test Methods

65

Mobility: Terrain:
Continuous Pitch and Roll Ramps (Yellow)



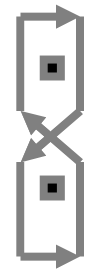
<u>Purpose</u>

The purpose of this test method is to quantitatively evaluate the mobility capabilities of a remotely teleoperated robot operating in confined areas with continuous **full ramp and half ramp terrain** elements in lighted and dark conditions.

<u>Metrics</u>

- Completion of 10 figure-8 **repetitions**
- Average time per **<u>repetition</u>**

Mobility: Terrain:
Continuous Pitch and Roll Ramps (Yellow)



Purpose

The purpose of this test method is to quantitatively evaluate the mobility capabilities of a remotely teleoperated robot operating in confined areas with continuous full ramp and half ramp terrain elements in lighted and dark conditions.

Metrics

- Completion of 10 figure-8 repetitions
- Average time per repetition

66

Apparatus

- The flooring terrain consists of continuous 15 degree **full ramp and half ramp terrain elements** .
- Two pylons define the prescribed figure-8 path.
- This test apparatus is intended to fit into a 12 m x 2.4 m (40 ft x 8 ft) standard ISO shipping container . It can also be setup as a freestanding apparatus with 1.2 m (4 ft) tall walls with supports.

Test Methods

Procedure

1. Place the robot at the starting position near the apparatus entrance.
2. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
3. Start the timer when the robot begins and capture total elapsed time for a complete set of repetitions.
4. Traverse the prescribed figure-8 path around the pylons for 10 continuous repetitions without intervention.

Fault Conditions: (Fill out an Event Report)
Failure to complete 10 continuous repetitions

Apparatus

- The flooring terrain consists of continuous 15 degree **full ramp and half ramp terrain elements** .
- Two pylons define the prescribed figure-8 path.
- This test apparatus is intended to fit into a 12 m x 2.4 m (40 ft x 8 ft) standard ISO shipping container . It can also be setup as a freestanding apparatus with 1.2 m (4 ft) tall walls with supports.

Test Methods

Procedure

1. Place the robot at the starting position near the apparatus entrance.
2. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
3. Start the timer when the robot begins and capture total elapsed time for a complete set of repetitions.
4. Traverse the prescribed figure-8 path around the pylons for 10 continuous repetitions without intervention.

Fault Conditions: (Fill out an Event Report)
Failure to complete 10 continuous repetitions

67

Mobility: Terrain: *Crossing Pitch and Roll Ramps (Orange)*

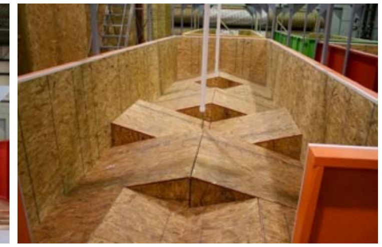

Purpose

The purpose of this test method is to quantitatively evaluate the mobility capabilities of a remotely teleoperated robot operating in confined areas with crossing (discontinuous) **full ramp and half ramp terrain** elements in lighted and dark conditions.

Metric

- Completion of prescribed figure-8 laps
- Average time per **repetition**

Mobility: Terrain: *Crossing Pitch and Roll Ramps (Orange)*

Purpose

The purpose of this test method is to quantitatively evaluate the mobility capabilities of a remotely teleoperated robot operating in confined areas with crossing (discontinuous) **full ramp and half ramp terrain** elements in lighted and dark conditions.

Metric

- Completion of prescribed figure-8 laps
- Average time per **repetition**

68

Apparatus

- The flooring terrain consists of crossing 15 degree **full ramp and half ramp terrain elements** setup .
- Two pylons define the prescribed figure-8 path.
- This test apparatus is intended to fit into a 12 m x 2.4 m (40 ft x 8 ft) standard ISO shipping container . It can also be setup as a freestanding apparatus with 1.2 m (4 ft) tall walls with supports.

Procedure

1. Place the robot at the starting position near the apparatus entrance.
2. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
3. Start the timer when the robot begins and capture total elapsed time for a complete set of **repetitions**.
4. Traverse the prescribed figure-8 path around the pylons for 10 continuous **repetitions** without intervention.

Fault Conditions: (Fill out an Event Report)

- Failure to complete 10 continuous **repetitions**

Apparatus

- The flooring terrain consists of crossing 15 degree **full ramp and half ramp terrain elements** setup .
- Two pylons define the prescribed figure-8 path.
- This test apparatus is intended to fit into a 12 m x 2.4 m (40 ft x 8 ft) standard ISO shipping container . It can also be setup as a freestanding apparatus with 1.2 m (4 ft) tall walls with supports.

Test Methods

Procedure

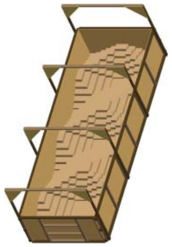
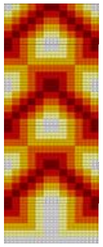
1. Place the robot at the starting position near the apparatus entrance.
2. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
3. Start the timer when the robot begins and capture total elapsed time for a complete set of **repetitions**.
4. Traverse the prescribed figure-8 path around the pylons for 10 continuous **repetitions** without intervention.

Fault Conditions: (Fill out an Event Report)

- Failure to complete 10 continuous **repetitions**

69

Mobility: Terrain:
Symmetric Stepfields (Red)

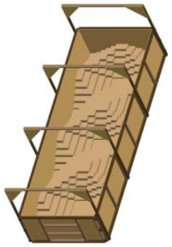
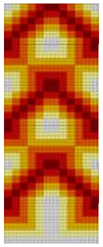
<u>Purpose</u>

The purpose of this test method is to quantitatively evaluate the mobility capabilities of a remotely teleoperated robot operating in confined areas with symmetric **stepfield terrain elements** in lighted and dark conditions.

<u>Metric</u>

- Completion of prescribed figure-8 laps
- Average time per **<u>repetition</u>**

Mobility: Terrain:
Symmetric Stepfields (Red)

Purpose

The purpose of this test method is to quantitatively evaluate the mobility capabilities of a remotely teleoperated robot operating in confined areas with symmetric stepfield terrain elements in lighted and dark conditions.

Metric

- Completion of prescribed figure-8 laps
- Average time per repetition

70

Apparatus

- The flooring terrain consists of symmetric **stepfield terrain element** fabricated using 10 cm (4 in) square wood posts cut to prescribed lengths (10 cm, 20 cm, 30 cm, 40 cm, and 50 cm (4 in, 8 in, 12 in, 16 in, and 20 in)) and setup in groups of four posts per step height.
- Two pylons define the prescribed figure-8 path.
- This test apparatus is intended to fit into a 12 m x 2.4 m (40 ft x 8 ft) standard ISO shipping container. It can also be setup as a freestanding apparatus with 1.2 m (4 ft) tall walls with supports.

Procedure

1. Place the robot at the starting position near the apparatus entrance.
2. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
3. Start the timer when the robot begins and capture total elapsed time for a complete set of **repetitions**.
4. Traverse the prescribed figure-8 path around the pylons for 10 continuous **repetitions** without intervention.

Fault Conditions: (Fill out an Event Report)

- Failure to complete 10 continuous **repetitions**

Apparatus

- The flooring terrain consists of symmetric **stepfield terrain element** fabricated using 10 cm (4 in) square wood posts cut to prescribed lengths (10 cm, 20 cm, 30 cm, 40 cm, and 50 cm (4 in, 8 in, 12 in, 16 in, and 20 in)) and setup in groups of four posts per step height.
- Two pylons define the prescribed figure-8 path.
- This test apparatus is intended to fit into a 12 m x 2.4 m (40 ft x 8 ft) standard ISO shipping container. It can also be setup as a freestanding apparatus with 1.2 m (4 ft) tall walls with supports.

Test Methods

Procedure

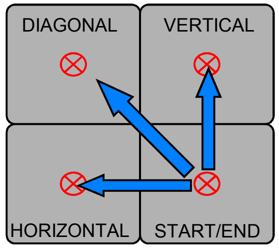
1. Place the robot at the starting position near the apparatus entrance.
2. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
3. Start the timer when the robot begins and capture total elapsed time for a complete set of **repetitions**.
4. Traverse the prescribed figure-8 path around the pylons for 10 continuous **repetitions** without intervention.

Fault Conditions: (Fill out an Event Report)

- Failure to complete 10 continuous **repetitions**

71

Mobility: Obstacle: Inclined Plane(0- 90°)



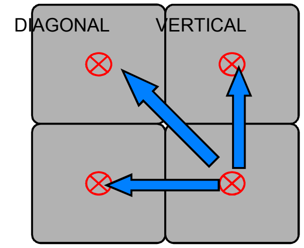
Purpose

The purpose of this test method is to quantitatively evaluate the incline plane maneuvering capabilities, including variable chassis configurations, rollover potential, and de-tracking, of a remotely teleoperated robot operating in lighted and dark conditions.

Metrics

- Maximum incline (degrees) while completing 10 repetitions each for vertical, diagonal, and horizontal paths.
- Average time per **repetition**

Mobility: Obstacle: Inclined Plane(0°- 90°)



Purpose

The purpose of this test method is to quantitatively evaluate the incline plane maneuvering capabilities, including variable chassis configurations, rollover potential, and de-tracking, of a remotely teleoperated robot operating in lighted and dark conditions.

Metrics

- Maximum incline (degrees) while completing 10 repetitions each for vertical, diagonal, and horizontal paths.
- Average time per **repetition**

Apparatus

- This test apparatus is fabricated from two 1.2 m x 2.4 m (4 ft x 8 ft) OSB panels divided into four quadrants with targets in each . Side walls are fabricated from 0.6 m x 2.4 m (2 ft x 8 ft) OSB panels attached to the side of the inclined surface.
- A grated friction surface (0.98 coefficient of friction) provides consistent traction.
- The surface inclines from 0 degrees to 90 degrees in increments of 5 degrees.
- A safety rope belay is routed through an eye bolt in the rear of the apparatus.

Procedure

1. Set the apparatus to the intended testing incline.
2. Place the robot at the starting position in a lower quadrant of the test surface facing up the incline. Robots may perform the task in any orientation. Attach safety rope belay.
3. Start the timer when the robot begins and capture total elapsed time for a complete set of **repetitions**.
4. Traverse a vertical path until the robot is fully contained within the upper quadrant then return to the start position. Repeat for 10 continuous **repetitions** without intervention.
5. Repeat for diagonal paths and then horizontal paths.
6. Increase the incline until unsuccessful in one of the **repetitions**.
7. Note the maximum incline completed for all **repetitions**.

Fault Conditions: (Fill out an Event Report)

- Intervention via rope belay is required
- Continuous contact with side walls
- Failure to complete 10 continuous **repetitions**

Test Methods

Apparatus

- This test apparatus is fabricated from two 1.2 m x 2.4 m (4 ft x 8 ft) OSB panels divided into four quadrants with targets in each. Side walls are fabricated from 0.6 m x 2.4 m (2 ft x 8 ft) OSB panels attached to the side of the inclined surface.
- A grated friction surface (0.98 coefficient of friction) provides consistent traction.
- The surface inclines from 0 degrees to 90 degrees in increments of 5 degrees.
- A safety rope belay is routed through an eye bolt in the rear of the apparatus.

Procedure

1. Set the apparatus to the intended testing incline.
2. Place the robot at the starting position in a lower quadrant of the test surface facing up the incline. Robots may perform the task in any orientation. Attach safety rope belay.
3. Start the timer when the robot begins and capture total elapsed time for a complete set of **repetitions**.
4. Traverse a vertical path until the robot is fully contained within the upper quadrant then return to the start position. Repeat for 10 continuous **repetitions** without intervention.
5. Repeat for diagonal paths and then horizontal paths.
6. Increase the incline until unsuccessful in one of the **repetitions**.
7. Note the maximum incline completed for all **repetitions**.

Fault Conditions: (Fill out an Event Report)

- Intervention via rope belay is required
- Continuous contact with side walls
- Failure to complete 10 continuous **repetitions**

73

Mobility: Obstacle: Gap Crossing: Static, Dynamic

Purpose

The purpose of this test method is to quantitatively evaluate the horizontal gap traversing capabilities, including variable chassis configurations and coordinated traversal behaviors, of a remotely teleoperated robot operating in confined areas in lighted and dark conditions.

Metrics

- Maximum gap (cm) traversed for 10 **repetitions**
- □Average time per repetition

Mobility: Obstacle: Gap Crossing: Static, Dynamic

Purpose

The purpose of this test method is to quantitatively evaluate the horizontal gap traversing capabilities, including variable chassis configurations and coordinated traversal behaviors, of a remotely teleoperated robot operating in confined areas in lighted and dark conditions.

Metrics

- Maximum gap (cm) traversed for 10 **repetitions**
- □Average time per repetition

Test Methods

Apparatus

- This test apparatus is fabricated from two 1.2 m x 1.2 m (4 ft x 4 ft) OSB **flat floor pallet elements** placed side by side, separated by a controlled gap, with a surrounding containment wall.
- 10 cm (4 in) diameter pipes are level with the surface of the far edge of the gap and are free to roll to provide an uncertain reach edge on the initial traverse and launch edge on the return.
- The gap can be incremented from 10 cm to 100 cm (4 in to 40 in) in 10 cm (4 in) increments.
- A safety rope belay is routed through an eye bolt in the rear of the apparatus.

Procedure

1. Set the apparatus to the intended testing gap.
2. Place the robot at the starting position on one pallet facing the obstacle. Robots may perform the task in any orientation. Attach safety rope belay.
3. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
4. Start the timer when the robot begins and capture total elapsed time for a complete set of **repetitions**.
5. Traverse the gap fully without touching the bottom surface of the gap until the entire robot is on the opposite platform, then similarly return to the start position. Repeat for 10 continuous **repetitions** without intervention.
6. Increase the gap until unsuccessful in one of the **repetitions**.
7. Note the maximum gap completed for all **repetitions**.

Fault Conditions: (Fill out an Event Report)

- Intervention via safety rope belay is required
- Touching bottom surface of the gap at any time
- Failure to complete 10 continuous **repetitions**

Test Methods

Apparatus

- This test apparatus is fabricated from two 1.2 m x 1.2 m (4 ft x 4 ft) OSB **flat floor pallet elements** placed side by side, separated by a controlled gap, with a surrounding containment wall.
- 10 cm (4 in) diameter pipes are level with the surface of the far edge of the gap and are free to roll to provide an uncertain reach edge on the initial traverse and launch edge on the return.
- The gap can be incremented from 10 cm to 100 cm (4 in to 40 in) in 10 cm (4 in) increments.
- A safety rope belay is routed through an eye bolt in the rear of the apparatus.

Procedure

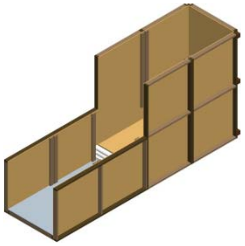
1. Set the apparatus to the intended testing gap.
2. Place the robot at the starting position on one pallet facing the obstacle. Robots may perform the task in any orientation. Attach safety rope belay.
3. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
4. Start the timer when the robot begins and capture total elapsed time for a complete set of **repetitions**.
5. Traverse the gap fully without touching the bottom surface of the gap until the entire robot is on the opposite platform, then similarly return to the start position. Repeat for 10 continuous **repetitions** without intervention.
6. Increase the gap until unsuccessful in one of the **repetitions**.
7. Note the maximum gap completed for all **repetitions**.

Fault Conditions: (Fill out an Event Report)

- Intervention via safety rope belay is required
- Touching bottom surface of the gap at any time
- Failure to complete 10 continuous **repetitions**

75

Mobility: Obstacle: Pipe Steps



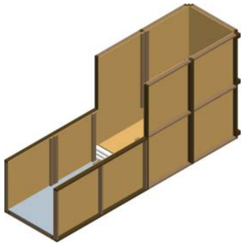
Purpose

The purpose of this test method is to quantitatively evaluate the vertical step surmounting capabilities, including variable chassis configurations and coordinated climbing behaviors, of a remotely teleoperated robot operating in confined areas in lighted and dark conditions.

Metrics

- Maximum elevation (cm) surmounted
- Average time per **repetition**
- Maximum elevation (cm) surmounted for 10 **repetitions**
- Average time per repetition

Mobility: Obstacle: Pipe Steps



Purpose

The purpose of this test method is to quantitatively evaluate the vertical step surmounting capabilities, including variable chassis configurations and coordinated climbing behaviors, of a remotely teleoperated robot operating in confined areas in lighted and dark conditions.

Metrics

- Maximum elevation (cm) surmounted
- Average time per **repetition**
- Maximum elevation (cm) surmounted for 10 **repetitions**
- Average time per repetition

76

Apparatus

- This test apparatus is fabricated from two stacks of 1.2 m x 1.2 m (4 ft x 4 ft) OSB **flat floor pallet elements** placed side by side to form a step with a surrounding containment wall.
- The elevated stack can be increased from 10 cm to 100 cm (4 in to 40 in) in 10 cm (4 in) increments.
- Plastic pipes with a diameter of 10 cm (4 in) are stacked along with the each pallet to reduce edge traction.
- The plastic pipes are constrained against the elevated pallets but are free to rotate.
- A safety rope belay is routed through an eye bolt in the rear wall of the apparatus.

Test Methods

Procedure

1. Set the apparatus to the intended testing elevation.
2. Place the robot at the starting position on one pallet facing the obstacle. Robots may perform the task in any orientation. Attach safety rope belay.
3. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
4. Start the timer when the robot begins and capture total elapsed time for a complete set of **repetitions**.
5. Surmount the pipe step fully so that the entire robot is on the elevated platform with no overhang or contact with the pipes, then return to the start position. Repeat for 10 continuous **repetitions** without intervention.
6. Increase the pipe step elevation until unsuccessful in one of the **repetitions**.

Fault Conditions: (Fill out an Event Report)

- Intervention via safety rope belay is required
- Failure to complete 10 continuous **repetitions**

Apparatus

- This test apparatus is fabricated from two stacks of 1.2 m x 1.2 m (4 ft x 4 ft) OSB **flat floor pallet elements** placed side by side to form a step with a surrounding containment wall.
- The elevated stack can be increased from 10 cm to 100 cm (4 in to 40 in) in 10 cm (4 in) increments.
- Plastic pipes with a diameter of 10 cm (4 in) are stacked along with the each pallet to reduce edge traction.
- The plastic pipes are constrained against the elevated pallets but are free to rotate.
- A safety rope belay is routed through an eye bolt in the rear wall of the apparatus.

Test Methods

Procedure

1. Set the apparatus to the intended testing elevation.
2. Place the robot at the starting position on one pallet facing the obstacle. Robots may perform the task in any orientation. Attach safety rope belay.
3. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
4. Start the timer when the robot begins and capture total elapsed time for a complete set of **repetitions**.
5. Surmount the pipe step fully so that the entire robot is on the elevated platform with no overhang or contact with the pipes, then return to the start position. Repeat for 10 continuous **repetitions** without intervention.
6. Increase the pipe step elevation until unsuccessful in one of the **repetitions**.

Fault Conditions: (Fill out an Event Report)

- Intervention via safety rope belay is required
- Failure to complete 10 continuous **repetitions**

77

Mobility: Obstacle: Stairs (30°/35°/40°/45°;Wood/Metal)



Purpose

The purpose of this test method is to quantitatively evaluate the stair ascending/descending capabilities, including variable chassis configurations, coordinated climbing behaviors, and tread surface vulnerabilities, for a remotely teleoperated robot operating in confined areas in lighted and dark conditions.

Metrics

- Maximum successful incline (degrees) with a variety of surface conditions for 10 **repetitions**
- Average time per repetition

Mobility: Obstacle: Stairs (30°/35°/40°/45°;Wood/Metal)



Purpose

The purpose of this test method is to quantitatively evaluate the stair ascending/descending capabilities, including variable chassis configurations, coordinated climbing behaviors, and tread surface vulnerabilities, for a remotely teleoperated robot operating in confined areas in lighted and dark conditions.

Metrics

- Maximum successful incline (degrees) with a variety of surface conditions for 10 repetitions
- Average time per repetition

78

Apparatus

- Four different stair inclines (30°, 35°, 40°, 45°) are available with two different stair tread surfaces, wood and “diamond plate” steel .
- Each apparatus contains five stairs with 20 cm (8 in) risers and 20 cm (8 in) treads with enclosed lower and upper landings made of 1.2 m x 1.2 m (4 ft x 4 ft) OSB.
- A removable containment wall encloses the lower landing at the start point.
- A safety rope belay is routed through an eye bolt in the rear wall of the apparatus.

Procedure

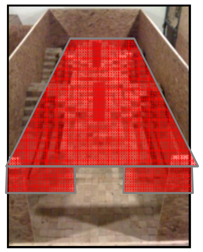
1. Set the apparatus to the intended testing incline and surface.
2. Place the robot at the starting position facing the obstacle. Robots may perform the task in any orientation. Attach safety rope belay. Enclose the robot with the lower landing containment wall
3. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
4. Start the timer when the robot begins and capture total elapsed time for a complete set of **repetitions**.
5. Surmount the stairs fully so that the entire robot is on the elevated landing with no overhang or contact with the stairs, then return to the start position. Repeat for 10 continuous **repetitions** without intervention..
6. Repeat with other stair tread surfaces.
7. Increase the stair incline until unsuccessful in one of the **repetitions**.
8. Note the maximum incline completed with all surfaces for all **repetitions**.

Fault Conditions: (Fill out an Event Report)

- Intervention via safety rope belay is required
- Failure to complete 10 continuous **repetitions**

Apparatus
- Four different stair inclines (30°, 35°, 40°, 45°) are available with two different stair tread surfaces, wood and “diamond plate” steel .
- Each apparatus contains five stairs with 20 cm (8 in) risers and 20 cm (8 in) treads with enclosed lower and upper landings made of 1.2 m x 1.2 m (4 ft x 4 ft) OSB.
- A removable containment wall encloses the lower landing at the start point.
- A safety rope belay is routed through an eye bolt in the rear wall of the apparatus.
Test Methods
Procedure
1. Set the apparatus to the intended testing incline and surface.
2. Place the robot at the starting position facing the obstacle. Robots may perform the task in any orientation. Attach safety rope belay. Enclose the robot with the lower landing containment wall
3. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
4. Start the timer when the robot begins and capture total elapsed time for a complete set of repetitions.
5. Surmount the stairs fully so that the entire robot is on the elevated landing with no overhang or contact with the stairs, then return to the start position. Repeat for 10 continuous repetitions without intervention..
6. Repeat with other stair tread surfaces.
7. Increase the stair incline until unsuccessful in one of the repetitions.
8. Note the maximum incline completed with all surfaces for all repetitions.
Fault Conditions: (Fill out an Event Report)
- Intervention via safety rope belay is required
- Failure to complete 10 continuous repetitions
79

Mobility: Obstacle: Confined Space



Purpose

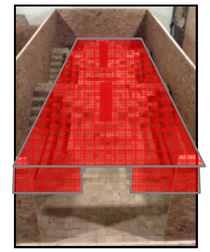
The purpose of this test method is to quantitatively evaluate the confined space maneuvering capabilities of a robot while being remotely teleoperated in complex terrain with lighted and dark conditions.

.

Metrics

- Completion of 10 figure-8 repetitions
- Average time per repetition

Mobility: Obstacle: Confined Space



Purpose

The purpose of this test method is to quantitatively evaluate the confined space maneuvering capabilities of a robot while being remotely teleoperated in complex terrain with lighted and dark conditions.

.

Metrics

- Completion of 10 figure-8 repetitions
- Average time per repetition

Apparatus

- The flooring terrain consists of symmetric stepfield terrain element fabricated using 10 cm (4 in) square wood posts cut to prescribed lengths (10 cm, 20 cm, 30 cm, 40 cm, and 50 cm(4 in, 8 in, 12 in, 16 in, and 20 in) and setup in groups of four posts per step height .
- Two pylons define the prescribed figure-8 path.
- This test apparatus is intended to fit into a 12 m x 2.4 m (40 ft x 8 ft) standard ISO shipping container . It can also be setup as a freestanding apparatus with 1.2 m (4 ft) tall walls with supports.
- A descending ceiling element with stalactites is used to narrow the vertical access dimension in 10 cm (4 in) increments. The pattern of stalactites is inverted from the flooring terrain so that ceiling features fill the valley features of the flooring terrain.

Procedure

1. Place the robot at the starting position near the apparatus entrance.
2. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
3. Start the timer when the robot begins and capture total elapsed time for a complete set of repetitions.
4. Traverse the figure-8 path around the pylons continuously without intervention until all repetitions are complete

Fault Conditions: (Fill out an Event Report)

- Failure to complete 10 continuous **repetitions**

Apparatus

- The flooring terrain consists of symmetric stepfield terrain element fabricated using 10 cm (4 in) square wood posts cut to prescribed lengths (10 cm, 20 cm, 30 cm, 40 cm, and 50 cm(4 in, 8 in, 12 in, 16 in, and 20 in) and setup in groups of four posts per step height .
- Two pylons define the prescribed figure-8 path.
- This test apparatus is intended to fit into a 12 m x 2.4 m (40 ft x 8 ft) standard ISO shipping container . It can also be setup as a freestanding apparatus with 1.2 m (4 ft) tall walls with supports.
- A descending ceiling element with stalactites is used to narrow the vertical access dimension in 10 cm (4 in) increments. The pattern of stalactites is inverted from the flooring terrain so that ceiling features fill the valley features of the flooring terrain.

Procedure

1. Place the robot at the starting position near the apparatus entrance.
2. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
3. Start the timer when the robot begins and capture total elapsed time for a complete set of repetitions.
4. Traverse the figure-8 path around the pylons continuously without intervention until all repetitions are complete

Fault Conditions: (Fill out an Event Report)

- Failure to complete 10 continuous **repetitions**

Test Methods

81

Mobility: Towing: Grasped Sleds

Purpose

The purpose of this test method is to quantitatively evaluate the grasped towing capabilities for a remotely teleoperated robot operating on a flat/paved surface with confined area turns.

Metrics

- Maximum weight dragged (kg) for 10 **repetitions**
- Average time per repetition

Mobility: Towing: Grasped Sleds

Purpose

The purpose of this test method is to quantitatively evaluate the grasped towing capabilities for a remotely teleoperated robot operating on a flat/paved surface with confined area turns.

Metrics

- Maximum weight dragged (kg) for 10 **repetitions**
- Average time per repetition

Apparatus

- This test apparatus is a flat, straight, paved path of 50 m (165 ft) between two pylons
- Each pylon has a clearly marked turning boundary with a radius of 2 m (6.5 ft) marked by a chalk or paint line (FIGURE B).
- A drag sled with a knotted handle is used for towing
- A set of standard weights of 2 kg (5 lbs) and 11 kg (25 lbs) are available to load the sled.
- A set of backpacks weighing 5 kg (10 lbs) and 9 kg (20 lbs) can also be used for drag weights less than the sled itself.

Procedure

1. Place the drag sled at the starting position within a pylon turning boundary. The operator may select the initial drag weight.
2. Place the robot at the starting position within a pylon turning boundary, near the drag sled but not attached in any way.
3. Start the timer when the robot begins and capture total elapsed time for a complete set of **repetitions**.
4. Remotely teleoperate the robot to grasp the sled in any convenient manner.
5. Traverse the prescribed figure-8 path around the pylons for 10 continuous **repetitions** without intervention. Maintain at least part of the robot and drag sled clearly inside the marked turning boundaries.
6. Failure to stay within the turning boundary negates the current lap. Teleoperate the robot to the starting position and continue with the timer running.
7. Increase the drag weight according to the operator's chosen increment and repeat until unsuccessful in one of the **repetitions** or the operator is content with the last successful drag weight.
8. Note the maximum drag weight completed for all **repetitions.**

Fault Conditions: (Fill out an Event Report)

- Failure to complete 10 continuous **repetitions**

Test Methods

Apparatus

- This test apparatus is a flat, straight, paved path of 50 m (165 ft) between two pylons
- Each pylon has a clearly marked turning boundary with a radius of 2 m (6.5 ft) marked by a chalk or paint line (FIGURE B).
- A drag sled with a knotted handle is used for towing
- A set of standard weights of 2 kg (5 lbs) and 11 kg (25 lbs) are available to load the sled.
- A set of backpacks weighing 5 kg (10 lbs) and 9 kg (20 lbs) can also be used for drag weights less than the sled itself.

Procedure

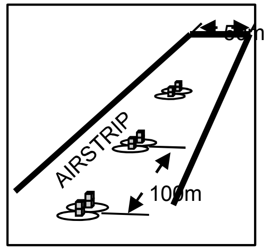
1. Place the drag sled at the starting position within a pylon turning boundary. The operator may select the initial drag weight.
2. Place the robot at the starting position within a pylon turning boundary, near the drag sled but not attached in any way.
3. Start the timer when the robot begins and capture total elapsed time for a complete set of **repetitions**.
4. Remotely teleoperate the robot to grasp the sled in any convenient manner.
5. Traverse the prescribed figure-8 path around the pylons for 10 continuous **repetitions** without intervention. Maintain at least part of the robot and drag sled clearly inside the marked turning boundaries.
6. Failure to stay within the turning boundary negates the current lap. Teleoperate the robot to the starting position and continue with the timer running.
7. Increase the drag weight according to the operator's chosen increment and repeat until unsuccessful in one of the **repetitions** or the operator is content with the last successful drag weight.
8. Note the maximum drag weight completed for all **repetitions.**

Fault Conditions: (Fill out an Event Report)

- Failure to complete 10 continuous **repetitions**

83

Radio Communications: Control and Perception Tasks:
Line-of-Sight Environment



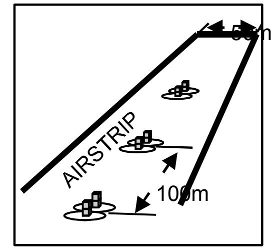
Purpose

The purpose of this test method is to quantitatively evaluate the line of sight (LOS) radio communications range for a remotely teleoperated robot.

Metrics

- Maximum distance (m) downrange at which the robot completes tasks to verify the functionality of control, video, and audio transmissions.

Radio Communications: Control and Perception Tasks:
Line-of-Sight Environment



Purpose
The purpose of this test method is to quantitatively evaluate the line of sight (LOS) radio communications range for a remotely teleoperated robot.
Metrics
- Maximum distance (m) downrange at which the robot completes tasks to verify the functionality of control, video, and audio transmissions.
84

Apparatus

- The test apparatus for the LOS test is a straight flat section of airstrip, roadway or similar surface at least 1 km (0.6 mi) long (longer if possible). The surface shall be consistent (e.g. asphalt or concrete) and be free of reflective objects at least 50 m (164 ft) on either side of the centerline.
- A figure-8 path with two 2 m (6.5 ft) radius lobes and 4 targets, facing four directions, shall be located at test distances of 50 m, 100 m, 200 m, 300 m (165 ft, 330 ft, 660 ft, 990 ft)... through the entire range of the test course.
- Operator station antennas shall be limited to a maximum of 2 m (6.5 ft) elevation above the ground.

Procedure

1. Place the robot in the start position near the operator station.
2. Traverse downrange to the next test station.
3. The control signal is tested by following the curved line. The video signal is tested by identifying hazmat labels. The two-way audio is tested by an endless loop playing a predetermined set of keywords with the operator and administrator at each end identifying the words heard.
4. Upon arrival at a test station, center the robot wheels/tracks on the figure-8 path and follow the curve while maintaining line between tracks until directly in view of a recessed **target** placed at the center of the figure-8. Turn the robot towards the target and use any forward-facing sensor to identify the **target**. Panning of sensors is not allowed. Driving towards the **target** is allowed, but contact with the **target** is not. Return to the figure-8 path and continue around to next **target** until all four **target** are identified.
5. Repeat until a station is reached at which the control, video or audio transmissions fail. Report the last successful station range.

Fault Conditions: (Fill out an Event Report)

- Deviating from prescribed figure-8 path while traversing between **targets** within a station.
- Touching the **targets** while attempting identification

Test Methods

Apparatus

- The test apparatus for the LOS test is a straight flat section of airstrip, roadway or similar surface at least 1 km (0.6 mi) long (longer if possible). The surface shall be consistent (e.g. asphalt or concrete) and be free of reflective objects at least 50 m (164 ft) on either side of the centerline.
- A figure-8 path with two 2 m (6.5 ft) radius lobes and 4 targets, facing four directions, shall be located at test distances of 50 m, 100 m, 200 m, 300 m (165 ft, 330 ft, 660 ft, 990 ft)... through the entire range of the test course.
- Operator station antennas shall be limited to a maximum of 2 m (6.5 ft) elevation above the ground.

Procedure

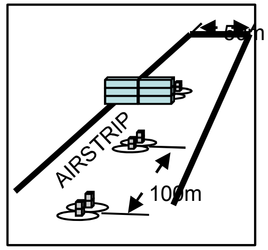
1. Place the robot in the start position near the operator station.
2. Traverse downrange to the next test station.
3. The control signal is tested by following the curved line. The video signal is tested by identifying hazmat labels. The two-way audio is tested by an endless loop playing a predetermined set of keywords with the operator and administrator at each end identifying the words heard.
4. Upon arrival at a test station, center the robot wheels/tracks on the figure-8 path and follow the curve while maintaining line between tracks until directly in view of a recessed **target** placed at the center of the figure-8. Turn the robot towards the target and use any forward-facing sensor to identify the **target**. Panning of sensors is not allowed. Driving towards the **target** is allowed, but contact with the **target** is not. Return to the figure-8 path and continue around to next **target** until all four **target** are identified.
5. Repeat until a station is reached at which the control, video or audio transmissions fail. Report the last successful station range.

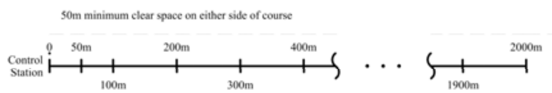
Fault Conditions: (Fill out an Event Report)

- Deviating from prescribed figure-8 path while traversing between **targets** within a station.
- Touching the **targets** while attempting identification

85

Radio Communications:
Control and Perception Tasks:
Non-Line-of-Sight Range





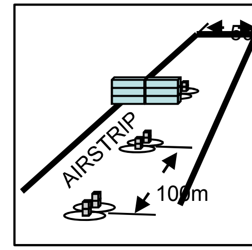
Purpose

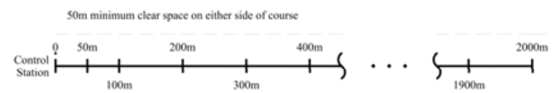
The purpose of this test method is to quantitatively evaluate the non-line-of-sight (NLOS) radio communications range for a remotely teleoperated robot.

Metrics

- Maximum distance (m) behind a downrange metal monolith at which the robot completes tasks to verify the functionality of control, video, and audio transmissions

Radio Communications:
Control and Perception Tasks:
Non-Line-of-Sight Range





Purpose
The purpose of this test method is to quantitatively evaluate the non-line-of-sight (NLOS) radio communications range for a remotely teleoperated robot.

Metrics
- Maximum distance (m) behind a downrange metal monolith at which the robot completes tasks to verify the functionality of control, video, and audio transmissions

Apparatus

- The test apparatus for the NLOS test is identical to the LOS except at a distance of 500 m (1640 ft) there is a wall constructed of standard ISO shipping containers (7.3 m high x 24.4 m wide (24 ft high x 80 ft wide)) with one edge aligned with the test course centerline and the long face perpendicular to the direction of robot travel.
- Three additional figure-8 paths are located behind and tangent to the metal wall to test robot operations in the radio shadow.
- Operator station antennas shall be limited to a maximum of 2 m (6.5 ft) elevation above the ground.

Procedure

1. Determine standoff distance of operator station from metal wall based on half the robot's LOS performance data.
2. Place the robot in the start position near the operator station.
3. Traverse downrange to the next test station.
4. The control signal is tested by following the curved line. The video signal is tested by identifying hazmat labels. The two-way audio is tested by an endless loop playing a predetermined set of keywords with the operator and administrator at each end identifying the words heard.
5. Upon arrival at a test station, center the robot wheels/tracks on the figure-8 path and follow the curve while maintaining line between tracks until directly in view of a recessed **target** placed at the center of the figure-8. Turn the robot towards the target and use any forward-facing sensor to identify the **target**. Panning of sensors is not allowed. Driving towards the **target** is allowed, but contact with the **target** is not. Return to the figure-8 path and continue around to next **target** until all four **target** are identified.
6. Upon arrival at the ISO container monolith the robot should turn behind the container and proceed to a figure-8 test at 2 m (6.5 ft), 5 m (16.5 ft), and 12 m (40 ft) from the corner.
7. Repeat until a station is reached at which the control, video or audio transmissions fail. Report the last successful station range.

Fault Conditions: (Fill out an Event Report)

- Deviating from prescribed figure-8 path while traversing between **targets** within a station.
- Touching the **targets** while attempting identification.

Apparatus

- The test apparatus for the NLOS test is identical to the LOS except at a distance of 500 m (1640 ft) there is a wall constructed of standard ISO shipping containers (7.3 m high x 24.4 m wide (24 ft high x 80 ft wide)) with one edge aligned with the test course centerline and the long face perpendicular to the direction of robot travel.
- Three additional figure-8 paths are located behind and tangent to the metal wall to test robot operations in the radio shadow.
- Operator station antennas shall be limited to a maximum of 2 m (6.5 ft) elevation above the ground.

Test Methods

Procedure

1. Determine standoff distance of operator station from metal wall based on half the robot's LOS performance data.
2. Place the robot in the start position near the operator station.
3. Traverse downrange to the next test station.
4. The control signal is tested by following the curved line. The video signal is tested by identifying hazmat labels. The two-way audio is tested by an endless loop playing a predetermined set of keywords with the operator and administrator at each end identifying the words heard.
5. Upon arrival at a test station, center the robot wheels/tracks on the figure-8 path and follow the curve while maintaining line between tracks until directly in view of a recessed **target** placed at the center of the figure-8. Turn the robot towards the target and use any forward-facing sensor to identify the **target**. Panning of sensors is not allowed. Driving towards the **target** is allowed, but contact with the **target** is not. Return to the figure-8 path and continue around to next **target** until all four **target** are identified.
6. Upon arrival at the ISO container monolith the robot should turn behind the container and proceed to a figure-8 test at 2 m (6.5 ft), 5 m (16.5 ft), and 12 m (40 ft) from the corner.
7. Repeat until a station is reached at which the control, video or audio transmissions fail. Report the last successful station range.

Fault Conditions: (Fill out an Event Report)

- Deviating from prescribed figure-8 path while traversing between **targets** within a station.
- Touching the **targets** while attempting identification.

87

Manipulation:
Directed Perception: Open Access

Purpose

The purpose of this test method is to quantitatively evaluate the manipulator positioning capabilities of a remotely teleoperated robot operating on increasingly complex terrain in confined areas in lighted and dark conditions.

Metrics

- Number of correctly identified **targets** within sub-divided cells at various proximities and elevations relative to the robot
- Average time per task

Manipulation:
Directed Perception: Open Access

Purpose

The purpose of this test method is to quantitatively evaluate the manipulator positioning capabilities of a remotely teleoperated robot operating on increasingly complex terrain in confined areas in lighted and dark conditions.

Metrics

- Number of correctly identified **targets** within sub-divided cells at various proximities and elevations relative to the robot
- Average time per task

88

Apparatus

- The apparatus for this test method contains two alcoves which sub-divide the work volume to the front and side of the robot into roughly cubic cells in which **targets** are placed to be identified.
- Each alcove allows shelf placement at prescribed elevations (0 cm to 200 cm (0 in to 80 in) in 50 cm (20 in) increments).
- Each shelf is sub-divided into four cells.
- The cells are accessible via circular holes of 15 cm (6 in) diameter with hinged doors and magnetic closures.
- Ground level (0 cm (0 in)) cells have no front holes.
- **Full ramp terrain elements** or symmetric **stepfields terrain elements**, provide complexity in robot orientation and mobility.
- The start/end line is two terrain elements away from the front alcove.

Procedure

1. Set the shelves to the intended testing elevation. Close cell doors.
2. Place the robot outside the start/end line facing the alcoves.
3. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
4. Start the timer when the robot crosses the start/end line to capture total elapsed time for a complete shelf elevation, ending when the robot exits past the start/end line.
5. Open each reachable cell access door with the manipulator tool tip and identify the **target** within. Bumping the apparatus to open doors is not allowed.
6. Repeat at the next higher shelf elevation until all elevations have been tested or the robot is no longer able to reach the cells.
7. Repeat all shelf elevations with other flooring options.
8. Robots may exit past the start/end line for maintenance or repairs.

Fault Conditions: (Fill out an Event Report)

- Failure to return past the start/end line

Apparatus
- The apparatus for this test method contains two alcoves which sub-divide the work volume to the front and side of the robot into roughly cubic cells in which targets are placed to be identified.
- Each alcove allows shelf placement at prescribed elevations (0 cm to 200 cm (0 in to 80 in) in 50 cm (20 in) increments).
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- Full ramp terrain elements or symmetric stepfields terrain elements, provide complexity in robot orientation and mobility.
- The start/end line is two terrain elements away from the front alcove.
Procedure
1. Set the shelves to the intended testing elevation. Close cell doors.
2. Place the robot outside the start/end line facing the alcoves.
3. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
4. Start the timer when the robot crosses the start/end line to capture total elapsed time for a complete shelf elevation, ending when the robot exits past the start/end line.
5. Open each reachable cell access door with the manipulator tool tip and identify the target within. Bumping the apparatus to open doors is not allowed.
6. Repeat at the next higher shelf elevation until all elevations have been tested or the robot is no longer able to reach the cells.
7. Repeat all shelf elevations with other flooring options.
8. Robots may exit past the start/end line for maintenance or repairs.
Fault Conditions: (Fill out an Event Report)
- Failure to return past the start/end line
Test Methods
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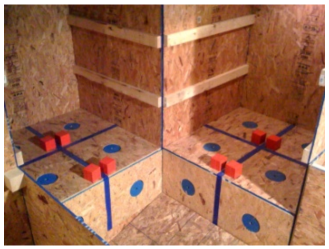
Manipulation: Grasping Dexterity: Open Access



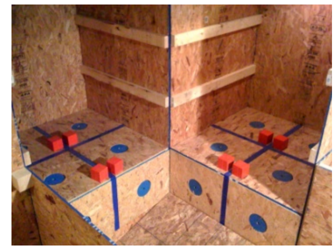
Purpose

The purpose of this test method is to quantitatively evaluate the manipulator grasping and placement capability of a remotely teleoperated robot operating on increasingly complex terrain in confined areas in lighted and dark conditions.

Metrics

- Number of grasped **pick and place objects** within sub-divided cells at various proximities and elevations relative to the robot
- Average time per task

Manipulation: Grasping Dexterity: Open Access



Purpose

The purpose of this test method is to quantitatively evaluate the manipulator grasping and placement capability of a remotely teleoperated robot operating on increasingly complex terrain in confined areas in lighted and dark conditions.

Metrics

- Number of grasped pick and place objects within sub-divided cells at various proximities and elevations relative to the robot
- Average time per task

Test Methods

Apparatus

- The apparatus for this test method contains two alcoves which sub-divide the work volume to the front and side of the robot into roughly cubic cells in which pick and place tasks are performed.
- Each alcove allows shelf placement at prescribed elevations (0 cm, 50 cm, 100 cm, 150 cm, 200 cm (0 in, 20 in, 40 in, 60 in, 80 in)).
- Each shelf is sub-divided into four cells with 10 cm (4 in) **pick and place objects** placed on pegs in the near corner (shown as red in FIGURE A) and circular holes of 15 cm (6 in) diameter with hinged doors and magnetic closures (shown as blue in FIGURE A).
- Ground level (0 cm (0 in)) cells have no front holes.
- Non-flat flooring conditions, either **full ramp terrain elements** or symmetric **stepfield terrain elements**, provide complexity in robot orientation and mobility.
- The start/end line is two terrain elements away from the front alcove.

Procedure

1. Set the shelves to the intended testing elevation. Close cell doors. Place the **pick and place object**s on their appropriate pegs.
2. Place the robot outside the start/end line facing the alcoves.
3. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
4. Start the timer when the robot crosses the start/end line to capture total elapsed time for a complete shelf elevation, ending when the robot exits past the start/end line.
5. Grasp each reachable **pick and place object** with the manipulator tool tip, remove from its recessed peg mount, and place through the corresponding cell access door.
6. Repeat at the next higher shelf elevation until all elevations have been tested or the robot is no longer able to reach the cells.
7. Repeat all shelf elevations with other flooring options.
8. Robots may exit past the start/end line for maintenance or repairs.

Fault Conditions: (Fill out an Event Report)

- Failure to return past the start/end line

Test Methods

Apparatus

- The apparatus for this test method contains two alcoves which sub-divide the work volume to the front and side of the robot into roughly cubic cells in which pick and place tasks are performed.
- Each alcove allows shelf placement at prescribed elevations (0 cm, 50 cm, 100 cm, 150 cm, 200 cm (0 in, 20 in, 40 in, 60 in, 80 in)).
- Each shelf is sub-divided into four cells with 10 cm (4 in) **pick and place objects** placed on pegs in the near corner (shown as red in FIGURE A) and circular holes of 15 cm (6 in) diameter with hinged doors and magnetic closures (shown as blue in FIGURE A).
- Ground level (0 cm (0 in)) cells have no front holes.
- Non-flat flooring conditions, either **full ramp terrain elements** or symmetric **stepfield terrain elements**, provide complexity in robot orientation and mobility.
- The start/end line is two terrain elements away from the front alcove.

Procedure

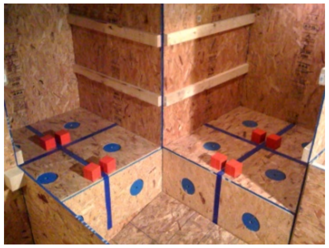
1. Set the shelves to the intended testing elevation. Close cell doors. Place the **pick and place object**s on their appropriate pegs.
2. Place the robot outside the start/end line facing the alcoves.
3. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
4. Start the timer when the robot crosses the start/end line to capture total elapsed time for a complete shelf elevation, ending when the robot exits past the start/end line.
5. Grasp each reachable **pick and place object** with the manipulator tool tip, remove from its recessed peg mount, and place through the corresponding cell access door.
6. Repeat at the next higher shelf elevation until all elevations have been tested or the robot is no longer able to reach the cells.
7. Repeat all shelf elevations with other flooring options.
8. Robots may exit past the start/end line for maintenance or repairs.

Fault Conditions: (Fill out an Event Report)

- Failure to return past the start/end line

91

Manipulation:
Grasping Dexterity: Weight Payloads



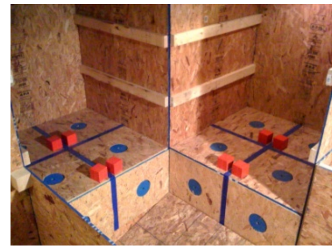

Purpose

The purpose of this test method is to quantitatively evaluate the the manipulator grasping and placement capabilities of a robot on increasingly complex terrain, including weighted payloads, while being remotely teleoperated in confined areas with lighted and dark conditions.

Metrics

- Number of grasped pick and place objects within sub-divided cells at various proximities and elevations relative to the robot
- Average time per task

Manipulation:
Grasping Dexterity: Weight Payloads




Purpose

The purpose of this test method is to quantitatively evaluate the the manipulator grasping and placement capabilities of a robot on increasingly complex terrain, including weighted payloads, while being remotely teleoperated in confined areas with lighted and dark conditions.

Metrics

- Number of grasped pick and place objects within sub-divided cells at various proximities and elevations relative to the robot
- Average time per task

APPARATUS AND PROCEDURE
PROTOTYPE
UNDER DEVELOPMENT

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Apparatus

- The apparatus for this test method contains two alcoves which sub-divide the work volume to the front and side of the robot into roughly cubic cells in which pick and place tasks are performed.
- Each alcove allows shelf placement at prescribed elevations (0 cm, 50 cm, 100 cm, 150 cm, 200 cm (0 in, 20 in, 40 in, 60 in, 80 in).
- Each shelf is sub-divided into four cells with 10 cm (4 in) diameter cylindrical pick and place objects with weights of 0.5kg (1lb), 3kg (7lbs), 7kg (15lbs) placed on pegs in the near corner and circular holes of 15 cm (6 in) diameter.
- Ground level (0 cm (0 in)) cells have no front holes.
- Non-flat flooring conditions, either full ramp terrain elements or symmetric stepfield terrain elements, provide complexity in robot orientation and mobility.
- The start/end line is two terrain elements away from the front alcove .

Procedure

1. Set the shelves to the intended testing elevation. Close cell doors. Place the pick and place objects on their appropriate pegs.
2. Place the robot outside the start/end line facing the alcoves.
3. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
4. Start the timer when the robot crosses the start/end line to capture total elapsed time for a complete shelf elevation, ending when the robot exits past the start/end line.
5. Grasp each reachable pick and place object with the manipulator tool tip, remove from its recessed peg mount, and place through the corresponding cell access door.
6. Repeat at the next higher shelf elevation until all elevations have been tested or the robot is no longer able to reach the cells.
7. Repeat all shelf elevations with other flooring options.
8. Robots may exit past the start/end line for maintenance or repairs.

Fault Conditions: (Fill out an Event Report)

- Failure to return past the start/end line

Apparatus

- The apparatus for this test method contains two alcoves which sub-divide the work volume to the front and side of the robot into roughly cubic cells in which pick and place tasks are performed.
- Each alcove allows shelf placement at prescribed elevations (0 cm, 50 cm, 100 cm, 150 cm, 200 cm (0 in, 20 in, 40 in, 60 in, 80 in).
- Each shelf is sub-divided into four cells with 10 cm (4 in) diameter cylindrical pick and place objects with weights of 0.5kg (1lb), 3kg (7lbs), 7kg (15lbs) placed on pegs in the near corner and circular holes of 15 cm (6 in) diameter.
- Ground level (0 cm (0 in)) cells have no front holes.
- Non-flat flooring conditions, either full ramp terrain elements or symmetric stepfield terrain elements, provide complexity in robot orientation and mobility.
- The start/end line is two terrain elements away from the front alcove .

Test Methods

Procedure

1. Set the shelves to the intended testing elevation. Close cell doors. Place the pick and place objects on their appropriate pegs.
2. Place the robot outside the start/end line facing the alcoves.
3. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
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5. Grasp each reachable pick and place object with the manipulator tool tip, remove from its recessed peg mount, and place through the corresponding cell access door.
6. Repeat at the next higher shelf elevation until all elevations have been tested or the robot is no longer able to reach the cells.
7. Repeat all shelf elevations with other flooring options.
8. Robots may exit past the start/end line for maintenance or repairs.

Fault Conditions: (Fill out an Event Report)

- Failure to return past the start/end line

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Manipulation: Door Opening and Traversal Tasks

Purpose

The purpose of this test method is to quantitatively evaluate the door opening capability of a remotely teleoperated robot operating in confined areas in lighted and dark conditions.

Metrics

- Completion of two subtasks: unlatching the door and traversing through
- Average time per **repetition**

Manipulation: Door Opening and Traversal Tasks

Purpose

The purpose of this test method is to quantitatively evaluate the door opening capability of a remotely teleoperated robot operating in confined areas in lighted and dark conditions.

Metrics

- Completion of two subtasks: unlatching the door and traversing through
- Average time per **repetition**

Apparatus

- The apparatus for this test method uses a set of common household 90 cm (36 in) entry doors that are installed on frames.
- The doors are to have the following types of handles and locks for opening: lever and knob, push and pull, spring loaded and not, flat and with a step.
- The latches can be on left or right side of the door .
- The starting line will be marked on the floor at 1.2 m (4 ft) from the door.

Procedure

1. Place the robot at the starting position facing the door. Ensure that the door is latched, but not locked.
2. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
3. Start the timer when the robot begins and capture total elapsed time for a complete set of **repetitions**.
4. Open the door and drive through to the other side so the robot is clear of the door (spring loaded doors should shut). Repeat for 10 continuous **repetitions** without intervention.
5. Repeat the same door from the opposite side for 10 continuous **repetitions** without intervention.
6. Repeat for all other doors handle types and conditions.

Fault Conditions: (Fill out an Event Report)

- Failure to complete 10 continuous **repetitionsd**

Apparatus

- The apparatus for this test method uses a set of common household 90 cm (36 in) entry doors that are installed on frames.
- The doors are to have the following types of handles and locks for opening: lever and knob, push and pull, spring loaded and not, flat and with a step.
- The latches can be on left or right side of the door .
- The starting line will be marked on the floor at 1.2 m (4 ft) from the door.

Test Methods

Procedure

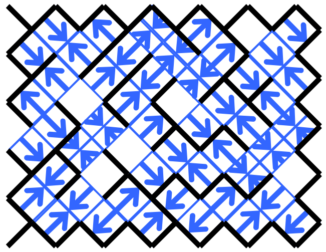
1. Place the robot at the starting position facing the door. Ensure that the door is latched, but not locked.
2. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
3. Start the timer when the robot begins and capture total elapsed time for a complete set of **repetitions**.
4. Open the door and drive through to the other side so the robot is clear of the door (spring loaded doors should shut). Repeat for 10 continuous **repetitions** without intervention.
5. Repeat the same door from the opposite side for 10 continuous **repetitions** without intervention.
6. Repeat for all other doors handle types and conditions.

Fault Conditions: (Fill out an Event Report)

- Failure to complete 10 continuous **repetitionsd**

95

Human System Interaction: Navigation Tasks: Random Maze Navigation with Complex Terrain

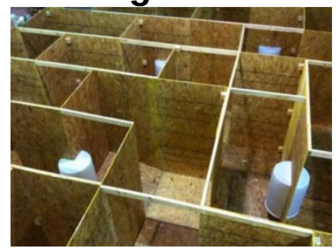
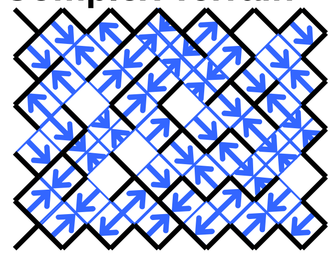
Purpose

The purpose of this test method is to quantitatively evaluate the maneuvering navigation capability of a remotely teleoperated robot operating on complex terrain in confined areas in lighted and dark conditions..

Metrics

- Number of **full and half ramp flooring elements** traversed while wall following ("right-hand" or "left-hand") through the maze (complexity measure).
- Completion time.

Human System Interaction: Navigation Tasks: Random Maze Navigation with Complex Terrain

Purpose

The purpose of this test method is to quantitatively evaluate the maneuvering navigation capability of a remotely teleoperated robot operating on complex terrain in confined areas in lighted and dark conditions..

Metrics

- Number of **full and half ramp flooring elements** traversed while wall following ("right-hand" or "left-hand") through the maze (complexity measure).
- Completion time.

Apparatus

- This test apparatus is a random maze of 1.2 m (4 ft) wide hallways constructed with 1.2 m x 2.4 m (4 ft x 8 ft) tall OSB walls.
- The overall dimensions are roughly 10 m x 15 m (33 ft x 50 ft).
- The flooring is made of continuous **full and half ramp flooring elements** to provide complexity in robot orientation and operator awareness .
- **Targets** are placed on the far walls of dead-ends only.

Test Methods

Procedure

1. Place the robot at the starting position facing into the apparatus.
2. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
3. Start the timer when the robot begins and capture total elapsed time for a complete negotiation of the maze ending when the robot returns to the start position.
4. Traverse the maze using the prescribed "**right hand"** or "**left hand" wall following** technique to navigate completely through the maze. Contact with the walls is allowed. Flooring pallets in dead-ends must be fully occupied to be counted (touch the **Target** on the far wall).
5. The robot may return to the start point to allow for maintenance and/or repairs during the test. The timer will be paused during maintenance and an Event Report should be generated.
6. The robot must return to the start point at the end of the test.

Fault Conditions: (Fill out an Event Report)

- Failure to return to start point.

Apparatus

- This test apparatus is a random maze of 1.2 m (4 ft) wide hallways constructed with 1.2 m x 2.4 m (4 ft x 8 ft) tall OSB walls.
- The overall dimensions are roughly 10 m x 15 m (33 ft x 50 ft).
- The flooring is made of continuous **full and half ramp flooring elements** to provide complexity in robot orientation and operator awareness .
- **Targets** are placed on the far walls of dead-ends only.

Test Methods

Procedure

1. Place the robot at the starting position facing into the apparatus.
2. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
3. Start the timer when the robot begins and capture total elapsed time for a complete negotiation of the maze ending when the robot returns to the start position.
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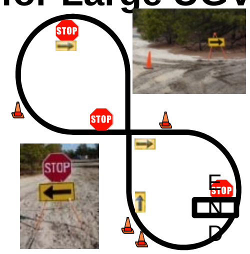
5. The robot may return to the start point to allow for maintenance and/or repairs during the test. The timer will be paused during maintenance and an Event Report should be generated.
6. The robot must return to the start point at the end of the test.

Fault Conditions: (Fill out an Event Report)

- Failure to return to start point.

97

Human System Interaction: Navigation Tasks: Outdoor Navigation for Large UGV



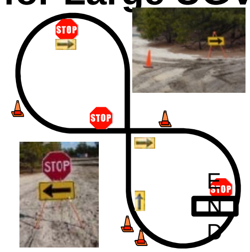
Purpose

The purpose of this test method is to quantitatively evaluate a remotely operated robot capability to efficiently and completely map an unknown space with moderate feature complexities.

Metrics

- Modified Cooper-Harper Criteria
- Number of Safety Stops
- Time to complete

Human System Interaction: Navigation Tasks: Outdoor Navigation for Large UGV



Purpose

The purpose of this test method is to quantitatively evaluate a remotely operated robot capability to efficiently and completely map an unknown space with moderate feature complexities.

Metrics

- Modified Cooper-Harper Criteria
- Number of Safety Stops
- Time to complete

APPARATUS AND PROCEDURE
PROTOTYPE
UNDER DEVELOPMENT

98

Apparatus

This test apparatus is a basic Figure-8 test course that is approximately 470 m (1531 ft) defined by a series of traffic control devices (stop signs and warning arrows), traffic cones, and organic obstacles. Stop signs accompanied by a sign containing red “X” signifies the end of the course.

Test Methods

Procedure

1. Robot is placed at the start position and make sure the course is clear
2. Once safety officer confirms status, start timer and begin run.
3. Drive the test course adhering the rules of the road
4. Avoid obstacles.
5. Follow traffic signs
6. Keep traffic cones on left
7. During test, contact with walls and unsafe driving maneuvers will result in a safety stop.
8. Stop at end the end of course.

Apparatus

This test apparatus is a basic Figure-8 test course that is approximately 470 m (1531 ft) defined by a series of traffic control devices (stop signs and warning arrows), traffic cones, and organic obstacles. Stop signs accompanied by a sign containing red “X” signifies the end of the course.

Test Methods

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4. Avoid obstacles.
5. Follow traffic signs
6. Keep traffic cones on left
7. During test, contact with walls and unsafe driving maneuvers will result in a safety stop.
8. Stop at end the end of course.

99

Human System Interaction: Search Tasks: Random Maze Navigation with Complex Terrain


Purpose

The purpose of this test method is to quantitatively evaluate the maneuvering search capability of a remotely teleoperated robot operating on complex terrain in confined areas in lighted and dark conditions.

Metrics

- Percentage (%) of **targets** correctly identified, incorrectly identified (visual acuity), multiply identified (loss of spatial awareness), or missed (field of view).
- Completion time.

Human System Interaction: Search Tasks: Random Maze Navigation with Complex Terrain


Purpose

The purpose of this test method is to quantitatively evaluate the maneuvering search capability of a remotely teleoperated robot operating on complex terrain in confined areas in lighted and dark conditions.

Metrics

- Percentage (%) of **targets** correctly identified, incorrectly identified (visual acuity), multiply identified (loss of spatial awareness), or missed (field of view).
- Completion time.

100

Apparatus

- This test apparatus is a random maze of 1.2 m (4 ft) wide hallways constructed with 1.2 m x 2.4 m (4 ft x 8 ft) tall OSB walls.
- The overall dimensions are roughly 10 m x 15 m (33 ft x 50 ft).
- The flooring is made of continuous **full and half ramp flooring elements** to provide complexity in robot orientation and operator awareness .
- **Targets** are distributed throughout the maze in quantities unknown to the robot operator.

Procedure

1. Place the robot at the starting position facing into the apparatus.
2. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
3. Start the timer when the robot begins and capture total elapsed time for a complete search ending when the robot returns to the start position.
4. Search the maze to find, identify, and map all targets, contact with the walls is allowed.
5. The robot may return to the start point to allow for maintenance and/or repairs during the test. The timer will be paused during maintenance and an Event Report should be generated.
6. The robot must return to the start point at the end of the test.

Fault Conditions: (Fill out an Event Report)
Failure to return to start point.

Test Methods

Apparatus

- This test apparatus is a random maze of 1.2 m (4 ft) wide hallways constructed with 1.2 m x 2.4 m (4 ft x 8 ft) tall OSB walls.
- The overall dimensions are roughly 10 m x 15 m (33 ft x 50 ft).
- The flooring is made of continuous **full and half ramp flooring elements** to provide complexity in robot orientation and operator awareness .
- **Targets** are distributed throughout the maze in quantities unknown to the robot operator.

Procedure

1. Place the robot at the starting position facing into the apparatus.
2. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
3. Start the timer when the robot begins and capture total elapsed time for a complete search ending when the robot returns to the start position.
4. Search the maze to find, identify, and map all targets, contact with the walls is allowed.
5. The robot may return to the start point to allow for maintenance and/or repairs during the test. The timer will be paused during maintenance and an Event Report should be generated.
6. The robot must return to the start point at the end of the test.

Fault Conditions: (Fill out an Event Report)
Failure to return to start point.

Test Methods

101

Human System Interaction: Search Tasks: Under-Body Voids with Complex Terrain

Purpose

The purpose of this test method is to quantitatively evaluate the camera pointing capability of a remotely teleoperated robot operating underneath a low underpass, such as under a vehicle, with **half ramp terrain elements** and recessed targets in lighted and dark conditions.

Metrics

- Percentage of **targets** successfully identified at each level
- Completion time.

Human System Interaction: Search Tasks: Under-Body Voids with Complex Terrain

Purpose

The purpose of this test method is to quantitatively evaluate the camera pointing capability of a remotely teleoperated robot operating underneath a low underpass, such as under a vehicle, with **half ramp terrain elements** and recessed targets in lighted and dark conditions.

Metrics

- Percentage of **targets** successfully identified at each level
- Completion time.

Apparatus

- The flooring terrain consists of continuous **half ramp terrain elements** setup to provide complexity for camera pointing.
- The ceiling consists of five 1.2 m x 2.4 m (4 ft x 8 ft) OSB panels with four 15 cm (6 in) holes cut in the various patterns, and 5 cm x 10 cm (2 in x 4 in) wood ribbing as occlusions.
- The ceiling panel elevations are adjustable in 10 cm (4 in) increments. This provides variable clearance underneath for different size robots.
- Each hole is covered by an inverted, opaque, 4 liter (1 gallon) can with a **target** inside to provide a recessed inspection task.
- Panels have unique hole locations therefore switching panels changes the hole patterns for the overall test .
- Not all holes are always fitted with cans and not every can has a **target** inside to identify.
- Empty holes are plugged to limit lighting under the ceiling.
- This test apparatus is intended to fit into a 12 m x 2.4 m (40 ft x 8 ft) standard ISO shipping container. It can also be setup as a freestanding apparatus with 1.2 m (4 ft) tall walls with supports.

Test Methods

Procedure

1. Set the ceiling apparatus to the intended clearance elevation for testing. Note panel placement changes on form.
2. Place the robot at the starting position facing the apparatus.
3. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
4. Start the timer to capture total elapsed time for a complete search, ending when the robot returns to the start position.
5. Search the underpass at the elevation to identify all **targets** then return to the start point.
6. Change the **target** locations and/or the ceiling panels. Lower the ceiling one increment of 10 cm (4 in) and repeat.

Fault Conditions: (Fill out an Event Report)

- Failure to return to start point.

Apparatus

- The flooring terrain consists of continuous **half ramp terrain elements** setup to provide complexity for camera pointing.
- The ceiling consists of five 1.2 m x 2.4 m (4 ft x 8 ft) OSB panels with four 15 cm (6 in) holes cut in the various patterns, and 5 cm x 10 cm (2 in x 4 in) wood ribbing as occlusions.
- The ceiling panel elevations are adjustable in 10 cm (4 in) increments. This provides variable clearance underneath for different size robots.
- Each hole is covered by an inverted, opaque, 4 liter (1 gallon) can with a **target** inside to provide a recessed inspection task.
- Panels have unique hole locations therefore switching panels changes the hole patterns for the overall test .
- Not all holes are always fitted with cans and not every can has a **target** inside to identify.
- Empty holes are plugged to limit lighting under the ceiling.
- This test apparatus is intended to fit into a 12 m x 2.4 m (40 ft x 8 ft) standard ISO shipping container. It can also be setup as a freestanding apparatus with 1.2 m (4 ft) tall walls with supports.

Test Methods

Procedure

1. Set the ceiling apparatus to the intended clearance elevation for testing. Note panel placement changes on form.
2. Place the robot at the starting position facing the apparatus.
3. Turn the lights on (>100 lux) or off (<1 lux) if testing in darkness.
4. Start the timer to capture total elapsed time for a complete search, ending when the robot returns to the start position.
5. Search the underpass at the elevation to identify all **targets** then return to the start point.
6. Change the **target** locations and/or the ceiling panels. Lower the ceiling one increment of 10 cm (4 in) and repeat.

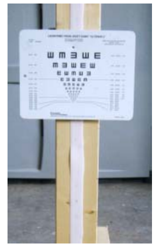
Fault Conditions: (Fill out an Event Report)

- Failure to return to start point.

103

Sensor: Visual:
Acuity and Field of View





Purpose

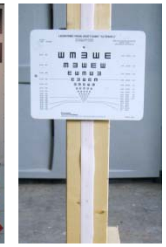
The purpose of this test method is to quantitatively evaluate the color video, visual acuity, field of view (FOV), zooming, and variable illumination capabilities of a remotely teleoperated robot operating in lighted and dark conditions.

Metrics

- Color video capability (check)
- Near field acuity (Snellen fraction)
- Far field acuity (Snellen fraction)
- Field of view (degrees)

Sensor: Visual:
Acuity and Field of View





Purpose

The purpose of this test method is to quantitatively evaluate the color video, visual acuity, field of view (FOV), zooming, and variable illumination capabilities of a remotely teleoperated robot operating in lighted and dark conditions.

Metrics

- Color video capability (check)
- Near field acuity (Snellen fraction)
- Far field acuity (Snellen fraction)
- Field of view (degrees)

Apparatus

- This test apparatus is implemented in a 12 m x 2.4 m (40 ft x 8 ft) standard ISO shipping container.
- No flooring terrain is used.
- Snellen far field eye charts and an assortment of hazmat labels are posted on the wall at the far end of the container, 6 m (20 ft) from the centerline of the container, which is the standard distance for the eye chart usage.
- A Snellen near field eye chart is placed on a free standing pole which allows elevation adjustments for the eye chart to be aligned at 40 cm (16 in) away from the container center line and at the same level as the individual camera on the robot.
- The field of view lines are marked on the wall starting at the far end of the container with 5° separation from the point of view of the robot. Each side ranges from 5° to 60° to accommodate a 120° field of view

Procedure

1. Note the camera features for each camera on the robot as per the form, and measure the lighting to ensure at least 1000 lux.
2. Place the robot at the center of the container anywhere behind the 6 m (20 ft) line. The robot is allowed to move within the container but no part of the robot may cross the line.
3. Measure the field of view of the camera by counting orange lines to the widest angle.
4. Read the eye charts from the 6 m (20 ft) distance and circle the decimal equivalent for the smallest correct line read normally and then with the zoom lens if available.
5. Place the near field chart in front of the robot, 40 cm (16 in) from the line and at the same level as the camera being tested. Read the near field chart and circle smallest correct line read normally and with the zoom lens if available.
6. Repeat with the lights out (<1 lux).
7. Repeat for all cameras on the robot.

Test Methods

Apparatus

- This test apparatus is implemented in a 12 m x 2.4 m (40 ft x 8 ft) standard ISO shipping container.
- No flooring terrain is used.
- Snellen far field eye charts and an assortment of hazmat labels are posted on the wall at the far end of the container, 6 m (20 ft) from the centerline of the container, which is the standard distance for the eye chart usage.
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5. Place the near field chart in front of the robot, 40 cm (16 in) from the line and at the same level as the camera being tested. Read the near field chart and circle smallest correct line read normally and with the zoom lens if available.
6. Repeat with the lights out (<1 lux).
7. Repeat for all cameras on the robot.

105

Sensor: Visual Directed Search: Detailed



Purpose

The purpose of this test method is to quantitatively evaluate the camera pointing capabilities of a remotely teleoperated operating on complex terrain in lighted and dark conditions

Metrics

- Correct identification of the three colors of the smallest diameter cylinders for each **shape totem**.

Sensor: Visual Directed Search: Detailed



Purpose

The purpose of this test method is to quantitatively evaluate the camera pointing capabilities of a remotely teleoperated operating on complex terrain in lighted and dark conditions

Metrics

- Correct identification of the three colors of the smallest diameter cylinders for each **shape totem**.

Apparatus

- This test apparatus is contained in a 2.4 m x 12 m (8 ft x 40 ft) standard ISO shipping container to allow testing in almost complete darkness (< 1 lux) and environmental complexity such as smoke, rain, etc.
- A **full ramp terrain element** with friction surface is placed at the center of the container to maintain the robot on a side roll orientation relative to the major container axes and provide complexity in camera pointing.
- Twenty **shape totems** are placed along the edge of the container, equally spaced at five cross-planes from end to end.
- Each totem contains four cylindrical sections of decreasing diameter 100 mm, 50 mm, 10 mm, 1 mm (4 in, 2 in, 0.4 in, 0.04 in) .
- Each cylinder section is taped in three colors (red, green, and blue) in random order with lengths equal to the cylinder diameter.

Procedure

1. Place the robot on the full ramp terrain element in the center of the container. The robot may rotate but must stay on the ramp during the entirety of the test. If the robot falls off the ramp, the robot must return to the ramp before continuing identification of targets. Use any available cameras.
2. Identify all shape totems by identifying the colors for the smallest visible cylinders. Test administrator will verify over operator's shoulder.
3. Points are given for each diameter cylinder: 1 point for the largest diameter to 4 points for the smallest diameter. Only the smallest correctly identified cylinders are scored for a given shape totem.
4. For each of the 5 targets (around the full ramp terrain element and on the ceiling above the ramp) each identifier is worth 4 point for a total of 20 points available.
5. Repeat with the lights out (<1 lux) if testing in darkness.

Apparatus

- This test apparatus is contained in a 2.4 m x 12 m (8 ft x 40 ft) standard ISO shipping container to allow testing in almost complete darkness (< 1 lux) and environmental complexity such as smoke, rain, etc.
- A **full ramp terrain element** with friction surface is placed at the center of the container to maintain the robot on a side roll orientation relative to the major container axes and provide complexity in camera pointing.
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Test Methods

Procedure

1. Place the robot on the full ramp terrain element in the center of the container. The robot may rotate but must stay on the ramp during the entirety of the test. If the robot falls off the ramp, the robot must return to the ramp before continuing identification of targets. Use any available cameras.
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4. For each of the 5 targets (around the full ramp terrain element and on the ceiling above the ramp) each identifier is worth 4 point for a total of 20 points available.
5. Repeat with the lights out (<1 lux) if testing in darkness.

107

Sensor: Visual Directed Search: Rapid



Purpose

The purpose of this test method is to quantitatively evaluate the camera pointing capabilities of a remotely teleoperated operating on complex terrain in lighted and dark conditions.

Metrics

- Number of **targets** correctly identified.
- Average time per **target**.

Sensor: Visual Directed Search: Rapid



Purpose
The purpose of this test method is to quantitatively evaluate the camera pointing capabilities of a remotely teleoperated operating on complex terrain in lighted and dark conditions.
Metrics
- Number of targets correctly identified.
- Average time per target.
APPARATUS AND PROCEDURE
PROTOTYPE
UNDER DEVELOPMENT
108

Apparatus

- This test apparatus is contained in a 2.4 m x 12 m (8 ft x 40 ft) standard ISO shipping container to allow testing in almost complete darkness (< 1 lux) and environmental complexity such as smoke, rain, etc.
- A **full ramp terrain element** with friction surface is placed at the center of the container to maintain the robot on a side roll orientation relative to the major container axes and provide complexity in camera pointing.
- Twenty **totems** are placed along the edge of the container, equally spaced at five cross-planes from end to end.
- Each totem contains four cylindrical sections of decreasing diameter (100 mm, 50 mm, 10 mm, 1 mm (4 in, 2 in, 0.4 in, 0.04 in)) .
- Each cylinder section is taped in three colors (red, green, and blue) in random order with lengths equal to the cylinder diameter.

Procedure

1. Place the robot on the **full ramp terrain element** in the center of the container. The robot may rotate but must stay on the ramp during the entirety of the test. If the robot falls off the ramp, the robot must return to the ramp before continuing identification of **targets**. Use any available cameras.
2. Indicate a sequence of 10 **targets** alternating from floor to ceiling and front to back. The two required **targets** in the mid-plane are the ceiling **target** and one of the four available ramp **targets**. Pick one floor **target** and one ceiling **target** from each of the other four cross-planes.
3. Record the number of **targets** correctly identified and the elapsed time.
4. Repeat with the lights off (<1 lux).

Fault Conditions: (Fill out an Event Report)

- Failure to identify all 10 **targets** indicated

Apparatus

- This test apparatus is contained in a 2.4 m x 12 m (8 ft x 40 ft) standard ISO shipping container to allow testing in almost complete darkness (< 1 lux) and environmental complexity such as smoke, rain, etc.
- A **full ramp terrain element** with friction surface is placed at the center of the container to maintain the robot on a side roll orientation relative to the major container axes and provide complexity in camera pointing.
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- Each cylinder section is taped in three colors (red, green, and blue) in random order with lengths equal to the cylinder diameter.

Test Methods

Procedure

1. Place the robot on the **full ramp terrain element** in the center of the container. The robot may rotate but must stay on the ramp during the entirety of the test. If the robot falls off the ramp, the robot must return to the ramp before continuing identification of **targets**. Use any available cameras.
2. Indicate a sequence of 10 **targets** alternating from floor to ceiling and front to back. The two required **targets** in the mid-plane are the ceiling **target** and one of the four available ramp **targets**. Pick one floor **target** and one ceiling **target** from each of the other four cross-planes.
3. Record the number of **targets** correctly identified and the elapsed time.
4. Repeat with the lights off (<1 lux).

Fault Conditions: (Fill out an Event Report)

- Failure to identify all 10 **targets** indicated

109

Sensor: Speech Intelligibility Rhyming Words (2-way)

Purpose

The purpose of this test method is to quantitatively evaluate the one/two-way audio capabilities of a remotely teleoperated robot.

Metrics

- Percentage of words correctly identified from lists of standard rhyming words spoken by male and female voices

Sensor: Speech Intelligibility Rhyming Words (2-way)

Purpose

The purpose of this test method is to quantitatively evaluate the one/two-way audio capabilities of a remotely teleoperated robot.

Metrics

- Percentage of words correctly identified from lists of standard rhyming words spoken by male and female voices

Apparatus

- This test apparatus is a set of pre-recorded audio pronunciations from male and female voices speaking standard rhyming words [ANSI S3.2 19/number sets.
- A computer or portable player is need to play randomly select words through a speaker system with a subwoofer.
- The speakers are initially placed 3 m (10 ft) in front of the remote robot the operator to identify at the operator station
- Then the system is reversed so the speakers play words at the operator station microphone for the operator to identify at the robot.
- Then the speakers are placed at the operator station.

Procedure

1. Measure the background audio to ensure it is less than 50 dB.
2. Place the robot at the start point facing the speakers.
3. To test the system from ROBOT TO OPERATOR, play an alternating list of 12 male and 12 female words through the speakers in front of the robot. The words should be randomly generated and equally distributed between male and female. The robot operator should circle the word heard through the OCU on a list of all possible words provided. Headphones are allowed.
4. Reverse the system to test from OPERATOR TO ROBOT by switching the location of the speakers to the OCU and move the operator to the the position 3 m (10 ft) in front of the remote robot.
5. Play a different alternating male and female list of 24 words through the speakers into the OCU microphone. The words should be randomly generated and equally distributed between male and female. The operator should circle the word heard through the robot speaker(s) on a list of all possible words provided.

Test Methods

Apparatus

- This test apparatus is a set of pre-recorded audio pronunciations from male and female voices speaking standard rhyming words [ANSI S3.2 19/number sets.
- A computer or portable player is need to play randomly select words through a speaker system with a subwoofer.
- The speakers are initially placed 3 m (10 ft) in front of the remote robot the operator to identify at the operator station
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4. Reverse the system to test from OPERATOR TO ROBOT by switching the location of the speakers to the OCU and move the operator to the the position 3 m (10 ft) in front of the remote robot.
5. Play a different alternating male and female list of 24 words through the speakers into the OCU microphone. The words should be randomly generated and equally distributed between male and female. The operator should circle the word heard through the robot speaker(s) on a list of all possible words provided.

111

Sensor: Spectrum Response Tones

Purpose

The purpose of this test method is to quantitatively evaluate the one/two-way audio capabilities of a remotely teleoperated robot.

Metrics

- Percentage of input

Sensor: Spectrum Response Tones

Purpose

The purpose of this test method is to quantitatively evaluate the one/two-way audio capabilities of a remotely teleoperated robot.

Metrics

- Percentage of input

APPARATUS AND PROCEDURE
PROTOTYPE
UNDER DEVELOPMENT

112

Apparatus

- This test apparatus includes a sound booth, a loudspeaker measurement system, a personnel audio monitor, a calibrated microphone, and a turntable. During the test, the robot rests on the turntable within the sound booth. The microphone and audio monitor are alternately in the sound booth and station depending on the direction of the test.

Test Methods

Procedure

1. Position the turntable at one end of the sound booth and the audio monitor at the opposite end. The loudspeaker measurement system should be to not interfere with either the sound booth or robot control station.
2. Set up the collection sweep from 20Hz to 14000Hz with a minimum of one reading per octave.
3. Collect initial background levels. Position the microphone on the turntable facing the audio monitor. With the audio monitor disabled, collect an audio sweep.
4. Set output level. With the audio monitor enabled, collect a sequence of audio sweeps. Adjust the monitor output such that the measurements are 30db above background.
5. Collect sound booth background levels. Collect an audio sweep. Rotate the turntable by 45°. Collect an audio sweep at 45°, 90°, 135°, 180°, 225°, 270°, 315°, and again at 0°.
6. Position the robot on the turntable facing the audio monitor. Position the microphone near the robot controller's speakers, where near relates to the common use of the robot control station.
7. Collect control station background levels. With the robot's audio turned off, collect an audio sweep.
8. Collect robot background levels. With the audio monitor turned off, collect an audio sweep.
9. Collect robot radio audio levels. Collect an audio sweep with the turntable at 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°, and again at 0°.
10. Position the microphone in the sound booth and the audio monitor at the robot control station.
11. Collect sound booth background levels. With the robot's audio turned off, collect an audio sweep.
12. Collect control station background levels. With the audio monitor turned off, collect an audio sweep.
13. Collect robot radio audio levels. Collect an audio sweep with the turntable at 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°, and again at 0°.

Apparatus

- This test apparatus includes a sound booth, a loudspeaker measurement system, a personnel audio monitor, a calibrated microphone, and a turntable. During the test, the robot rests on the turntable within the sound booth. The microphone and audio monitor are alternately in the sound booth and station depending on the direction of the test.

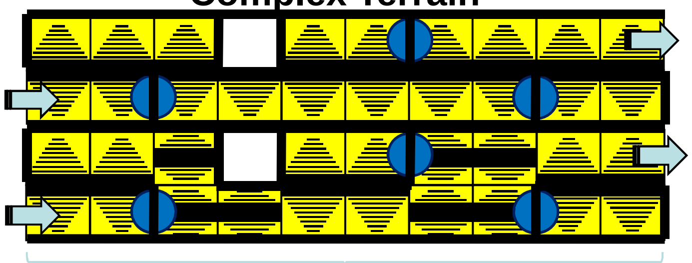
Test Methods

Procedure

1. Position the turntable at one end of the sound booth and the audio monitor at the opposite end. The loud-
2. speaker measurement system should be to not interfere with either the sound booth or robot control station.
3. Set up the collection sweep from 20Hz to 14000Hz with a minimum of one reading per octave.
4. Collect initial background levels. Position the microphone on the turntable facing the audio monitor. With the audio monitor disabled, collect an audio sweep.
5. Set output level. With the audio monitor enabled, collect a sequence of audio sweeps. Adjust the monitor output such that the measurements are 30db above background.
6. Collect sound booth background levels. Collect an audio sweep. Rotate the turntable by 45°. Collect an audio sweep at 45°, 90°, 135°, 180°, 225°, 270°, 315°, and again at 0°.
7. Position the robot on the turntable facing the audio monitor. Position the microphone near the robot controller's speakers, where near relates to the common use of the robot control station.
8. Collect control station background levels. With the robot's audio turned off, collect an audio sweep.
9. Collect robot background levels. With the audio monitor turned off, collect an audio sweep.
10. Collect robot radio audio levels. Collect an audio sweep with the turntable at 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°, and again at 0°.
11. Position the microphone in the sound booth and the audio monitor at the robot control station.
12. Collect sound booth background levels. With the robot's audio turned off, collect an audio sweep.
13. Collect control station background levels. With the audio monitor turned off, collect an audio sweep.
14. Collect robot radio audio levels. Collect an audio sweep with the turntable at 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°, and again at 0°.

113

Sensor: Localization and Mapping Tasks: Hallway Labyrinths with Complex Terrain



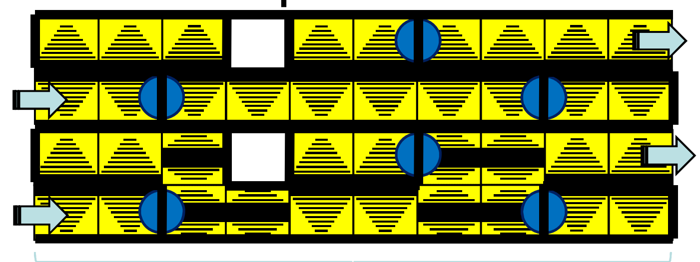
Purpose

The purpose of this test method is to quantitatively evaluate a remotely operated robot capability to efficiently and completely map an unknown, indoor space with moderate terrain complexity ambient and dark conditions.

Metrics

- Coverage – ratio of fiducial elements to total number of fiducial available
- Fiducial Consistency – error between adjoining fiducial elements
- Structural Consistency – error in structural elements
- Relative Accuracy - error between neighboring fiducials
- Global Accuracy – error in locations of fiducials with respect to a fixed coordinate frame
- Relative Displacement – error in pose estimate

Sensor: Localization and Mapping Tasks: Hallway Labyrinths with Complex Terrain



Purpose

The purpose of this test method is to quantitatively evaluate a remotely operated robot capability to efficiently and completely map an unknown, indoor space with moderate terrain complexity ambient and dark conditions.

Metrics

- Coverage – ratio of fiducial elements to total number of fiducial available
- Fiducial Consistency – error between adjoining fiducial elements
- Structural Consistency – error in structural elements
- Relative Accuracy - error between neighboring fiducials
- Global Accuracy – error in locations of fiducials with respect to a fixed coordinate frame
- Relative Displacement – error in pose estimate

APPARATUS AND PROCEDURE
PROTOTYPE
UNDER DEVELOPMENT

114

Apparatus

- This test apparatus is a wall labyrinth constructed with 1.2 x 2.4 m (4 x 8 ft) OSB walls to form 1.2 m (4 ft) with an overall dimension of 12 x 2.4 m (40 x 8 ft). The flooring is made of continuous 15° pitch/roll full and half ramp flooring elements. Fiducial markers, approximately 1.2 m (4 ft) in diameter, will be distributed throughout the labyrinth in quantities unknown to the robot operator.

Procedure

1. Robot is placed at the start position of the closed course apparatus and start timer
2. Traverse labyrinth to find, identify, and map all fiducial markers.
3. During test, contact with walls are allowed. Maintenance and repairs to robot are not permitted.
4. Produce geo-reference map, identifying all fiducial markers
5. Repeat 10 times

Apparatus

- This test apparatus is a wall labyrinth constructed with 1.2 x 2.4 m (4 x 8 ft) OSB walls to form 1.2 m (4 ft) with an overall dimension of 12 x 2.4 m (40 x 8 ft). The flooring is made of continuous 15° pitch/roll full and half ramp flooring elements. Fiducial markers, approximately 1.2 m (4 ft) in diameter, will be distributed throughout the labyrinth in quantities unknown to the robot operator.

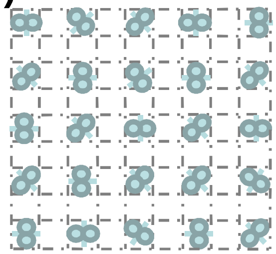
Test Methods

Procedure

1. Robot is placed at the start position of the closed course apparatus and start timer
2. Traverse labyrinth to find, identify, and map all fiducial markers.
3. During test, contact with walls are allowed. Maintenance and repairs to robot are not permitted.
4. Produce geo-reference map, identifying all fiducial markers
5. Repeat 10 times

115

Sensor: Localization and Mapping Tasks: Sparse Feature Maze (Yellow)

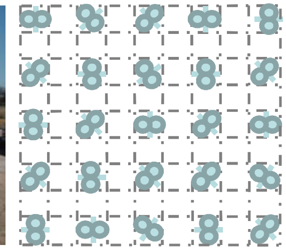
Purpose

The purpose of this test method is to quantitatively evaluate a remotely operated robot capability to efficiently and completely map an unknown space with moderate feature complexities.

Metrics

- Coverage – ratio of fiducial elements to total number of fiducial available
- Fiducial Consistency – error between adjoining fiducial elements
- Structural Consistency – error in structural elements
- Relative Accuracy - error between neighboring fiducials
- Global Accuracy – error in locations of fiducials with respect to a fixed coordinate frame
- Relative Displacement – error in pose estimate

Sensor: Localization and Mapping Tasks: Sparse Feature Maze (Yellow)

Purpose

The purpose of this test method is to quantitatively evaluate a remotely operated robot capability to efficiently and completely map an unknown space with moderate feature complexities.

Metrics

- Coverage – ratio of fiducial elements to total number of fiducial available
- Fiducial Consistency – error between adjoining fiducial elements
- Structural Consistency – error in structural elements
- Relative Accuracy - error between neighboring fiducials
- Global Accuracy – error in locations of fiducials with respect to a fixed coordinate frame
- Relative Displacement – error in pose estimate

Apparatus

- This test apparatus is sparse feature maze is based on the 9 x 9 square grid consisting of 2.4 m (8 ft) cells whose overall dimensions are roughly 19.5 x 19.5 m (64 x 64 ft). Fiducial markers will cover 30% of overall area.

Procedure

1. Robot is placed at the start position of the apparatus and start timer
2. Traverse labyrinth to find, identify, and map all fiducial markers.
3. During test, contact with walls are allowed. Maintenance and repairs to robot are not permitted.
4. Produce geo-reference map, identifying all fiducial markers

Apparatus

- This test apparatus is sparse feature maze is based on the 9 x 9 square grid consisting of 2.4 m (8 ft) cells whose overall dimensions are roughly 19.5 x 19.5 m (64 x 64 ft). Fiducial markers will cover 30% of overall area.

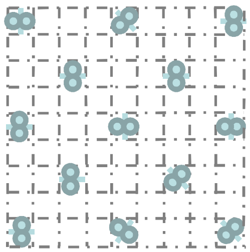
Test Methods

Procedure

1. Robot is placed at the start position of the apparatus and start timer
2. Traverse labyrinth to find, identify, and map all fiducial markers.
3. During test, contact with walls are allowed. Maintenance and repairs to robot are not permitted.
4. Produce geo-reference map, identifying all fiducial markers

117

Sensor: Localization and Mapping Tasks: Sparse Feature Maze (Orange)



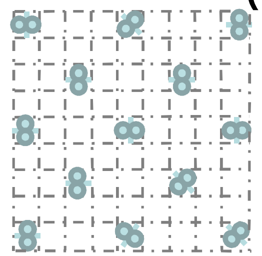
Purpose

The purpose of this test method is to quantitatively evaluate a remotely operated robot capability to efficiently and completely map an unknown space with moderate feature complexities.

Metrics

- Coverage – ratio of fiducial elements to total number of fiducial available
- Fiducial Consistency – error between adjoining fiducial elements
- Structural Consistency – error in structural elements
- Relative Accuracy - error between neighboring fiducials
- Global Accuracy – error in locations of fiducials with respect to a fixed coordinate frame
- Relative Displacement – error in pose estimate

Sensor: Localization and Mapping Tasks: Sparse Feature Maze (Orange)



Purpose
The purpose of this test method is to quantitatively evaluate a remotely operated robot capability to efficiently and completely map an unknown space with moderate feature complexities.
Metrics
- Coverage – ratio of fiducial elements to total number of fiducial available
- Fiducial Consistency – error between adjoining fiducial elements
- Structural Consistency – error in structural elements
- Relative Accuracy - error between neighboring fiducials
- Global Accuracy – error in locations of fiducials with respect to a fixed coordinate frame
- Relative Displacement – error in pose estimate
APPARATUS AND PROCEDURE
PROTOTYPE
UNDER DEVELOPMENT
118

Apparatus

- This test apparatus is sparse feature maze is based on the 9 x 9 square grid consisting of 2.4 m (8 ft) cells whose overall dimensions are roughly 19.5 x 19.5 m (64 x 64 ft). Fiducial markers will cover 16% of overall area.

Procedure

1. Robot is placed at the start position of the apparatus and start timer
2. Traverse labyrinth to find, identify, and map all fiducial markers.
3. During test, contact with walls are allowed. Maintenance and repairs to robot are not permitted.
4. Produce geo-reference map, identifying all fiducial markers

Apparatus

- This test apparatus is sparse feature maze is based on the 9 x 9 square grid consisting of 2.4 m (8 ft) cells whose overall dimensions are roughly 19.5 x 19.5 m (64 x 64 ft). Fiducial markers will cover 16% of overall area.

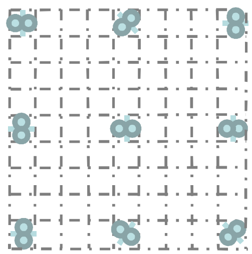
Procedure

1. Robot is placed at the start position of the apparatus and start timer
2. Traverse labyrinth to find, identify, and map all fiducial markers.
3. During test, contact with walls are allowed. Maintenance and repairs to robot are not permitted.
4. Produce geo-reference map, identifying all fiducial markers

Test Methods

119

Sensor: Localization and Mapping Tasks: Sparse Feature Maze (Red)



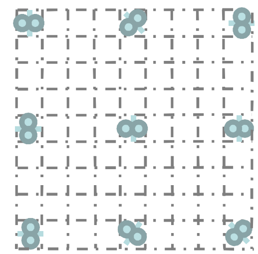
Purpose

The purpose of this test method is to quantitatively evaluate a remotely operated robot capability to efficiently and completely map an unknown space with moderate feature complexities.

Metrics

- Coverage – ratio of fiducial elements to total number of fiducial available
- Fiducial Consistency – error between adjoining fiducial elements
- Structural Consistency – error in structural elements
- Relative Accuracy - error between neighboring fiducials
- Global Accuracy – error in locations of fiducials with respect to a fixed coordinate frame
- Relative Displacement – error in pose estimate

Sensor: Localization and Mapping Tasks: Sparse Feature Maze (Red)



Purpose

The purpose of this test method is to quantitatively evaluate a remotely operated robot capability to efficiently and completely map an unknown space with moderate feature complexities.

Metrics

- Coverage – ratio of fiducial elements to total number of fiducial available
- Fiducial Consistency – error between adjoining fiducial elements
- Structural Consistency – error in structural elements
- Relative Accuracy - error between neighboring fiducials
- Global Accuracy – error in locations of fiducials with respect to a fixed coordinate frame
- Relative Displacement – error in pose estimate

Apparatus

- This test apparatus is sparse feature maze is based on the 9 x 9 square grid consisting of 2.4 m (8 ft) cells whose overall dimensions are roughly 19.5 x 19.5 m (64 x 64 ft). Fiducial markers will cover 11% of overall area.

Procedure

1. Robot is placed at the start position of the apparatus and start timer
2. Traverse labyrinth to find, identify, and map all fiducial markers.
3. During test, contact with walls are allowed. Maintenance and repairs to robot are not permitted.
4. Produce geo-reference map, identifying all fiducial markers

Apparatus

- This test apparatus is sparse feature maze is based on the 9 x 9 square grid consisting of 2.4 m (8 ft) cells whose overall dimensions are roughly 19.5 x 19.5 m (64 x 64 ft). Fiducial markers will cover 11% of overall area.

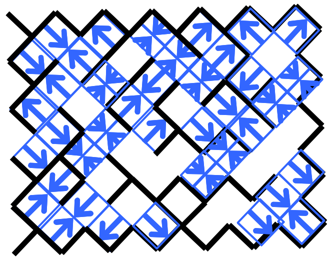
Procedure

1. Robot is placed at the start position of the apparatus and start timer
2. Traverse labyrinth to find, identify, and map all fiducial markers.
3. During test, contact with walls are allowed. Maintenance and repairs to robot are not permitted.
4. Produce geo-reference map, identifying all fiducial markers

Test Methods

121

Sensor: Localization and Mapping Tasks: Random Maze

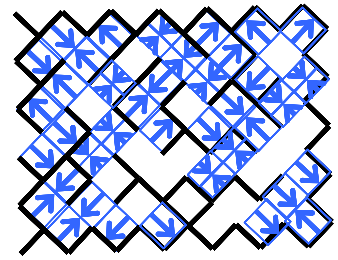
Purpose

The purpose of this test method is to quantitatively evaluate a remotely operated robot capability to efficiently and completely map an unknown space with moderate feature complexities. .

Metrics

- Coverage – ratio of fiducial elements to total number of fiducial available
- Fiducial Consistency – error between adjoining fiducial elements
- Structural Consistency – error in structural elements
- Relative Accuracy - error between neighboring fiducials
- Global Accuracy – error in locations of fiducials with respect to a fixed coordinate frame
- Relative Displacement – error in pose estimate

Sensor: Localization and Mapping Tasks: Random Maze

Purpose

The purpose of this test method is to quantitatively evaluate a remotely operated robot capability to efficiently and completely map an unknown space with moderate feature complexities. .

Metrics

- Coverage – ratio of fiducial elements to total number of fiducial available
- Fiducial Consistency – error between adjoining fiducial elements
- Structural Consistency – error in structural elements
- Relative Accuracy - error between neighboring fiducials
- Global Accuracy – error in locations of fiducials with respect to a fixed coordinate frame
- Relative Displacement – error in pose estimate

Apparatus

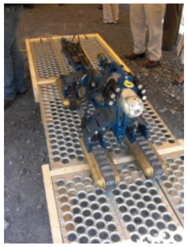
- This test apparatus is a random maze constructed with 1.2 x 2.4 m (4 x 8 ft) OSB walls to form 1.2 m (4 ft) hallways and rooms of variable size (FIGURE B). The overall dimensions are roughly 10 x 15 m (33 x 50 ft) . The flooring is made of continuous 15° pitch/roll full and half ramp flooring elements and in a prescribed configuration (. Mapping elements are white cylindrical objects with a 1 m (1.2 ft) diameter that are distributed throughout the maze in quantities unknown to the robot operator.

Procedure

1. Robot is placed at the start position of the apparatus and start timer
2. Traverse labyrinth to find, identify, and map all fiducial markers.
3. During test, contact with walls are allowed. Maintenance and repairs to robot are not permitted.
4. Produce geo-reference map, identifying all fiducial markers

Apparatus
• This test apparatus is a random maze constructed with 1.2 x 2.4 m (4 x 8 ft) OSB walls to form 1.2 m (4 ft) hallways and rooms of variable size (FIGURE B). The overall dimensions are roughly 10 x 15 m (33 x 50 ft) . The flooring is made of continuous 15° pitch/roll full and half ramp flooring elements and in a prescribed configuration (. Mapping elements are white cylindrical objects with a 1 m (1.2 ft) diameter that are distributed throughout the maze in quantities unknown to the robot operator.
Test Methods
Procedure
1. Robot is placed at the start position of the apparatus and start timer
2. Traverse labyrinth to find, identify, and map all fiducial markers.
3. During test, contact with walls are allowed. Maintenance and repairs to robot are not permitted.
4. Produce geo-reference map, identifying all fiducial markers
123

Safety/Environment: Decontamination



Purpose

The purpose of this test method is to qualitatively evaluate a remotely operated robot's washdown vulnerabilities and identify specific design issues that hinder complete decontamination.

Metrics

- Best practice, involves no metric

Safety/Environment: Decontamination



Purpose

The purpose of this test method is to qualitatively evaluate a remotely operated robot's washdown vulnerabilities and identify specific design issues that hinder complete decontamination.

Metrics

- Best practice, involves no metric

124

Apparatus

- This test uses a simulated contaminant applied consistently over the robot that is invisible in normal lighting, but glows in ultra-violet.
- The apparatus consists of an elevated platform in a washdown tub, a similar elevated platform in a rinsing tub, and an adjoining bridge.
- A low pressure water supply is used along with a set of typical brushes and additional tools used by the emergency responder community.
- A hand-held ultra-violet light source (black light) is also used.

Procedure

1. Contaminate the robot with powder and/or liquid simulants in a controlled area.
2. Drive the robot onto the elevated platform in the washdown tub.
3. Operator decontaminate the robot using water and/or brushes for 5 minutes.
4. Administrator uses the black light to examine for the existence of contaminants out of sight of operator.
5. Repeat steps 3-4 until the robot is free of contaminants or 50 minutes of decontamination elapse.

Apparatus

- This test uses a simulated contaminant applied consistently over the robot that is invisible in normal lighting, but glows in ultra-violet.
- The apparatus consists of an elevated platform in a washdown tub, a similar elevated platform in a rinsing tub, and an adjoining bridge.
- A low pressure water supply is used along with a set of typical brushes and additional tools used by the emergency responder community.
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Procedure

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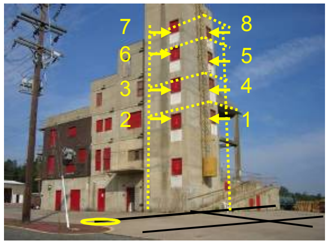
2. Drive the robot onto the elevated platform in the washdown tub.
3. Operator decontaminate the robot using water and/or brushes for 5 minutes.
4. Administrator uses the black light to examine for the existence of contaminants out of sight of operator.
5. Repeat steps 3-4 until the robot is free of contaminants or 50 minutes of decontamination elapse.

125

AERIAL: sUAS (GROUP I) VTOL ENDURANCE



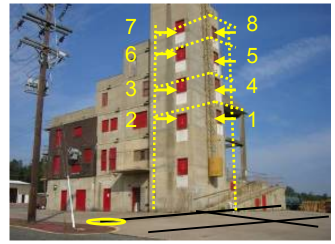
Purpose

The purpose of this test method is to quantitatively evaluate the aerial endurance capabilities of a small unmanned aircraft system (sUAS) with vertical take-off and landing flight operations while being remotely teleoperated in lighted and dark conditions. This test method is intended for Group I sUAS systems defined by the FAA Aviation Rulemaking Committee as having less than 2kg (4.4.bs) gross take-off weight, under 30 knots air speed at full power in level flight, and made in a frangible manner.

Metrics

- Average of smallest correctly read lines via remote video display (an optional still image capture) while hovering near each eye chart for 10 repetitions
- Average time per repetition

AERIAL: sUAS (GROUP I) VTOL ENDURANCE



Purpose

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Metrics

- Average of smallest correctly read lines via remote video display (an optional still image capture) while hovering near each eye chart for 10 repetitions
- Average time per repetition

APPARATUS AND PROCEDURE
PROTOTYPE
UNDER DEVELOPMENT

126

Test Methods

Apparatus

- Five sets of eye charts and hazmat placards and labels (for reference size and color only) .
- Set the targets 5 meters apart to form a square with one at the center .
- Targets should be mounted on a vertical wall and on the ground separately to test forward and downward facing sensors.

Procedure

1. The test should be conducted indoors to control for wind and lighting. However, if conducted outdoors, note the average wind speed and any wind gusts that disrupt target identification stand-offs.
2. Place the robot at the starting position near the operator station 10 meters from the apparatus.
3. Start the timer when the robot begins and capture total elapsed time for a complete set of repetitions at all the available targets identified twice.
4. The targets may be identified in any order, but never the same target sequentially. Robots should maintain a stand-off 2 meters from the target for 20 continuous seconds while identifying
5. Note the average minimum line sizes for all repetitions.
6. (Additional capabilities can also be noted by capturing high-resolution still images for evaluation)

Fault Conditions: (Fill out an Event Report)
Failure to complete 10 continuous repetitions

Test Methods

Apparatus
- Five sets of eye charts and hazmat placards and labels (for reference size and color only) .
- Set the targets 5 meters apart to form a square with one at the center .
- Targets should be mounted on a vertical wall and on the ground separately to test forward and downward facing sensors.

Procedure
1. The test should be conducted indoors to control for wind and lighting. However, if conducted outdoors, note the average wind speed and any wind gusts that disrupt target identification stand-offs.
2. Place the robot at the starting position near the operator station 10 meters from the apparatus.
3. Start the timer when the robot begins and capture total elapsed time for a complete set of repetitions at all the available targets identified twice.
4. The targets may be identified in any order, but never the same target sequentially. Robots should maintain a stand-off 2 meters from the target for 20 continuous seconds while identifying
5. Note the average minimum line sizes for all repetitions.
6. (Additional capabilities can also be noted by capturing high-resolution still images for evaluation)

Fault Conditions: (Fill out an Event Report)
Failure to complete 10 continuous repetitions

127

AERIAL: AERIAL: sUAS (GROUP I) VTOL STATION-KEEPING

Purpose

The purpose of this test method is to quantitatively evaluate the aerial station-keeping capabilities of a small unmanned aircraft system (sUAS) with vertical take-off and landing flight operations, including visual acuity and obstacle avoidance/interaction, while being remotely teleoperated in lighted and dark conditions. This test method is intended for Group I sUAS systems defined by the FAA Aviation Rulemaking Committee as having less than 2kg (4.4.bs) gross take-off weight, under 30 knots air speed at full power in level flight, and made in a frangible manner.

Metrics

- Average of smallest correctly read lines via remote video display (an optional still image capture) while hovering near each eye chart for 10 repetitions
- Average time per repetition

AERIAL: AERIAL: sUAS (GROUP I) VTOL STATION-KEEPING

Purpose

The purpose of this test method is to quantitatively evaluate the aerial station-keeping capabilities of a small unmanned aircraft system (sUAS) with vertical take-off and landing flight operations, including visual acuity and obstacle avoidance/interaction, while being remotely teleoperated in lighted and dark conditions. This test method is intended for Group I sUAS systems defined by the FAA Aviation Rulemaking Committee as having less than 2kg (4.4.bs) gross take-off weight, under 30 knots air speed at full power in level flight, and made in a frangible manner.

Metrics

- Average of smallest correctly read lines via remote video display (an optional still image capture) while hovering near each eye chart for 10 repetitions
- Average time per repetition

APPARATUS AND PROCEDURE
PROTOTYPE
UNDER DEVELOPMENT

128

Apparatus

- Five sets of eye charts and hazmat placards and labels (for reference size and color only) .
- Set the targets 5 meters apart to form a square with one at the center .
- Targets should be mounted on a vertical wall and on the ground separately to test forward and downward facing sensors.

Procedure

1. The test should be conducted indoors to control for wind and lighting. However, if conducted outdoors, note average wind speed and any wind gusts that disrupt target identification.
2. Place the robot at the starting position near the operator station 10 meters from the apparatus.
3. Start the timer when the robot begins and capture total elapsed time for a complete set of repetitions at all the available targets identified twice.
4. The targets may be identified in any order, but never the same target sequentially. Robots should maintain a stand-off 2 meters from the target for 20 continuous seconds while identifying
5. Note the average minimum line sizes for all repetitions.
6. (Additional capabilities can also be noted by capturing high-resolution still images for evaluation)

Fault Conditions: (Fill out an Event Report)
Failure to complete 10 continuous repetitions

Apparatus

- Five sets of eye charts and hazmat placards and labels (for reference size and color only) .
- Set the targets 5 meters apart to form a square with one at the center .
- Targets should be mounted on a vertical wall and on the ground separately to test forward and downward facing sensors.

Procedure

1. The test should be conducted indoors to control for wind and lighting. However, if conducted outdoors, note average wind speed and any wind gusts that disrupt target identification.
2. Place the robot at the starting position near the operator station 10 meters from the apparatus.
3. Start the timer when the robot begins and capture total elapsed time for a complete set of repetitions at all the available targets identified twice.
4. The targets may be identified in any order, but never the same target sequentially. Robots should maintain a stand-off 2 meters from the target for 20 continuous seconds while identifying
5. Note the average minimum line sizes for all repetitions.
6. (Additional capabilities can also be noted by capturing high-resolution still images for evaluation)

Fault Conditions: (Fill out an Event Report)
Failure to complete 10 continuous repetitions

Test Methods

129

Operational Task:
Radio Comms: Nike Site

Purpose

The purpose of this operational task is to quantitatively evaluate the radio communications range, both line of sight (LOS) and non line of sight (NLOS), for a remotely teleoperated robot.

Metrics

- Percent of available stations completed for each task.

Operational Task:
Radio Comms: Nike Site

Purpose

The purpose of this operational task is to quantitatively evaluate the radio communications range, both line of sight (LOS) and non line of sight (NLOS), for a remotely teleoperated robot.

Metrics

- Percent of available stations completed for each task.

130

Apparatus

- The test apparatus for the NIKE Site Radio Comms test is a series of stations placed approximately 100 m (300 ft) from each other along a specified course around the NIKE Site. Each station contains figure-8 paths surrounding **targets**.
- Operator station antennas shall be limited to a maximum of 2 m (6.5 ft) elevation above the ground.

Procedure

1. Place the robot in the start position near the operator station.
2. Traverse downrange to the next test station.
3. Center robot tracks on the figure-8 path and follow the curve, while maintaining line between tracks, until directly in view of a recessed **target** placed at the center of the figure-8. Turn the robot towards the target and use any forward-facing sensor to identify the **target**. Panning of sensors is not allowed. Driving towards the **target** is allowed, but contact with the **target** is not. Return to the figure-8 path and continue around to next **target**.
4. Repeat steps 2 & 3 until a station is reached at which the video or control fails.
5. The radio systems shall be evaluated indirectly by monitoring video and control system relative to a reference LOS distance of 50 m (164 ft).
6. Two-way audio will be tested by an endless loop playing a predetermined set of keywords. Operator will note the line number and which words were audible.

Fault Conditions: (Fill out an Event Report)

- While traversing between **targets** within a station, deviating from prescribed figure-8 path. If robot leaves the line due to latency or other reason, the test is ended at that station.

Apparatus

- The test apparatus for the NIKE Site Radio Comms test is a series of stations placed approximately 100 m (300 ft) from each other along a specified course around the NIKE Site. Each station contains figure-8 paths surrounding **targets**.
- Operator station antennas shall be limited to a maximum of 2 m (6.5 ft) elevation above the ground.

Test Methods

Procedure

1. Place the robot in the start position near the operator station.
2. Traverse downrange to the next test station.
3. Center robot tracks on the figure-8 path and follow the curve, while maintaining line between tracks, until directly in view of a recessed **target** placed at the center of the figure-8. Turn the robot towards the target and use any forward-facing sensor to identify the **target**. Panning of sensors is not allowed. Driving towards the **target** is allowed, but contact with the **target** is not. Return to the figure-8 path and continue around to next **target**.
4. Repeat steps 2 & 3 until a station is reached at which the video or control fails.
5. The radio systems shall be evaluated indirectly by monitoring video and control system relative to a reference LOS distance of 50 m (164 ft).
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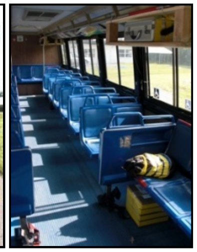
Fault Conditions: (Fill out an Event Report)

- While traversing between **targets** within a station, deviating from prescribed figure-8 path. If robot leaves the line due to latency or other reason, the test is ended at that station.

131

Operational Task: Metrobus Package Removal/Disruption

Purpose

The purpose of this operational task is to demonstrate several elemental test methods within an operational context to perform specified tasks.

Metrics

- Successful removal or disruption of targets.

Operational Task: Metrobus Package Removal/Disruption

Purpose

The purpose of this operational task is to demonstrate several elemental test methods within an operational context to perform specified tasks.

Metrics

- Successful removal or disruption of targets.

Apparatus

- Metrobus with seating and overhead shelves.
- The Metrobus is populated with cases/backpacks weighing 4.5 kg (10 lbs) and 9 kg (20 lbs), and small/large boxes.
- All packages lay flat with handles, if any, facing the seat front, or facing the aisle if located on the shelf and flush with the shelf edge.

Procedure

1. Operator is located in **operator station**.
2. Robot starts 100 m (328 ft) from bus and can be outfitted with trailers or other such payloads to accomplish the task.
3. Task 1 is to remove targets with handles from all possible locations on the bus, transporting them to a location 100 m (328 ft) from the bus.
4. Task 2 is to disrupt in place (align disrupter with target, (simulated)) any targets that cannot be removed from the bus.
5. Locations include: front (wide aisle which allows diagonal approach), mid-bus (narrow aisle which requires working to the side of the robot), and back (wide aisle which allows diagonal approach but with occluded features and farther reach).
6. Elevations include: under seat which is 0 cm to 20 cm (0 in to 8 in), on seat, which is 50 cm to 70 cm (20 in to 28 in), and overhead shelf which is 160 cm to 178 cm (63 in to 70 in).

Apparatus

- Metrobus with seating and overhead shelves.
- The Metrobus is populated with cases/backpacks weighing 4.5 kg (10 lbs) and 9 kg (20 lbs), and small/large boxes.
- All packages lay flat with handles, if any, facing the seat front, or facing the aisle if located on the shelf and flush with the shelf edge.

Procedure

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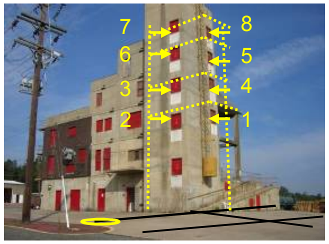
5. Locations include: front (wide aisle which allows diagonal approach), mid-bus (narrow aisle which requires working to the side of the robot), and back (wide aisle which allows diagonal approach but with occluded features and farther reach).
6. Elevations include: under seat which is 0 cm to 20 cm (0 in to 8 in), on seat, which is 50 cm to 70 cm (20 in to 28 in), and overhead shelf which is 160 cm to 178 cm (63 in to 70 in).

Test Methods

133

Operational Task:sUAS (GROUP I) VOTL EXTERIOR BUILDING RECON:



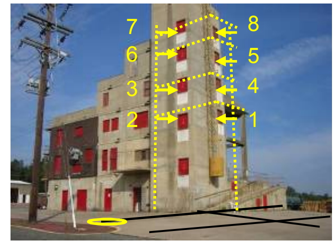
Purpose

The purpose of this operational task is to evaluate the aerial search capabilities of a small unmanned aircraft system (sUAS) with vertical take-off and landing flight operations, including station-keeping, visual acuity, and obstacle avoidance/interaction, while being remotely teleoperated around a multi-story building in lighted and dark conditions. This test method is intended for Group I sUAS systems defined by the FAA Aviation Rulemaking Committee as having less than 2kg (4.4.bs) gross take-off weight, under 30 knots air speed at full power in level flight, and made in a frangible manner..

Metrics

- Successful identification of targets in specified windows.

Operational Task:sUAS (GROUP I) VOTL EXTERIOR BUILDING RECON:



Purpose

The purpose of this operational task is to evaluate the aerial search capabilities of a small unmanned aircraft system (sUAS) with vertical take-off and landing flight operations, including station-keeping, visual acuity, and obstacle avoidance/interaction, while being remotely teleoperated around a multi-story building in lighted and dark conditions. This test method is intended for Group I sUAS systems defined by the FAA Aviation Rulemaking Committee as having less than 2kg (4.4.bs) gross take-off weight, under 30 knots air speed at full power in level flight, and made in a frangible manner..

Metrics

- Successful identification of targets in specified windows.

134

Apparatus

- Multi-story building with three or more floors and some openable windows, preferably on two sides of a building corner to include wind effects. Roof access can provide additional upward-facing target locations.
- Targets within each window should consist of visual acuity charts and hazmat placards (large) and labels (small).
- Four different target viewing conditions should be setup:
    - Open window, flush mounted
    - Open window, recessed 2-meters inside
    - Closed window, flush mounted
    - Closed window, recessed 2-meters inside

Test Methods

Procedure

1. Operator is located in **operator** station 50 meters from building.
2. Robot starts at the designated start position near the operator station.
3. Locate and search each window in the path shown to correctly identify the smallest visual targets possible in as many windows as possible before returning to the the start position to land.

Apparatus

- Multi-story building with three or more floors and some openable windows, preferably on two sides of a building corner to include wind effects. Roof access can provide additional upward-facing target locations.
- Targets within each window should consist of visual acuity charts and hazmat placards (large) and labels (small).
- Four different target viewing conditions should be setup:
    - Open window, flush mounted
    - Open window, recessed 2-meters inside
    - Closed window, flush mounted
    - Closed window, recessed 2-meters inside

Test Methods

Procedure

1. Operator is located in **operator** station 50 meters from building.
2. Robot starts at the designated start position near the operator station.
3. Locate and search each window in the path shown to correctly identify the smallest visual targets possible in as many windows as possible before returning to the the start position to land.

Underwater Navigation and Search

Maneuvering Aquatic


Purpose

The purpose of this test method is to quantitatively evaluate robot's ability to provide video of a underwater environment to facilitate operator's ability to gain spatial awareness and to conduct teleoperated search. This test method allows direct comparisons across different robot models and particular configurations of similar robot models.

Metrics

Whether reaching the end point or not; time used; number of targets correctly and incorrectly identified, missed, or multiply identified

Underwater Navigation and Search

Maneuvering Aquatic


Purpose

The purpose of this test method is to quantitatively evaluate robot's ability to provide video of a underwater environment to facilitate operator's ability to gain spatial awareness and to conduct teleoperated search. This test method allows direct comparisons across different robot models and particular configurations of similar robot models.

Metrics

Whether reaching the end point or not; time used; number of targets correctly and incorrectly identified, missed, or multiply identified

136

Apparatus

This test apparatus is implemented in lake or river . A set of standardized objects is used and individual objects can be randomly ordered.

Procedure

1. Operator place the robot at the starting point.
2. Teleoperate robot underwater and search the pre-placed objects until all the objects are identified, time expires, or for any other reason when the robot is not able to continue the search.

Test Methods

Apparatus

This test apparatus is implemented in lake or river . A set of standardized objects is used and individual objects can be randomly ordered.

Procedure

1. Operator place the robot at the starting point.
2. Teleoperate robot underwater and search the pre-placed objects until all the objects are identified, time expires, or for any other reason when the robot is not able to continue the search.

Test Methods

137

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Ground Robots

Ground Robots

Ground
Robots

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Recon Scout

ReconRobotics, Inc.
http://www.reconrobotics.com


Manufacturer's Specs:

Width:	3 in (7.6 cm)
Length:	7.36 in (18.7 cm)
Height:	3 in (7.6 cm)
Weight:	1.2 lbs (544 g)
Steering:	Two-wheel independent
Turning Diam:	0 in (0 cm)
Max Speed:	1 fps (0.3 mps)
Power Source:	11.4 V DC Lithium Polymer
Endurance:	60 minutes
Tether:	Wireless
Control:	Remote teleop
Sensors:	InfraRed, camera
Payload:	N/A
Manipulator:	N/A

* Has not attended any exercises to date

Radio Tx: 433 MHz / 250 mW (video), 75 MHz / 250 mW (command)
Radio Rx: 433 MHz / 250 mW (video), 75 MHz / 250 mW (command)

Recon Scout

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http://www.reconrobotics.com


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Endurance:	60 minutes
Tether:	Wireless
Control:	Remote teleop
Sensors:	InfraRed, camera
Payload:	N/A
Manipulator:	N/A

* Has not attended any exercises to date

Radio Tx: 433 MHz / 250 mW (video), 75 MHz / 250 mW (command)
Radio Rx: 433 MHz / 250 mW (video), 75 MHz / 250 mW (command)

EyeBall R1

O.D.F. Optronics
www.odfopt.com
336-302-9309/ilanit Gedalyoviche

Ground Robots

Manufacturer's Specs:

- Circumference: 3.25 in (8.25 cm)
- Weight: 1.25 lbs (.566kg)
- Turning Diam: 0 in
- Max Speed: rotates 4 RPM
- Power Source: battery
- Endurance: 3 hours
- Tether: none
- Control: eyes-on, remote teleop
- Sensors: camera
- Payload: N/A
- Manipulator: N/A

Radio Tx:	2400 MHz, 902-928MHz (RF)
Radio Rx:	2400 MHz, 902-928MHz (RF)

EyeBall R1

O.D.F. Optronics
www.odfopt.com
336-302-9309/ilanit Gedalyoviche

Ground Robots

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- Power Source: battery
- Endurance: 3 hours
- Tether: none
- Control: eyes-on, remote teleop
- Sensors: camera
- Payload: N/A
- Manipulator: N/A

Radio Tx:	2400 MHz, 902-928MHz (RF)
Radio Rx:	2400 MHz, 902-928MHz (RF)

141

ToughBot

Omnitech Robotics International LLC
www.omnitech.com
303-922-7773/Dave Parish

Manufacturer's Specs:

- Width: 3.14 in (8 cm)
- Length: 4.3 in (11 cm)
- Height: 4.3 in (11 cm)
- Weight: 2 lb (.9 kg)
- Turning Diam: 0 in
- Max Speed: TBD
- Power Source: battery
- Endurance: 1 hour
- Tether: none
- Control: eyes-on, remote teleop
- Sensors: 2 camera (wide and narrow)
- Payload: N/A
- Manipulator: N/A

Radio Tx:	2400 MHz, 868MHz
Radio Rx:	2400 MHz, 868MHz

ToughBot
Omnitech Robotics International LLC
www.omnitech.com
303-922-7773/Dave Parish

Manufacturer's Specs:

- Width: 3.14 in (8 cm)
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- Power Source: battery
- Endurance: 1 hour
- Tether: none
- Control: eyes-on, remote teleop
- Sensors: 2 camera (wide and narrow)
- Payload: N/A
- Manipulator: N/A

Radio Tx: 2400 MHz, 868MHz
Radio Rx: 2400 MHz, 868MHz

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Active Scope Camera

Tohoku University, Tadokoro Laboratory
www.rm.is.tohoku.ac.jp

Ground Robots

Manufacturer's Specs:

- Width: 1 in (2.5cm)
- Length: 320 in (80 cm)
- Height: 1 in (2.5 cm)
- Weight: 13 lbs (5.9 kg)
- Turning Dia: 6 in – 80 in (15 cm – 200 cm)
- Max Speed: .2 fps (60 mmps)
- Power Source: battery
- Endurance: 60 min
- Tether: body is the tether
- Control: teleop
- Sensors: CCD camera
- Payload: N/A
- Manipulator: N/A

Radio TX: Tethered
Radio RX:

Active Scope Camera

Tohoku University, Tadokoro Laboratory
www.rm.is.tohoku.ac.jp

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- Max Speed: .2 fps (60 mmps)
- Power Source: battery
- Endurance: 60 min
- Tether: body is the tether
- Control: teleop
- Sensors: CCD camera
- Payload: N/A
- Manipulator: N/A

Radio TX: Tethered
Radio RX:

143

Pointman (LRV)

Applied Research Associates
www.ARA.com
303-795-8106/Andrew Poulter

Manufacturer's Specs:

- Width: 20 in (51 cm)
- Length: 14 in (36 cm)
- Height: 6.5 in (16 cm)
- Weight: 14 lbs (6.3 kg)
- Turning Diam: 20 in (51 cm)
- Max Speed: 6 fps (1.8 mps)
- Power Source: 8.5 AH Lithium Polymer
- Endurance: 60-240 min
- Tether: Option
- Control: Remote tele-operation
- Sensors: Color / IR Cameras
- Payload: 1.2 lb(0.5 kg) , drag 20 lb (9 kg)
- Manipulator: N/A –future option, existing boom reach is 18 in (45 cm

Radio Tx: 75MHz(75mW), 900 MHz(100mW),2400MHz(200mW)
Radio Rx: 75 MHz , 900 MHz , 2400 MHz

Pointman (LRV)

Applied Research Associates
www.ARA.com
303-795-8106/Andrew Poulter

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- Width: 20 in (51 cm)
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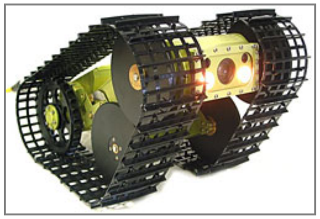
- Sensors: Color / IR Cameras
- Payload: 1.2 lb(0.5 kg) , drag 20 lb (9 kg)
- Manipulator: N/A –future option, existing boom reach is 18 in (45 cm

Radio Tx: 75MHz(75mW), 900 MHz(100mW),2400MHz(200mW)
Radio Rx: 75 MHz , 900 MHz , 2400 MHz

144

VGTV-Extreme

Inuktun
www.inuktun.com/
1-877-468-5886/ Derek Naughton



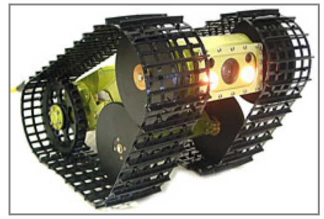
Ground Robots

Manufacturer's Specs:

- Width: 10.9 in (27.7 cm)
- Length: 16.8 in (42.7 cm)
- Height: 5.5 in (14 cm) Lowered
- Weight: 14-20 lbs(6.2-9.1kg)
- Turning Diam: 0 in (0 cm)
- Max Speed: 1.5 fps (.45 mps)
- Power Source: lithium ion battery
- Endurance: >360 min
- Tether: power, comms
- Control: eyes-on, remote teleop
- Sensors: tilt camera 300º
- Payload: 10 lb (4.5 kg)
- Manipulator: N/A

Radio Tx: (tether only)
Radio Rx: (tether only)

VGTV-Extreme
Inuktun
www.inuktun.com/
1-877-468-5886/ Derek Naughton



Ground Robots

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- Length: 16.8 in (42.7 cm)
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- Weight: 14-20 lbs(6.2-9.1kg)
- Turning Diam: 0 in (0 cm)
- Max Speed: 1.5 fps (.45 mps)
- Power Source: lithium ion battery
- Endurance: >360 min
- Tether: power, comms
- Control: eyes-on, remote teleop
- Sensors: tilt camera 300º
- Payload: 10 lb (4.5 kg)
- Manipulator: N/A

Radio Tx: (tether only)
Radio Rx: (tether only)

145

Dragon Runner SUGV

Qinetiq North America / Foster-Miller Inc
www.foster-miller.com/lemming.htm
781-684-3960

Manufacturer's Specs:

- Width: 12.2 in (31 cm)
- Length: 16.6 in (42 cm)
- Height: 6 in (15.2 cm)
- Weight: 14 lbs (6.4 kg)
- Turning Diam: Zero-Turn; Swept
- Max Speed: 7.5 - 29 fps (5 - 20 mph)
- Power Source: battery (Li Ion)
- Endurance: 2 hours mph on flat ground
- Tether: none
- Control: remote teleop, loss-of-comms back-tracking, cruise-control
- Sensors: thermal (PIR), acoustic, visual (wide-angle FF lens; IR illuminator)
- Payload: 10 lb (4.5 kg)
- Manipulator: 2 or 3 degree of motion w/gripper

Radio Tx: Low S-Band MHz(1 – 1k mW)L-Band MHz (1–1K mW)
Radio Rx: n/a

Dragon Runner SUGV

Qinetiq North America / Foster-Miller Inc
www.foster-miller.com/lemming.htm
781-684-3960/Joanne Arms

Manufacturer's Specs:

- Width: 12.2 in (31 cm)
- Length: 16.6 in (42 cm)
- Height: 6 in (15.2 cm)
- Weight: 14 lbs (6.4 kg)
- Turning Diam: Zero-Turn; Swept
- Max Speed: 7.5 - 29 fps (5 - 20 mph)
- Power Source: battery (Li Ion)
- Endurance: 2 hours mph on flat ground
- Tether: none
- Control: remote teleop, loss-of-comms back-tracking, cruise-control
- Sensors: thermal (PIR), acoustic, visual (wide-angle FF lens; IR illuminator)
- Payload: 10 lb (4.5 kg)
- Manipulator: 2 or 3 degree of motion w/gripper

Radio Tx: Low S-Band MHz(1 – 1k mW)L-Band MHz (1–1K mW)
Radio Rx: n/a

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BomBot

WVHTC Foundation
www.wvhtf.org
304-333-6461/Brian Stolarik


Ground Robots

Manufacturer's Specs:

- Width: 18 in (45.72 cm)
- Length: 20 in (50.8 cm)
- Height: 32 in (81.28 cm)
- Weight: 15 lbs (6.8kg)
- Turning Diam: 2ft. (60.96 cm)
- Max Speed: 20 mph (32 km/hr)
- Power Source: battery
- Endurance: 3-4 hrs.
- Tether: none
- Control: eyes-on, remote teleop
- Sensors: none
- Payload: 10 lbs (4.5kg)
- Manipulator: N/A

Radio Tx: 2400 MHz
Radio Rx: 2400 MHz

BomBot

WVHTC Foundation
www.wvhtf.org
304-333-6461/Brian Stolarik


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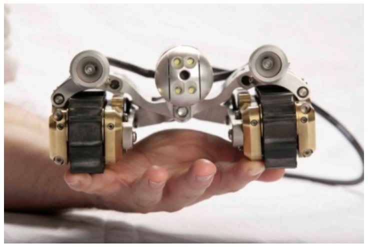
- Length: 20 in (50.8 cm)
- Height: 32 in (81.28 cm)
- Weight: 15 lbs (6.8kg)
- Turning Diam: 2ft. (60.96 cm)
- Max Speed: 20 mph (32 km/hr)
- Power Source: battery
- Endurance: 3-4 hrs.
- Tether: none
- Control: eyes-on, remote teleop
- Sensors: none
- Payload: 10 lbs (4.5kg)
- Manipulator: N/A

Radio Tx: 2400 MHz
Radio Rx: 2400 MHz

147

Versatrax 100

SeaTrepid
www.inuktun.com
Bob Christ



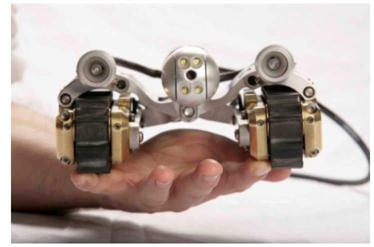
Manufacturer's Specs:

• Width:	Inline: 4 in (10 cm)
•	Parallel: 5.5 in (14cm)&larger
• Length:	Inline: 34.6 in (87.88cm)
•	Parallel: 9.5 in (24cm)
• Height:	Inline: 4 in (10 cm)
•	Parallel: 5 in (12.7 cm)
• Weight:	20 lbs (9 kg)
• Steering:	Skid steering
• Turning Diam:	Various; depending on pipe diameters
• Max Speed:	32 fpm (10 mpm)
• Power Source:	88-264 VAC 50/60 Hz
• Endurance:	Continuous
• Tether:	Power and comms
• Control:	Remote teleop
• Sensors:	N/A
• Payload:	N/A
• Manipulator:	N/A

Radio TX:
Radio RX:

Versatrax 100

SeaTrepid
www.inuktun.com
Bob Christ



Manufacturer's Specs:

• Width:	Inline: 4 in (10 cm)
•	Parallel: 5.5 in (14cm)&larger
• Length:	Inline: 34.6 in (87.88cm)
•	Parallel: 9.5 in (24cm)
• Height:	Inline: 4 in (10 cm)
•	Parallel: 5 in (12.7 cm)
• Weight:	20 lbs (9 kg)
• Steering:	Skid steering
• Turning Diam:	Various; depending on pipe diameters
• Max Speed:	32 fpm (10 mpm)
• Power Source:	88-264 VAC 50/60 Hz
• Endurance:	Continuous
• Tether:	Power and comms
• Control:	Remote teleop
• Sensors:	N/A
• Payload:	N/A
• Manipulator:	N/A

Radio TX:
Radio RX:

G2Bot

Mesa Robotics, Inc.
www.mesa-robotics.com
256.258.2130/Toki Owens


Manufacturer's Specs:

- Width: 13.5 in (34.29 cm)
- Length: 21 in (53.34 cm)
- Height: 12 in (30.48 cm)
- Weight: 25 lbs (11.33 kg)
- Turning Dia: 21 in (53.34 cm)
- Max Speed: 4 mph (6.4 km/hr)
- Power Source: 12VDC, NiMH battery
- Endurance: 60 – 120 min
- Tether: none
- Control: rf 700 meters
- Sensors: Cameras
- Payload: 15 lbs (6.80 kg)
- Manipulator: none

Radio TX: 900 MHz control, 2400 MHz video
Radio RX: 900 MHz control, 2400 MHz video

G2Bot

Mesa Robotics, Inc.
www.mesa-robotics.com
256.258.2130/Toki Owens


Ground Robots

Manufacturer's Specs:

- Width: 13.5 in (34.29 cm)
- Length: 21 in (53.34 cm)
- Height: 12 in (30.48 cm)
- Weight: 25 lbs (11.33 kg)
- Turning Dia: 21 in (53.34 cm)
- Max Speed: 4 mph (6.4 km/hr)
- Power Source: 12VDC, NiMH battery
- Endurance: 60 – 120 min
- Tether: none
- Control: rf 700 meters
- Sensors: Cameras
- Payload: 15 lbs (6.80 kg)
- Manipulator: none

Radio TX: 900 MHz control, 2400 MHz video
Radio RX: 900 MHz control, 2400 MHz video

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Marv

Mesa Robotics, Inc.
www.mesa-robotics.com
256-464-7252/Mike Cole


Manufacturer's Specs:

- Width: 13.5 in (34.29 cm)
- Length: 20.5 in (52.07 cm)
- Height: 12 in (30.48 cm)
- Weight: 25 lbs (11.33 kg)
- Turning Dia: zero in
- Max Speed: 4 mph (6.4 km/hr)
- Power Source: 12VDC, NiMH battery
- Endurance: 60 – 120 min
- Tether: none
- Control: remote teleop
- Sensors: future option
- Payload: 10 lbs (4.5 kg)
- Manipulator: future option

Radio TX: 900 MHz control, 2400 MHz video
Radio RX: 900 MHz control, 2400 MHz video

Marv

Mesa Robotics, Inc.
www.mesa-robotics.com
256-464-7252/Mike Cole


Manufacturer's Specs:

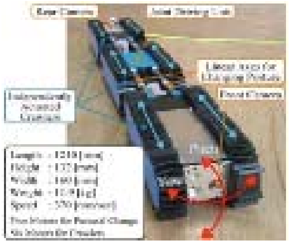
- Width: 13.5 in (34.29 cm)
- Length: 20.5 in (52.07 cm)
- Height: 12 in (30.48 cm)
- Weight: 25 lbs (11.33 kg)
- Turning Dia: zero in
- Max Speed: 4 mph (6.4 km/hr)
- Power Source: 12VDC, NiMH battery
- Endurance: 60 – 120 min
- Tether: none
- Control: remote teleop
- Sensors: future option
- Payload: 10 lbs (4.5 kg)
- Manipulator: future option

Radio TX: 900 MHz control, 2400 MHz video
Radio RX: 900 MHz control, 2400 MHz video

150

Souryu IV

International Rescue System Institute
www.rescuesystem.org
Shigeo Hirose

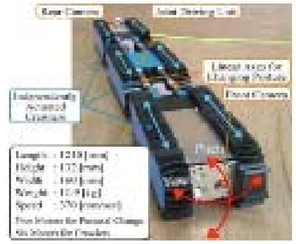


Ground Robots

Manufacturer's Specs:

•	Width:	5.9 in (16 cm)
•	Length:	47.2 in (121 cm)
•	Height:	5.1 in (13 cm)
•	Weight:	28.6 lbs (112 kg)
•	Turning Diam:	1.0 m
•	Max Speed:	370mm/sec
•	Power Source:	battery
•	Endurance:	
•	Tether:	comms
•	Control:	remote teleop
•	Sensors:	camera
•	Payload:	none
•	Manipulator:	none

Radio Tx: (tether only)
Radio Rx: (tether only)



Souryu IV
International Rescue System Institute
www.rescuesystem.org
Shigeo Hirose
Ground Robots
Manufacturer's Specs:
• Width: 5.9 in (16 cm)
• Length: 47.2 in (121 cm)
• Height: 5.1 in (13 cm)
• Weight: 28.6 lbs (112 kg)
• Turning Diam: 1.0 m
• Max Speed: 370mm/sec
• Power Source: battery
• Endurance:
• Tether: comms
• Control: remote teleop
• Sensors: camera
• Payload: none
• Manipulator: none
Radio Tx: (tether only)
Radio Rx: (tether only)
151

Souryu

International Rescue System Institute
www.rescuesystem.org
Shigeo Hirose

Manufacturer's Specs:

- Width: 5.9 in (15 cm)
- Length: 47.2 in (120 cm)
- Height: 5.1 in (13 cm)
- Weight: 28.6 lbs (13 kg)
- Turning Diam: 1.0 m
- Max Speed: 0.3 mps
- Power Source: battery
- Endurance: 20 min
- Tether: comms
- Control: remote teleop
- Sensors: thermal, camera, GAS(CO, O2, SO, CH)
- Payload: none
- Manipulator: none

Radio Tx: (tether only)
Radio Rx: (tether only)

Souryu

International Rescue System Institute
www.rescuesystem.org
Shigeo Hirose

Manufacturer's Specs:

- Width: 5.9 in (15 cm)
- Length: 47.2 in (120 cm)
- Height: 5.1 in (13 cm)
- Weight: 28.6 lbs (13 kg)
- Turning Diam: 1.0 m
- Max Speed: 0.3 mps
- Power Source: battery
- Endurance: 20 min
- Tether: comms
- Control: remote teleop
- Sensors: thermal, camera, GAS(CO, O2, SO, CH)
- Payload: none
- Manipulator: none

Radio Tx: (tether only)
Radio Rx: (tether only)

BomBot 2

WVHTC Foundation
www.wvhtf.org
304-333-6461/Brian Stolarik

Ground Robots

Manufacturer's Specs:

- Width: 19.5 in (49.5 cm)
- Length: 22.8 in (57.8 cm)
- Height: 10 in- 23 in (25.4 -58.4 cm)
- Weight: 30 lbs (13.6 kg)
- Turning Diam: 110 in (280 cm)
- Max Speed: 14.6 fps (4.5 mps)
- Power Source: 24VDC BB2590 or BB390 battery (2 vehicle, 1 OCU); 1.5V AA (4 in OCU)
- Endurance: 180 mins
- Tether: none
- Control: Remote teleoperation, line-of-sight
- Sensors: Wide-angle surveillance camera (modular mission plate to adapt sensors)
- Payload: 45 lbs (20.4 kg) on mission plate, 60 lbs (27.2 kg) towed (optional wagon)
- Manipulator: N/A

Radio TX: 2.4MHz/430MHz

BomBot 2

WVHTC Foundation
www.wvhtf.org
304-333-6461/Brian Stolarik

Ground Robots

Manufacturer's Specs:

- Width: 19.5 in (49.5 cm)
- Length: 22.8 in (57.8 cm)
- Height: 10 in- 23 in (25.4 -58.4 cm)
- Weight: 30 lbs (13.6 kg)
- Turning Diam: 110 in (280 cm)
- Max Speed: 14.6 fps (4.5 mps)
- Power Source: 24VDC BB2590 or BB390 battery (2 vehicle, 1 OCU); 1.5V AA (4 in OCU)
- Endurance: 180 mins
- Tether: none
- Control: Remote teleoperation, line-of-sight
- Sensors: Wide-angle surveillance camera (modular mission plate to adapt sensors)
- Payload: 45 lbs (20.4 kg) on mission plate, 60 lbs (27.2 kg) towed (optional wagon)
- Manipulator: N/A

Radio TX: 2.4MHz/430MHz

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Souryu V

International Rescue System Institute
www.rescuesystem.org
Shigeo Hirose

Manufacturer's Specs:

- Width: 7.9 in (20.2 cm)
- Length: 45.6 in – 54.3 in (116 - 138 cm)
- Height: 5.7 in (14.5 cm)
- Weight: 37.47 lbs (17 kg)
- Turning Diam: 50.3 in (128 cm)
- Max Speed: 0.25 mps
- Power Source: battery (14.4V, 7400mAh)
- Endurance: 40 min
- Tether: comms
- Control: remote teleop
- Sensors: Camera
- Payload: unknown
- Manipulator: none

Radio Tx: (tether only)
Radio Rx: (tether only)

Souryu V

International Rescue System Institute
www.rescuesystem.org
Shigeo Hirose

Manufacturer's Specs:

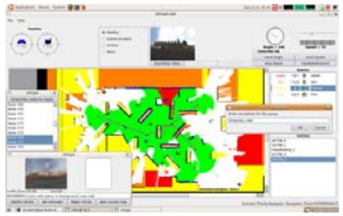
- Width: 7.9 in (20.2 cm)
- Length: 45.6 in – 54.3 in (116 - 138 cm)
- Height: 5.7 in (14.5 cm)
- Weight: 37.47 lbs (17 kg)
- Turning Diam: 50.3 in (128 cm)
- Max Speed: 0.25 mps
- Power Source: battery (14.4V, 7400mAh)
- Endurance: 40 min
- Tether: comms
- Control: remote teleop
- Sensors: Camera
- Payload: unknown
- Manipulator: none

Radio Tx: (tether only)
Radio Rx: (tether only)

154

Jacobs Rugged Robot

Jacobs University, Robotics Group, Bremen, Germany
http://robotics.jacobs-university.de
Prof. Dr. Andreas Birk



Ground Robots

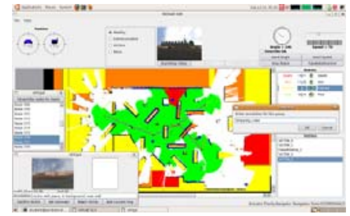
Manufacturer's Specs:

Width:	20.31 in (51.6 cm)
Length:	21.06 in (53.5 cm) -37.20 in (94.5 cm)
Height:	19.69 in (50 cm)
Weight:	39.68 lbs (18 kg)
Steering:	skid
Turning Diam:	0
Max Speed:	2.8 m/s (10.1 Km/h)
Power Source:	LiPo Batteries, 173 Wh
Endurance:	2 hours
Tether:	optional, solely for communication
Control:	autonomous/teleoperation
Sensors:	Hokuyo/Sick /FLIR
Payload:	55.12 lbs (25kg)
Manipulator:	optional Neuronics Katana arm (6 DOF, 37.4 in (95 cm) reach)

Radio Tx: 802.11 bg / a (2.4 GHz / 5.0 GHz)
Radio Rx: 802.11 bg / a (2.4 GHz / 5.0 GHz)

Jacobs Rugged Robot

Jacobs University, Robotics Group, Bremen, Germany
http://robotics.jacobs-university.de
Prof. Dr. Andreas Birk



Ground Robots

Manufacturer's Specs:

Width:	20.31 in (51.6 cm)
Length:	21.06 in (53.5 cm) -37.20 in (94.5 cm)
Height:	19.69 in (50 cm)
Weight:	39.68 lbs (18 kg)
Steering:	skid
Turning Diam:	0
Max Speed:	2.8 m/s (10.1 Km/h)
Power Source:	LiPo Batteries, 173 Wh
Endurance:	2 hours
Tether:	optional, solely for communication
Control:	autonomous/teleoperation
Sensors:	Hokuyo/Sick /FLIR
Payload:	55.12 lbs (25kg)
Manipulator:	optional Neuronics Katana arm (6 DOF, 37.4 in (95 cm) reach)

Radio Tx: 802.11 bg / a (2.4 GHz / 5.0 GHz)
Radio Rx: 802.11 bg / a (2.4 GHz / 5.0 GHz)

155

Element

Mesa Robotics, Inc.
www.mesa-robotics.com
256-258-2130/Don Jones

Manufacturer's Specs:

- Width: 21 in (53.34 cm)
- Length: 30 in (76.2cm)
- Height: 12 in (30.48 cm)
- Weight: 40 lbs (18 kg)
- Turning Dia: zero
- Max Speed: 2.0 mph
- Power Source: 12VCD battery, NiMH
- Endurance: 360 – 480 min
- Tether: fiber optic cable (data,video, audio)
- Control: remote teleop
- Sensors: biological, chemical, radiological
- Payload: 125 lbs
- Manipulator: 5 DOF with 44 in reach (adds 45lbs/20.4kg to weight)

Radio TX: 900 MHz control, 1800 MHz video, 469 MHz audio
Radio RX: 900 MHz control, 1800 MHz video, 469 MHz audio

Element

Mesa Robotics, Inc.
www.mesa-robotics.com
256-258-2130/Don Jones

Manufacturer's Specs:

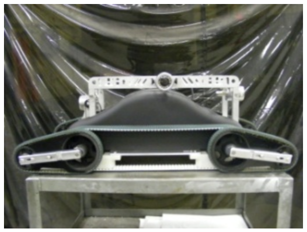
- Width: 21 in (53.34 cm)
- Length: 30 in (76.2cm)
- Height: 12 in (30.48 cm)
- Weight: 40 lbs (18 kg)
- Turning Dia: zero
- Max Speed: 2.0 mph
- Power Source: 12VCD battery, NiMH
- Endurance: 360 – 480 min
- Tether: fiber optic cable (data,video, audio)
- Control: remote teleop
- Sensors: biological, chemical, radiological
- Payload: 125 lbs
- Manipulator: 5 DOF with 44 in reach (adds 45lbs/20.4kg to weight)

Radio TX: 900 MHz control, 1800 MHz video, 469 MHz audio
Radio RX: 900 MHz control, 1800 MHz video, 469 MHz audio

156

Hero

First-Response Robotics, LLC
www.FirstResponseRobotics.com
513-752-6653 /Mike Cardarelli




Ground Robots

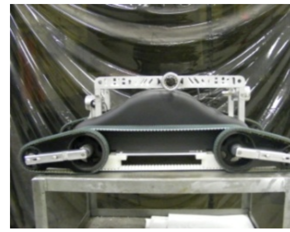
Manufacturer's Specs:

• Width:	21 in (53 cm)
• Length:	36 in (91 cm)
• Height:	17 in (43 cm)
• Weight:	42 lbs (19 kg)
• Turning Diam:	0 m (0 cm)
• Max Speed:	10 fps (3 mps)
• Power Source:	battery
• Endurance:	45 min
• Tether:	none
• Control:	remote teleop
• Sensors:	radiation, biological
• Payload:	130 lb (59 kg)
• Manipulator:	none

Radio TX: 72 MHz controller/1.0W (video), 2.4 MHz
900 MHz/0.5 W (telemetry), 1.2 MHz / 3W (video)

Hero

First-Response Robotics, LLC
www.FirstResponseRobotics.com
513-752-6653 /Mike Cardarelli




Ground Robots

Manufacturer's Specs:

• Width:	21 in (53 cm)
• Length:	36 in (91 cm)
• Height:	17 in (43 cm)
• Weight:	42 lbs (19 kg)
• Turning Diam:	0 m (0 cm)
• Max Speed:	10 fps (3 mps)
• Power Source:	battery
• Endurance:	45 min
• Tether:	none
• Control:	remote teleop
• Sensors:	radiation, biological
• Payload:	130 lb (59 kg)
• Manipulator:	none

Radio TX: 72 MHz controller/1.0W (video), 2.4 MHz
900 MHz/0.5 W (telemetry), 1.2 MHz / 3W (video)

157

Super Kenaf

International Rescue System Institute
www.rescuesystem.org
Eiji Koyanagi


Manufacturer's Specs:

Width:	16.9 in (43.0 cm)
Length:	37.0 (20.4)in (94.0(52.0) cm)
Height:	6.3 in (16.0 cm)
Weight:	43.3 lbs (19.0 kg)
Steering:	skid
Turning Diam:	diagonal for skid steer 0 in (0 cm)
Max Speed:	11.6 fps (3.5 mps)
Power Source:	battery
Endurance:	40 min
Tether:	none
Control:	remote teleop
Sensors:	None
Payload:	None
Manipulator:	None

Radio Tx: 802.11A
Radio Rx: 802.11A

Super Kenaf

International Rescue System Institute
www.rescuesystem.org
Eiji Koyanagi


Manufacturer's Specs:

Width:	16.9 in (43.0 cm)
Length:	37.0 (20.4)in (94.0(52.0) cm)
Height:	6.3 in (16.0 cm)
Weight:	43.3 lbs (19.0 kg)
Steering:	skid
Turning Diam:	diagonal for skid steer 0 in (0 cm)
Max Speed:	11.6 fps (3.5 mps)
Power Source:	battery
Endurance:	40 min
Tether:	none
Control:	remote teleop
Sensors:	None
Payload:	None
Manipulator:	None

Radio Tx: 802.11A
Radio Rx: 802.11A

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UMRS2009

International Rescue System Institute
www.rescuesystem.org

Ground Robots

Manufacturer's Specs:

Width:	19.7 in (50 cm)
Length:	23.2 in (59 cm)
Height:	8.7 in (22 cm)
Weight:	46.3 lbs (21 kg)
Steering:	
Turning Diam:	zero
Max Speed:	3.1 mph (5 km)
Power Source:	battery (Li Fe)
Endurance:	2.5 hours
Tether:	none
Control:	remote teleoperation
Sensors:	camera
Payload:	88 lb (40 kg)
Manipulator:	3 degree of motion w/gripper

Radio Tx: 802.11A/G
Radio Rx: 802.11A/G

UMRS2009

International Rescue System Institute
www.rescuesystem.org

Ground Robots

Manufacturer's Specs:

Width: 19.7 in (50 cm)
Length: 23.2 in (59 cm)
Height: 8.7 in (22 cm)
Weight: 46.3 lbs (21 kg)
Steering:
Turning Diam: zero
Max Speed: 3.1 mph (5 km)
Power Source: battery (Li Fe)
Endurance: 2.5 hours
Tether: none
Control: remote teleoperation
Sensors: camera
Payload: 88 lb (40 kg)
Manipulator: 3 degree of motion w/gripper

Radio Tx: 802.11A/G
Radio Rx: 802.11A/G

159

Kenaf

International Rescue System Institute
www.rescuesystem.org
Eiji Koyanagi

Manufacturer's Specs:

Width:	16.9 in (43.0 cm)
Length:	37.0 (20.4)in (94.0(52.0) cm)
Height:	7.7 in (19.5 cm)
Weight:	48.9 lbs (22.0 kg)
Steering:	skid
Turning Diam:	diagonal for skid steer 0 in (0 cm)
Max Speed:	1.2 fps (0.4 mps)
Power Source:	battery
Endurance:	120 min
Tether:	none
Control:	remote teleoperation
Sensors:	CCD Camera, Fisheye Camera, 3D Scanner (2D URG + Pant Tilt base)
Payload:	None
Manipulator:	None

Radio Tx: 802.11A
Radio Rx: 802.11A

Kenaf

International Rescue System Institute
www.rescuesystem.org
Eiji Koyanagi

Manufacturer's Specs:

Width:	16.9 in (43.0 cm)
Length:	37.0 (20.4)in (94.0(52.0) cm)
Height:	7.7 in (19.5 cm)
Weight:	48.9 lbs (22.0 kg)
Steering:	skid
Turning Diam:	diagonal for skid steer 0 in (0 cm)
Max Speed:	1.2 fps (0.4 mps)
Power Source:	battery
Endurance:	120 min
Tether:	none
Control:	remote teleoperation
Sensors:	CCD Camera, Fisheye Camera, 3D Scanner (2D URG + Pant Tilt base)
Payload:	None
Manipulator:	None

Radio Tx: 802.11A
Radio Rx: 802.11A

PackBot Explorer

iRobot
www.irobot.com
781-345-0200/Jeff Ostazewski


Ground Robots

Manufacturer's Specs:

- Width: 16 in - 20 in (40 - 50 cm)
- Length: 27 in(69 cm)
- Height: 7.5 in (19 cm)
- Weight: 48 lbs (22 kg)
- Turning Dia: 34 in (86.36 cm)
- Max Speed: Variable 0 - 5 mph (0 - 8 km/hr)
- Power Source: battery
- Endurance: 2-12 hours / 6+ mi (10+ km)
- Tether: optional
- Control: Teleop
- Sensors: Zoom & FLIR cameras, omni dirc mic
- Payload: Supports up to 8
- Manipulator: surveillance head is mounted on a 12 in (.3m) mast with a 360° pan and 270° tilt

Radio TX: 2400 MHz
Radio RX: 2400 MHz

PackBot Explorer

iRobot
www.irobot.com
781-345-0200/Jeff Ostazewski


Ground Robots

Manufacturer's Specs:

- Width: 16 in - 20 in (40 - 50 cm)
- Length: 27 in(69 cm)
- Height: 7.5 in (19 cm)
- Weight: 48 lbs (22 kg)
- Turning Dia: 34 in (86.36 cm)
- Max Speed: Variable 0 - 5 mph (0 - 8 km/hr)
- Power Source: battery
- Endurance: 2-12 hours / 6+ mi (10+ km)
- Tether: optional
- Control: Teleop
- Sensors: Zoom & FLIR cameras, omni dirc mic
- Payload: Supports up to 8
- Manipulator: surveillance head is mounted on a 12 in (.3m) mast with a 360° pan and 270° tilt

Radio TX: 2400 MHz
Radio RX: 2400 MHz

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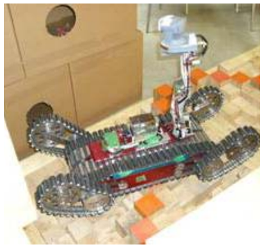
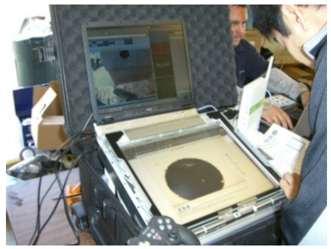
Hibiscus

Toin University of Yokohama
Chiba Institute of Technology
koyanagi@furo.org



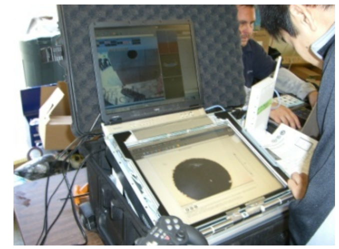


Manufacturer's Specs:

- Width: 14.5 in (37 cm)
- Length: 38.5 in (98 cm)
- Height: 7 in (18 cm)
- Weight: 49.6 lbs (22.5 kg)
- Turn Diam: diagonal for skid steer
- Max Speed: .7 mph (1.2 km/ph)
- Power Source: battery
- Endurance: 60 min
- Tether: none
- Control Features: diagnostics, wall following, centering
- Sensors: URG,Heat, Voice
- Payload: none
- Manipulator: Sensor arm 4DOF: Length: 14.1 in (36cm)

Radio TX: 2400 MHz
Radio RX: 2400 MHz

Hibiscus
Toin University of Yokohama
Chiba Institute of Technology
koyanagi@furo.org



Manufacturer's Specs:

- Width: 14.5 in (37 cm)
- Length: 38.5 in (98 cm)
- Height: 7 in (18 cm)
- Weight: 49.6 lbs (22.5 kg)
- Turn Diam: diagonal for skid steer
- Max Speed: .7 mph (1.2 km/ph)
- Power Source: battery
- Endurance: 60 min
- Tether: none
- Control Features: diagnostics, wall following, centering
- Sensors: URG,Heat, Voice
- Payload: none
- Manipulator: Sensor arm 4DOF: Length: 14.1 in (36cm)

Radio TX: 2400 MHz
Radio RX: 2400 MHz

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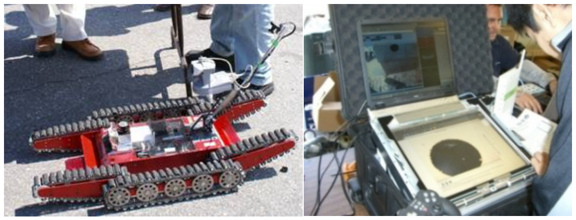
Cphea

Toin University of Yokohama
Chiba Institute of Technology
koyanagi@furo.org



Ground Robots

Manufacturer's Specs:

- Width: 20 in (52 cm)
- Length: 40 in (102 cm)
- Height: 9.4 in (24 cm)
- Weight: 49.6 lbs (22.5 kg)
- Turn Diam: diagonal for skid steer
- Max Speed: .37 mph (0.6 km/ph)
- Power Source: battery
- Endurance: 60 min
- Tether: none
- Control: diagnostics, wall following, centering
- Sensors: URG,Heat, Voice
- Payload: none
- Manipulator: Sensor arm 2DOF: Length (30cm)

Radio TX: 2400 MHz
Radio RX: 2400 MHz

Cphea

Toin University of Yokohama
Chiba Institute of Technology
koyanagi@furo.org

Ground Robots

Manufacturer's Specs:

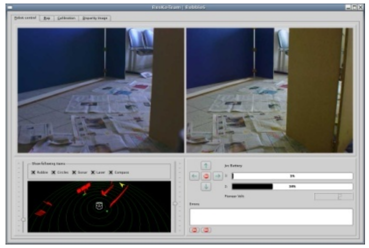
- Width: 20 in (52 cm)
- Length: 40 in (102 cm)
- Height: 9.4 in (24 cm)
- Weight: 49.6 lbs (22.5 kg)
- Turn Diam: diagonal for skid steer
- Max Speed: .37 mph (0.6 km/ph)
- Power Source: battery
- Endurance: 60 min
- Tether: none
- Control: diagnostics, wall following, centering
- Sensors: URG,Heat, Voice
- Payload: none
- Manipulator: Sensor arm 2DOF: Length (30cm)

Radio TX: 2400 MHz
Radio RX: 2400 MHz

163

Robbie 6

University of Koblenz-Landau, Germany
Johannes Pellenz, pellenz@uni-koblenz.de
www.uni-koblenz.de/agas



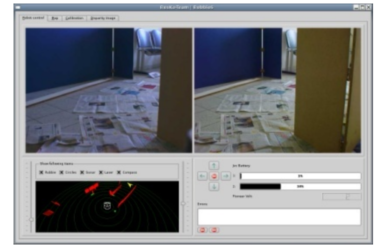
Manufacturer's Specs:

• Width:	19.3 in (49 cm)
• Length:	21.3 in (54 cm)
• Height:	29.5 in (75 cm)
• Weight:	55 lbs (25 kg)
• Steering:	skid
• Min Turn Diam:	26.77 (68 cm)
• Max Speed:	2.52 kmph
• Power Source:	battery
• Endurance:	about 150 min
• Tether:	none
• Control Features:	none
• Sensors:	Sonar, LRF, 3 FireWire Cameras, Compass
• Payload:	none
• Manipulator:	none

Radio TX: 802.11 a
Radio RX: 802.11 a

Robbie 6

University of Koblenz-Landau, Germany
Johannes Pellenz, pellenz@uni-koblenz.de
www.uni-koblenz.de/agas



Manufacturer's Specs:

• Width:	19.3 in (49 cm)
• Length:	21.3 in (54 cm)
• Height:	29.5 in (75 cm)
• Weight:	55 lbs (25 kg)
• Steering:	skid
• Min Turn Diam:	26.7 (68 cm)
• Max Speed:	2.52 kmph
• Power Source:	battery
• Endurance:	about 150 min
• Tether:	none
• Control Features:	none
• Sensors:	Sonar, LRF, 3 FireWire Cameras, Compass
• Payload:	none
• Manipulator:	none

Radio TX: 802.11 a
Radio RX: 802.11 a

164

Shinobi

Univ Electo-Communications
www.hi.mce.uec.ac.jp/matsuno-lab/matsuno_eng.html
Noritaka Sato

Ground Robots

Manufacturer's Specs:

- Width: 15. 74 in (40 cm)
- Length: 31.49 in (80 cm)
- Height: 15-74 in – 31.49 in (40cm- 80cm)
- Weight: 57.32 lbs (26 kg)
- Turning Dia: 0
- Max Speed: .21 mps (.33 kms)
- Power Source: battery
- Endurance: 60 min
- Tether: none
- Control: teleop
- Sensors: thermal , chemical (cO2)
- Payload: none
- Manipulator: none

Radio TX: 5200 MhZ (10mW)
Radio RX: 5200 MhZ (10mW)

Shinobi

Univ Electo-Communications
www.hi.mce.uec.ac.jp/matsuno-lab/matsuno_eng.html
Noritaka Sato

Ground Robots

Manufacturer's Specs:

- Width: 15. 74 in (40 cm)
- Length: 31.49 in (80 cm)
- Height: 15-74 in – 31.49 in (40cm- 80cm)
- Weight: 57.32 lbs (26 kg)
- Turning Dia: 0
- Max Speed: .21 mps (.33 kms)
- Power Source: battery
- Endurance: 60 min
- Tether: none
- Control: teleop
- Sensors: thermal , chemical (cO2)
- Payload: none
- Manipulator: none

Radio TX: 5200 MhZ (10mW)
Radio RX: 5200 MhZ (10mW)

165

Quince

International Rescue System Institute
www.rescuesystem.org

Manufacturer's Specs:

- Width: 19 in (48 cm)
- Length: 26 in – 43 in (66.5 – 109.9 cm)
- Height: 8.8 in (22.5 cm)
- Weight: 58 lbs (26.4 kg)
- Turning Diam: pivot turn
- Max Speed: 1.6 m/s
- Power Source: battery (Li-Ion)
- Endurance:
- Tether:
- Control: remote teleop with intelligent support
- Sensors: PTZ camera, bird eye camera
- Payload: 200 lbs (90 kg)
- Manipulator: 6 dof

Radio Tx: 802.11A
Radio Rx: 802.11A

Quince

International Rescue System Institute
www.rescuesystem.org

Manufacturer's Specs:

- Width: 19 in (48 cm)
- Length: 26 in – 43 in (66.5 – 109.9 cm)
- Height: 8.8 in (22.5 cm)
- Weight: 58 lbs (26.4 kg)
- Turning Diam: pivot turn
- Max Speed: 1.6 m/s
- Power Source: battery (Li-Ion)
- Endurance:
- Tether:
- Control: remote teleop with intelligent support
- Sensors: PTZ camera, bird eye camera
- Payload: 200 lbs (90 kg)
- Manipulator: 6 dof

Radio Tx: 802.11A
Radio Rx: 802.11A

166

PackBot

with CAM, SAM and EAP Payloads

iRobot
www.irobot.com
781-345-0200

Ground Robots

Manufacturer's Specs:

- Width: 20.5 in (52.1 cm)
- Length: 27 in (69 cm)
- Height: 12.0 in (30.5 cm)
- Weight: 58.8 lbs (26.7 kg)
    - Chassis (including full flippers) 31.0 lbs (14.1 kg)
    - Camera Arm "CAM": 5.8 lbs (2.6 kg)
    - Small Arm Manipulator "SAM": 8.2 lbs (3.7 kg)
    - Enhanced Aware Payload "EAP":2.5 lbs (1.1 kg)
    - COFDM Radio:5.0 lbs (2.3 kg)
    - Batteries (2 BB-2590s): 6.3 lbs (2.9 kg)

- Turning Dia:
- Max Speed:
- Power Source: battery
- Endurance: Approximately 4 hours
- Tether: Fiber-optic tether available
- Control: Eyes-on, remote teleop, preset poses
- Sensors: LWIR Thermal Camera
- Payload:
- Manipulator: 4 DOF

Radio TX/RX:COFDM: 4400 – 4940 MHz / 100mW
CommSelect: 4940 – 4990 MHz / 400 mW
Embedded Radio: 2412 – 2472 MHz / 630 mW

PackBot

with CAM, SAM and EAP Payloads

iRobot
www.irobot.com
781-345-0200

Ground Robots

Manufacturer's Specs:

- Width: 20.5 in (52.1 cm)
- Length: 27 in (69 cm)
- Height: 12.0 in (30.5 cm)
- Weight: 58.8 lbs (26.7 kg)
    - Chassis (including full flippers) 31.0 lbs (14.1 kg)
    - Camera Arm "CAM": 5.8 lbs (2.6 kg)
    - Small Arm Manipulator "SAM": 8.2 lbs (3.7 kg)
    - Enhanced Aware Payload "EAP":2.5 lbs (1.1 kg)
    - COFDM Radio:5.0 lbs (2.3 kg)
    - Batteries (2 BB-2590s): 6.3 lbs (2.9 kg)

- Turning Dia:
- Max Speed:
- Power Source: battery
- Endurance: Approximately 4 hours
- Tether: Fiber-optic tether available
- Control: Eyes-on, remote teleop, preset poses
- Sensors: LWIR Thermal Camera
- Payload:
- Manipulator: 4 DOF

Radio TX/RX:COFDM: 4400 – 4940 MHz / 100mW
CommSelect: 4940 – 4990 MHz / 400 mW
Embedded Radio: 2412 – 2472 MHz / 630 mW

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Matilda

Mesa Robotics, Inc.
www.mesa-robotics.com
256-258-2130/Don Jones

Manufacturer's Specs:

- Width: 21 in (53.34 cm)
- Length: 30 in – 34 in (76.2cm- 86.36cm)
- Height: 12 in (30.48 cm)
- Weight: 61 lbs (27.66 kg)
- Turning Dia: zero
- Max Speed: 2.0 mph
- Power Source: 12VCD battery, NiMH
- Endurance: 360 – 480 min
- Tether: fiber optic cable (data,video, audio)
- Control: remote teleop
- Sensors: biological, chemical, radiological
- Payload: 125 lbs
- Manipulator: 5 DOF with 44 in reach (adds 45lbs/20.4kg to weight)

Radio TX: 900 MHz control, 1800 MHz video, 469 MHz audio
Radio RX: 900 MHz control, 1800 MHz video, 469 MHz audio

Matilda

Mesa Robotics, Inc.
www.mesa-robotics.com
256-258-2130/Don Jones

Manufacturer's Specs:

- Width: 21 in (53.34 cm)
- Length: 30 in – 34 in (76.2cm- 86.36cm)
- Height: 12 in (30.48 cm)
- Weight: 61 lbs (27.66 kg)
- Turning Dia: zero
- Max Speed: 2.0 mph
- Power Source: 12VCD battery, NiMH
- Endurance: 360 – 480 min
- Tether: fiber optic cable (data,video, audio)
- Control: remote teleop
- Sensors: biological, chemical, radiological
- Payload: 125 lbs
- Manipulator: 5 DOF with 44 in reach (adds 45lbs/20.4kg to weight)

Radio TX: 900 MHz control, 1800 MHz video, 469 MHz audio
Radio RX: 900 MHz control, 1800 MHz video, 469 MHz audio

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Matilda II

Mesa Robotics, Inc.
www.mesa-robotics.com
256-258-2130/Don Jones


Ground Robots

Manufacturer's Specs:

- Width: 21 in (53.34 cm)
- Length: 30 in – 34 in (76.2cm- 86.36cm)
- Height: 12 in (30.48 cm)
- Weight: 61 lbs (27.66 kg)
- Turning Dia: zero
- Max Speed: 2.0 mph
- Power Source: 12VCD battery, NiMH
- Endurance: 360 – 480 min
- Tether: fiber optic cable (data,video, audio)
- Control: remote teleop
- Sensors: biological, chemical, radiological
- Payload: 125 lbs
- Manipulator: 5 DOF with 44 in reach (adds 45lbs/20.4kg to weight)

Radio TX: 900 MHz control, 1800 MHz video, 469 MHz audio
Radio RX: 900 MHz control, 1800 MHz video, 469 MHz audio

Matilda II

Mesa Robotics, Inc.
www.mesa-robotics.com
256-258-2130/Don Jones


Ground Robots

Manufacturer's Specs:

- Width: 21 in (53.34 cm)
- Length: 30 in – 34 in (76.2cm- 86.36cm)
- Height: 12 in (30.48 cm)
- Weight: 61 lbs (27.66 kg)
- Turning Dia: zero
- Max Speed: 2.0 mph
- Power Source: 12VCD battery, NiMH
- Endurance: 360 – 480 min
- Tether: fiber optic cable (data,video, audio)
- Control: remote teleop
- Sensors: biological, chemical, radiological
- Payload: 125 lbs
- Manipulator: 5 DOF with 44 in reach (adds 45lbs/20.4kg to weight)

Radio TX: 900 MHz control, 1800 MHz video, 469 MHz audio
Radio RX: 900 MHz control, 1800 MHz video, 469 MHz audio

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PackBot

with EOD Payloads

iRobot
www.irobot.com
781-345-0200

Manufacturer's Specs:

- Width: 20 1/2 in (52.1 cm)
- Length: 27 in (68.6 cm)
- Height: 16 in (40.6 cm)
- Weight: 62.8 lbs (328.5 kg)
    - Chassis (full flippers): 31.0 lbs (14.1 kg)
    - 3-Link Arm: 20.5 lbs (9.3 kg)
    - COFDM Radio: 5.0 lbs (2.3 kg)
    - Batteries (2 BB-2590s): 6.3 lbs (2.9 kg)
- Turning Dia: 0 in (0 cm)
- Max Speed: 8.5 fps (2.6 mps)
- Power Source: BB-2590 Lithium-Ion batteries
- Endurance: Approximately 4 hours
- Tether: Fiber-optic tether available
- Control: Eyes-on, remote teleop, preset poses
- Sensors: LWIR Thermal Camera
- Payload:
- Manipulator: 3 link arm DOF 8

Radio TX/RX:COFDM: 4400 – 4940 MHz / 100mW
CommSelect: 4940 – 4990 MHz / 400 mW
Embedded Radio: 2412 – 2472 MHz / 630 mW

PackBot

with EOD Payloads

iRobot
www.irobot.com
781-345-0200

Manufacturer's Specs:

- Width: 20 1/2 in (52.1 cm)
- Length: 27 in (68.6 cm)
- Height: 16 in (40.6 cm)
- Weight: 62.8 lbs (328.5 kg)
    - Chassis (full flippers): 31.0 lbs (14.1 kg)
    - 3-Link Arm: 20.5 lbs (9.3 kg)
    - COFDM Radio: 5.0 lbs (2.3 kg)
    - Batteries (2 BB-2590s): 6.3 lbs (2.9 kg)
- Turning Dia: 0 in (0 cm)
- Max Speed: 8.5 fps (2.6 mps)
- Power Source: BB-2590 Lithium-Ion batteries
- Endurance: Approximately 4 hours
- Tether: Fiber-optic tether available
- Control: Eyes-on, remote teleop, preset poses
- Sensors: LWIR Thermal Camera
- Payload:
- Manipulator: 3 link arm DOF 8

Radio TX/RX:COFDM: 4400 – 4940 MHz / 100mW
CommSelect: 4940 – 4990 MHz / 400 mW
Embedded Radio: 2412 – 2472 MHz / 630 mW

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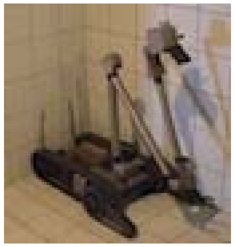
Packbot 510-EFR

iRobot
www.irobot.com
781-345-0200



Ground Robots

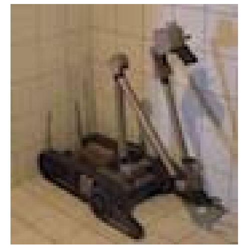
Manufacturer's Specs:

- Width: 20 1/2 in (52.1 cm)
- Length: 31 in (79 cm)
- Height: 17 in (43 cm)
- Weight: 69 lbs (31.3 kg)
- Turning Dia: within the length of vehicle
- Max Speed: 4.7 mph (7.5 km/hr)
- Power Source: 2 Lithium Ion Battery
- Endurance: 216 min (3 hrs, 36 mins)
- Tether: Not available
- Control: RF Control
- Sensors: 1 camera with low-light, 3 other cameras
- Payload: 30 lbs (13.6 kg) Arm compact position 10 lbs (4.5 kg) Arm extended position
- Manipulator: Arm Reach up: 91 in (231 cm)
- Horizontal Reach: 87 in (221 cm)

Radio TX: 4900 MHz control, video, audio (0.4W)
Radio RX: 4900 MHz control, video, audio (0.4W)

Packbot 510-EFR

iRobot
www.irobot.com
781-345-0200



Ground Robots

Manufacturer's Specs:

- Width: 20 1/2 in (52.1 cm)
- Length: 31 in (79 cm)
- Height: 17 in (43 cm)
- Weight: 69 lbs (31.3 kg)
- Turning Dia: within the length of vehicle
- Max Speed: 4.7 mph (7.5 km/hr)
- Power Source: 2 Lithium Ion Battery
- Endurance: 216 min (3 hrs, 36 mins)
- Tether: Not available
- Control: RF Control
- Sensors: 1 camera with low-light, 3 other cameras
- Payload: 30 lbs (13.6 kg) Arm compact position 10 lbs (4.5 kg) Arm extended position
- Manipulator: Arm Reach up: 91 in (231 cm)
- Horizontal Reach: 87 in (221 cm)

Radio TX: 4900 MHz control, video, audio (0.4W)
Radio RX: 4900 MHz control, video, audio (0.4W)

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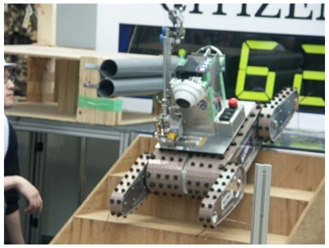
NuTech-R4

Nagaoka Univ. of Tech. / Nagaoka TEKKO-SEIKEN (Joint Team)
http://sessyu.nagaokaut.ac.jp/~kimuralab/
Tetsuya KIMURA, kimura@mech.nagaokaut.ac.jp

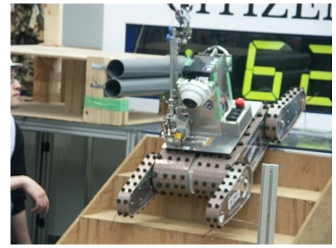


Manufacturer's Specs:

- Width: 16.93 in (43 cm)
- Length: 24.41 (62 cm) 35.43 (90 cm with flipper extension)
- Height: 17.72 in (45 cm)
- Weight: 77 lbs (35 kg)
- Steering: skid
- Turning Diam: 29.53 (75 cm)
- Max Speed: 0.3 mps
- Power Source: battery
- Endurance: 30 min
- Tether: communication (optional)
- Control: remote tele-operation
- Sensors: thermal, sound, arm camera
- Payload: 3 kg (body), 300 g (manipulator)
- Manipulator: 5 DOFs, reach 39.37 in (100 cm)

Radio TX: 802.11 a /g/n
Radio RX: 802.11 a /g/n

NuTech-R4
Nagaoka Univ. of Tech. / Nagaoka TEKKO-SEIKEN (Joint Team)
http://sessyu.nagaokaut.ac.jp/~kimuralab/
Tetsuya KIMURA, kimura@mech.nagaokaut.ac.jp



Manufacturer's Specs:
- Width: 16.93 in (43 cm)
- Length: 24.41 (62 cm) 35.43 (90 cm with flipper extension)
- Height: 17.72 in (45 cm)
- Weight: 77 lbs (35 kg)
- Steering: skid
- Turning Diam: 29.53 (75 cm)
- Max Speed: 0.3 mps
- Power Source: battery
- Endurance: 30 min
- Tether: communication (optional)
- Control: remote tele-operation
- Sensors: thermal, sound, arm camera
- Payload: 3 kg (body), 300 g (manipulator)
- Manipulator: 5 DOFs, reach 39.37 in (100 cm)

Radio TX: 802.11 a /g/n
Radio RX: 802.11 a /g/n

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Helios IX

International Rescue System Institute
www.rescuesystem.org

Ground Robots

Manufacturer's Specs:

- Width: 20 in (49 cm)
- Length: 22.44 in (57 cm)
- Height: 7.8 in – 48 in (20 cm - 122 cm)
- Weight: 88 lbs (40 kg)
- Turning Diam:
- Max Speed: 7 km/p
- Power Source: battery
- Endurance:
- Tether:
- Control: remote teleop
- Sensors: Camera, 2-D laser range finder, attitude
- Payload: unknown
- Manipulator: 6DOFs

Radio Tx: 802.11 a,b,g,n
Radio Rx: 802.11 a,b,g,n

Helios IX

International Rescue System Institute
www.rescuesystem.org

Ground Robots

Manufacturer's Specs:

- Width: 20 in (49 cm)
- Length: 22.44 in (57 cm)
- Height: 7.8 in – 48 in (20 cm - 122 cm)
- Weight: 88 lbs (40 kg)
- Turning Diam:
- Max Speed: 7 km/p
- Power Source: battery
- Endurance:
- Tether:
- Control: remote teleop
- Sensors: Camera, 2-D laser range finder, attitude
- Payload: unknown
- Manipulator: 6DOFs

Radio Tx: 802.11 a,b,g,n
Radio Rx: 802.11 a,b,g,n

KOHGA

International Rescue System Institute
www.rescuesystem.org

Manufacturer's Specs:

- Width: 17 in (43 cm)
- Length: 86 in (34 cm)
- Height: 29.5 (75 cm)
- Weight: 88 lbs (40 kg)
- Turning Diam:
- Max Speed: 3.0 m/s
- Power Source: battery
- Endurance: 60 min
- Tether: none
- Control: remote teleop
- Sensors: thermal, Co2,mic, Camera, URG-04LX,AMU
- Payload: unknown
- Manipulator: 6DOFs

Radio Tx: 5200 MhZ (10mW)
Radio Rx: 5200 MhZ (10mW)

KOHGA

International Rescue System Institute
www.rescuesystem.org

Manufacturer's Specs:

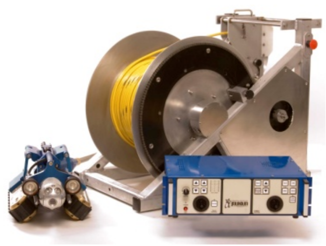
- Width: 17 in (43 cm)
- Length: 86 in (34 cm)
- Height: 29.5 (75 cm)
- Weight: 88 lbs (40 kg)
- Turning Diam:
- Max Speed: 3.0 m/s
- Power Source: battery
- Endurance: 60 min
- Tether: none
- Control: remote teleop
- Sensors: thermal, Co2,mic, Camera, URG-04LX,AMU
- Payload: unknown
- Manipulator: 6DOFs

Radio Tx: 5200 MhZ (10mW)
Radio Rx: 5200 MhZ (10mW)

174

Versatrax 150

SeaTrepid
www.inuktun.com
Bob Christ

Ground Robots

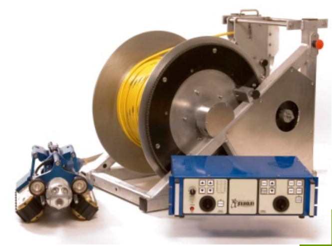
Manufacturer's Specs:

- Width: Inline: 4.5 in (11.43 cm)
- Parallel: 11.5 in (29.21cm) and larger
- Length: Inline: 64 in (162.5 cm)
- Parallel: 24 in (61cm)
- Height: Inline: 8.57 in (21.8 cm) and larger
- Weight: 88 lbs (40 kg)
- Steering: Skid steering
- Turning Diam: Various; depending on pipe diameters
- Max Speed: 30 fpm (9 mpm)
- Power Source: 88-264 VAC 50/60Hz
- Endurance: Continuous
- Tether: Power and comms
- Control: Remote teleop
- Sensors: Sonar, sonde
- Payload: N/A
- Manipulator: N/A

Radio TX:
Radio RX:

Versatrax 150

SeaTrepid
www.inuktun.com
Bob Christ

Ground Robots

Manufacturer's Specs:

- Width: Inline: 4.5 in (11.43 cm)
- Parallel: 11.5 in (29.21cm) and larger
- Length: Inline: 64 in (162.5 cm)
- Parallel: 24 in (61cm)
- Height: Inline: 8.57 in (21.8 cm) and larger
- Weight: 88 lbs (40 kg)
- Steering: Skid steering
- Turning Diam: Various; depending on pipe diameters
- Max Speed: 30 fpm (9 mpm)
- Power Source: 88-264 VAC 50/60Hz
- Endurance: Continuous
- Tether: Power and comms
- Control: Remote teleop
- Sensors: Sonar, sonde
- Payload: N/A
- Manipulator: N/A

Radio TX:
Radio RX:

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Talon Gen IV

Qinetiq North America / Foster-Miller Inc.
www.foster-miller.com/lemming.htm
781-684-4000


Manufacturer's Specs:

- Width: 22 in (56.88 cm)
- Length: 34 in (86.36 cm)
- Height: 11 in-52 in (27.9 c m - 132 cm)
- Weight: 115 to 140 lb (52kg to 64 kg)
- Turning Dia: turns in place
- Max Speed: 0 to 5.2 mph (0-8.3 km/hr
- Power Source: Single Lithium-ion Battery or Dual Lead-Acid Battery Pack
- Endurance: 4.5 hr (7.2 km/hr)
- Tether: Optional 300 or 500 m buffered fiber optic cable
- Control: digital/analog, 500-800 m LOS High Gain antenna range to 1200m LOS
- Sensors: Chemsentry 150 C, ADP 2000, RAE System MultiRAE, Canberra AN-UDR-14, RayTek temp. probe, targeting laser
- Payload: 100 lb (45 kg)
- Manipulator: 30 in-lb of gripping strength, 6 in wide opening, manual 340 degree wrist

Radio TX: Data 2400MHz / Video 1700-1800MHz
Radio RX: Data 2400MHz / Video 1700-1800MHz

Talon Gen IV

Qinetiq North America / Foster-Miller Inc.
www.foster-miller.com/lemming.htm
781-684-4000


Manufacturer's Specs:

- Width: 22 in (56.88 cm)
- Length: 34 in (86.36 cm)
- Height: 11 in-52 in (27.9 c m-132 cm)
- Weight: 115 to 140 lb (52kg to 64 kg)
- Turning Dia: turns in place
- Max Speed: 0 to 5.2 mph (0-8.3 km/hr
- Power Source: Single Lithium-ion Battery or Dual Lead-Acid Battery Pack
- Endurance: 4.5 hr (7.2 km/hr)
- Tether: Optional 300 or 500 m buffered fiber optic cable
- Control: digital/analog, 500-800 m LOS High Gain antenna range to 1200m LOS
- Sensors: Chemsentry 150 C, ADP 2000, RAE System MultiRAE, Canberra AN-UDR-14, RayTek temp. probe, targeting laser
- Payload: 100 lb (45 kg)
- Manipulator: 30 in-lb of gripping strength, 6 in wide opening, manual 340 degree wrist

Radio TX: Data 2400MHz / Video 1700-1800MHz
Radio RX: Data 2400MHz / Video 1700-1800MHz

Talon Gen IV -Hazmat

Qinetiq North America / Foster-Miller Inc.
www.foster-miller.com/lemming.htm
781-684-4000

Manufacturer's Specs:

- Width: 22.5 in (57.2 cm)
- Length: 34 in (86.4 cm)
- Height: 11 in (27.9 cm)
- Weight: 115 to 140 lb (52kg to 64 kg)
- Turning Dia: On axis
- Max Speed: 7.6 fps (1.8mps)
- Power Source: Battery Pack
- Endurance: 4.5 hr (7.2 km/hr)
- Tether: Fiber Optics (option)
- Control: remote teleop
- Sensors: chemical warfare agents (blood, nerve, blister), TIC, radiation

  Payload: 100 lb (45 kg)
- Manipulator: reach 52 in (1.3 m)

Radio TX: 1650-1900 MHz / 2000 mW (video), 148-174 MHz/ 600 mW (audio), 2.3-2.4 MHz / 5-500 mW (commands)

Talon Gen IV -Hazmat
Qinetiq North America / Foster-Miller Inc.
www.foster-miller.com/lemming.htm
781-684-4000

Ground Robots

Manufacturer's Specs:
- Width: 22.5 in (57.2 cm)
- Length: 34 in (86.4 cm)
- Height: 11 in (27.9 cm)
- Weight: 115 to 140 lb (52kg to 64 kg)
- Turning Dia: On axis
- Max Speed: 7.6 fps (1.8mps)
- Power Source: Battery Pack
- Endurance: 4.5 hr (7.2 km/hr)
- Tether: Fiber Optics (option)
- Control: remote teleop
- Sensors: chemical warfare agents (blood, nerve, blister), TIC, radiation
  Payload: 100 lb (45 kg)
- Manipulator: reach 52 in (1.3 m)

Radio TX: 1650-1900 MHz / 2000 mW (video), 148-174 MHz/ 600 mW (audio), 2.3-2.4 MHz / 5-500 mW (commands)

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Talon Gen IV -Shoulder

Qinetiq North America / Foster-Miller Inc.
www.foster-miller.com/lemming.htm
781-684-4000

Radio TX: 1650-1900 MHz / 2000 mW (video), 148-174 MHz/ 600 mW (audio), 2.3-2.4 MHz / 5-500 mW (commands)

Talon Gen IV -Shoulder
Qinetiq North America / Foster-Miller Inc.
www.foster-miller.com/lemming.htm
781-684-4000

Radio TX: 1650-1900 MHz / 2000 mW (video), 148-174 MHz/ 600 mW (audio), 2.3-2.4 MHz / 5-500 mW (commands)

178

Chaos

Autonomous Solutions.
www.autonomoussolutions.com
Omar Salas

Ground Robots

Manufacturer's Specs:

- Width: 28 in (70 cm)
- Length: 28 in (71 cm)
- Height: 8 in (20 cm)
- Weight: 120 lbs (55 kg)
- Turning Dia: 39 in (100)
- Max Speed: TBD
- Power Source: Lithium battery
- Endurance: 240 min
- Tether: None
- Control: remote teleop
- Sensors: 2 Cams
- Payload: TBD
- Manipulator: None

Radio TX: 2400 MHz/1000 mW (Video) 900 MHZ/1000 mW (data)
Radio RX: 2400 MHz/1000 mW (Video) 900 MHZ/1000 mW (data)

Chaos

Autonomous Solutions.
www.autonomoussolutions.com
Omar Salas

Ground Robots

Manufacturer's Specs:

- Width: 28 in (70 cm)
- Length: 28 in (71 cm)
- Height: 8 in (20 cm)
- Weight: 120 lbs (55 kg)
- Turning Dia: 39 in (100)
- Max Speed: TBD
- Power Source: Lithium battery
- Endurance: 240 min
- Tether: None
- Control: remote teleop
- Sensors: 2 Cams
- Payload: TBD
- Manipulator: None

Radio TX: 2400 MHz/1000 mW (Video) 900 MHZ/1000 mW (data)
Radio RX: 2400 MHz/1000 mW (Video) 900 MHZ/1000 mW (data)

179

Modular Logistics Platform

Segway, Inc.
www.segway.com
603-222-6000

Manufacturer's Specs:

- Width: 33 in (84 cm)
- Length: 26.5 in (67 cm)
- Height: xxx in (xxx cm)
- Weight: 120 lbs (55 kg)
- Turning Dia: 42 in (107 cm)
- Max Speed: 12.5 mph (20 km/h) Power Source: Two lithium-ion battery packs
- Endurance: 12 miles (19 km) off pavement
- Tether: None
- Control: dynamically stabilized, ride onboard, remote teleoperative or autonomous
- Sensors: gyros, wheel encoders, camera
- Payload: 260 lb (118 kg)
- Manipulator: None

Radio TX: 2400 MHz/XXXmW (Video) 2400 MHZ/xxx mW (data)

Modular Logistics Platform

Segway, Inc.
www.segway.com
603-222-6000

Manufacturer's Specs:

- Width: 33 in (84 cm)
- Length: 26.5 in (67 cm)
- Height: xxx in (xxx cm)
- Weight: 120 lbs (55 kg)
- Turning Dia: 42 in (107 cm)
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- Endurance: 12 miles (19 km) off pavement
- Tether: None
- Control: dynamically stabilized, ride onboard, remote teleoperative or autonomous
- Sensors: gyros, wheel encoders, camera
- Payload: 260 lb (118 kg)
- Manipulator: None

Radio TX: 2400 MHz/XXXmW (Video) 2400 MHZ/xxx mW (data)

180

ATRV mini

Idaho National Lab
www.inl.gov/adaptiverobotics
208-526-8659 /Curtis Nielsen


Ground Robots

Manufacturer's Specs:

•	Width:	22 in (55.8 cm)
•	Length:	27 in (68.6 cm)
•	Height:	25 in (63.5 cm)
•	Weight:	125 lbs (56.7 kg)
•	Turning Diam:	0 (turns on center off robot)
•	Max Speed:	6.5 fps (2 mps)
•	Power Source:	battery
•	Endurance:	30-45 min
•	Tether:	none
•	Control:	eyes-on, remote teleop, waypoints, go to landmarks, drive intent
•	Sensors: ultrasonic	color video, laser range scanner, sonar sensor.
•	Payload:	35 lb (15.9 kg)
•	Manipulator:	none

Radio TX: 900 MHz (500 mW), 2400 MHz (500 mW)
Radio RX: 900 MHz (500 mW), 2400 MHz

ATRV mini

Idaho National Lab
www.inl.gov/adaptiverobotics
208-526-8659 /Curtis Nielsen


Ground Robots

Manufacturer's Specs:

•	Width:	22 in (55.8 cm)
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•	Height:	25 in (63.5 cm)
•	Weight:	125 lbs (56.7 kg)
•	Turning Diam:	0 (turns on center off robot)
•	Max Speed:	6.5 fps (2 mps)
•	Power Source:	battery
•	Endurance:	30-45 min
•	Tether:	none
•	Control:	eyes-on, remote teleop, waypoints, go to landmarks, drive intent
•	Sensors: ultrasonic	color video, laser range scanner, sonar sensor.
•	Payload:	35 lb (15.9 kg)
•	Manipulator:	none

Radio TX: 900 MHz (500 mW), 2400 MHz (500 mW)
Radio RX: 900 MHz (500 mW), 2400 MHz

181

Digital Vanguard ROV

Allen Vanguard
http://www.allenvanguard.com/


Manufacturer's Specs:

- Width: 18 in (46 cm)
- Length: 41 in (104 cm)
- Height: 24 in (61 cm)
- Weight: 125.8 lbs (57 kg)
- Turning Dia: within the length of the vehicle
- Max Speed: 1.1 mph (1.7 km/hr)
- Power Source: 2 lead acid batteries
- Endurance: 70 mins
- Tether: 500ft Hard Command line or 1000ft Fiber Optic
- Control: Tethered or RF
- Sensors: 3 color cameras with low-light
  Payload: 180 lbs (81.6)
- Manipulator: 6 DOF
  Reach up:54–90.5 in (137-230 cm)
  Horizontal reach: 75 – 112.5 in (191 -286 cm)

Radio TX: 2400 MhZ
Radio RX: 2400 MhZ

Digital Vanguard ROV
Allen Vanguard
http://www.allenvanguard.com/


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- Width: 18 in (46 cm)
- Length: 41 in (104 cm)
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- Tether: 500ft Hard Command line or 1000ft Fiber Optic
- Control: Tethered or RF
- Sensors: 3 color cameras with low-light
  Payload: 180 lbs (81.6)
- Manipulator: 6 DOF
  Reach up:54–90.5 in (137-230 cm)
  Horizontal reach: 75 – 112.5 in (191 -286 cm)

Radio TX: 2400 MhZ
Radio RX: 2400 MhZ

Robotic Mobility Platform

(RMP 200/INL)

Segway, Inc.

www.segway.com/603-222-6000


Ground Robots

Manufacturer's Specs:

- Width: 29.5 in (75 cm)
- Length: 25 in 64 cm)
- Height: 24 in (61 cm)
- Weight: 140 lbs (64 kg)
- Turning Dia: 39 in (99 cm)
- Max Speed: 10 mph (16 km/h)
- Power Source: Two lithium-ion battery packs
- Endurance: 15 miles (24 km)
- Tether: None
- Control: dynamically stabilized, remote teleoperative or autonomous
- Sensors: gyros, wheel encoders, camera, laser scanner for mapping
- Payload: 200 lb (91 kg)
- Manipulator: Barrett Technology WAM

Radio TX: 2400 MHz/XXXmW (Video) 900 MHZ/xxx mW (data)

Robotic Mobility Platform

(RMP 200/INL)

Segway, Inc.

www.segway.com/603-222-6000


Ground Robots

Manufacturer's Specs:

- Width: 29.5 in (75 cm)
- Length: 25 in 64 cm)
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- Power Source: Two lithium-ion battery packs
- Endurance: 15 miles (24 km)
- Tether: None
- Control: dynamically stabilized, remote teleoperative or autonomous
- Sensors: gyros, wheel encoders, camera, laser scanner for mapping
- Payload: 200 lb (91 kg)
- Manipulator: Barrett Technology WAM

Radio TX: 2400 MHz/XXXmW (Video) 900 MHZ/xxx mW (data)

183

teleMAX

tele*rob* GmbH
www.telerob.de

Manufacturer's Specs:

- Width: 15.75 in (40 cm)
- Length: 31.5 in - 63 in (80 cm – 160 cm)
- Height: 29.53 in (75 cm) (stowed)
- Weight: 175 lbs (79.4 kg)
- Turning Dia: 39.37 in (100cm)
- Max Speed: tracks 2.16 mph (3.5 kmh), wheels 2.92 mph (4.7 kmh) Power
  Source: NiMh, 24V DC
- Endurance: 2 hours
- Tether: none, fiber with video and comms
- Control: eyes-on, remote teleop
- Sensors: optional chemical, radiation, gas, GPS
- Payload: 22 lbs (10kg)
- Manipulator: 7 DOFs, reach 92,52 in to 102,36 in (235 cm to 260 cm)

TEST DATA IS AVAILABLE

Radio TX: Data 433-435MHz/500mW, Video 2300 MHz/3W
Radio RX:

teleMAX

tele*rob* GmbH
www.telerob.de

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- Width: 15.75 in (40 cm)
- Length: 31.5 in - 63 in (80 cm – 160 cm)
- Height: 29.53 in (75 cm) (stowed)
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- Control: eyes-on, remote teleop
- Sensors: optional chemical, radiation, gas, GPS
- Payload: 22 lbs (10kg)
- Manipulator: 7 DOFs, reach 92,52 in to 102,36 in (235 cm to 260 cm)

TEST DATA IS AVAILABLE

Radio TX: Data 433-435MHz/500mW, Video 2300 MHz/3W
Radio RX:

Caliber MK3 EOD

ICOR Technology
www.icortechnology.com
613-745-3600

Ground Robots

Manufacturer's Specs:

- Width: 24 1/2 in (62 cm)
- Length: 43 1/2 in (111 cm)
- Height: 31 in (79 cm)
- Weight: 199 lbs (90.3 kg)
- Turning Dia: within the length of vehicle
- Max Speed: 2.9 mph (4.6 km/hr)
- Power Source: 1 Lead Acid Battery
- Endurance: 58 mins,1260 meters (as tested)
- Tether: Standard 300ft (92m) Tether; used as an alternative to RF control
- Control: Tether or RF
- Sensors: 6 cameras with low-light
- Payload: 65 lbs (29.5 kg)
- Manipulator: Arm Reach up: 71 1/2 in (182 cm) Horizontal Reach: 71 in (180 cm)

Radio TX RX: Control 900 Mhz/Video 2.4Mhz/Audio 465Mhz

Caliber MK3 EOD

ICOR Technology
www.icortechnology.com
613-745-3600

Ground Robots

Manufacturer's Specs:

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- Power Source: 1 Lead Acid Battery
- Endurance: 58 mins,1260 meters (as tested)
- Tether: Standard 300ft (92m) Tether; used as an alternative to RF control
- Control: Tether or RF
- Sensors: 6 cameras with low-light
- Payload: 65 lbs (29.5 kg)
- Manipulator: Arm Reach up: 71 1/2 in (182 cm) Horizontal Reach: 71 in (180 cm)

Radio TX RX: Control 900 Mhz/Video 2.4Mhz/Audio 465Mhz

Andros HD-1J

REMOTEC, Inc.
www.remotec-andros.com
865-483-0228/Jim Daniels

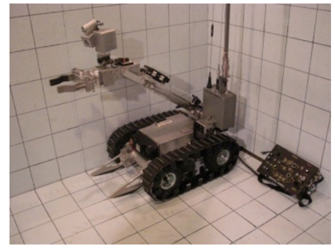
Manufacturer's Specs:

- Width: 26 in (66 cm)
- Length: 47.5 in (120.65 cm)
- Height: 30 in (76cm) antenna 70 in(177.8)
- Weight: 200 lbs (90.72 kg)
- Turning Dia:
- Max Speed: 4.3mph
- Power Source: Lithium Polymer Battery
- Endurance: 3-6 hr
- Tether: Fiber-Optic Cable
- Control: tethered/Radio Control
- Sensors: Color Camera/LED lighting/
- Payload: TBD
- Manipulator: 72 in (182.88 cm)Max. Gripper Height 6 in (15.2 cm) Gripper with 360 degree rotation, weapons with gripper capable

Radio TX RX: Control 464.5 Mhz/Video 2.4Mhz/Audio 151.9Mhz

Andros HD-1J

REMOTEC, Inc.
www.remotec-andros.com
865-483-0228/Jim Daniels



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- Sensors: Color Camera/LED lighting/
- Payload: TBD
- Manipulator: 72 in (182.88 cm)Max. Gripper Height 6 in (15.2 cm) Gripper with 360 degree rotation, weapons with gripper capable

Radio TX RX: Control 464.5 Mhz/Video 2.4Mhz/Audio 151.9Mhz

Mini-Andros II

REMOTEC, Inc.
www.remotec-andros.com
865-483-0228/Jim Daniels


Ground Robots

Manufacturer's Specs:

- Width: 24.5 in (62 cm)
- Length: 53 in (134c m)
- Height: 27 in (68 cm)
- Weight: 225 lbs (102.6 kg)
- Turning Dia: length of vehicle
- Max Speed: 1.1 mph(1.7 km/hr)
- Power Source: 24VDC - gel cell battery pack Battery
- Endurance: 3-6 hr
- Tether: Fiber-Optic Cable or hard tether cable
- Control: tethered,Radio Control
- Sensors: Color Camera
- Payload: 15 lbs (6.8 kg)
- Manipulator: 78 in (2 m) telescoping arm with four degrees of freedom

Radio TX: tethered or RF
Radio RX: tethered or RF

Mini-Andros II

REMOTEC, Inc.
www.remotec-andros.com
865-483-0228/Jim Daniels


Ground Robots

Manufacturer's Specs:

- Width: 24.5 in (62 cm)
- Length: 53 in (134 cm)
- Height: 27 in (68 cm)
- Weight: 225 lbs (102.6 kg)
- Turning Dia: length of vehicle
- Max Speed: 1.1 mph(1.7 km/hr)
- Power Source: 24VDC - gel cell battery pack Battery
- Endurance: 3-6 hr
- Tether: Fiber-Optic Cable or hard tether cable
- Control: tethered,Radio Control
- Sensors: Color Camera
- Payload: 15 lbs (6.8 kg)
- Manipulator: 78 in (2 m) telescoping arm with four degrees of freedom

Radio TX: tethered or RF
Radio RX: tethered or RF

Robotic Mobility Platform

(RMP 400/INL)

Segway, Inc.

www.segway.com/Will Pong/603-222-6000

Manufacturer's Specs:

- Width: 30 in (76 cm)
- Length: 44 in (112 cm)
- Height: 24 in (61 cm)
- Weight: 240 lbs (109 kg)
- Turning Dia: 53 in (135 cm)
- Max Speed: 18 mph (29 km/h)
- Power Source: Four lithium-ion battery packs
- Endurance: 15 miles (24 km)
- Tether: None
- Control: Statically stabilized, remote teleoperative or autonomous
- Sensors: gyros, wheel encoders,
- Payload: 400 lb (180 kg)
- Manipulator: Barrett Technology WAM

Radio TX: 75 MHz/XXXmW (Video) 2400 MHZ/xxx mW (data)

Robotic Mobility Platform

(RMP 400/INL)

Segway, Inc.

www.segway.com/Will Pong/603-222-6000

Manufacturer's Specs:

- Width: 30 in (76 cm)
- Length: 44 in (112 cm)
- Height: 24 in (61 cm)
- Weight: 240 lbs (109 kg)
- Turning Dia: 53 in (135 cm)
- Max Speed: 18 mph (29 km/h)
- Power Source: Four lithium-ion battery packs
- Endurance: 15 miles (24 km)
- Tether: None
- Control: Statically stabilized, remote teleoperative or autonomous
- Sensors: gyros, wheel encoders,
- Payload: 400 lb (180 kg)
- Manipulator: Barrett Technology WAM

Radio TX: 75 MHz/XXXmW (Video) 2400 MHZ/xxx mW (data)

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Andros F6A

REMOTEC, Inc.
www.remotec-andros.com
865-483-0228/Jim Daniels


Ground Robots

Manufacturer's Specs:

- Width: 29 in (73 cm
- Length: 52 in (132 cm)
- Height: 56.5 in (140 cm)
- Weight: 485 lb (219.99kg)
- Turning Dia: within the length of vehicle
- Max Speed: 3.5 mph (5.6 km/hr)
- Power Source: 24VDC 35 amp-hr gel-cell battery pack
- Endurance: 3-6 hr
- Tether: Interchangeable Fiber Optic Cable reel, RF system, or Hard-line cable reel system
- Control: tethered or RF
- Sensors: Color camera with low-light
- Payload: 45 lbs (20.4 kg)
- Manipulator: Arm -Vertical reach 109 in (2.76 m) with tracks down and arm fully extended, Horizontal reach 56 in (1.42 m) from front of vehicle

Radio TX: tethered or RF
Radio RX: tethered or RF

Andros F6A

REMOTEC, Inc.
www.remotec-andros.com
865-483-0228/Jim Daniels


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- Width: 29 in (73 cm
- Length: 52 in (132 cm)
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- Control: tethered or RF
- Sensors: Color camera with low-light
- Payload: 45 lbs (20.4 kg)
- Manipulator: Arm -Vertical reach 109 in (2.76 m) with tracks down and arm fully extended, Horizontal reach 56 in (1.42 m) from front of vehicle

Radio TX: tethered or RF
Radio RX: tethered or RF

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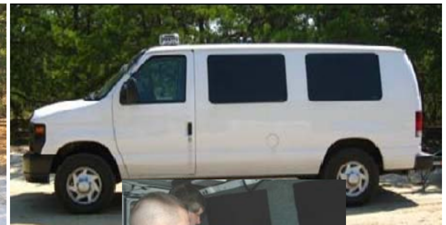
Centaur

The MITRE Corporation
www.mitre.org
rbolling@mitre.org

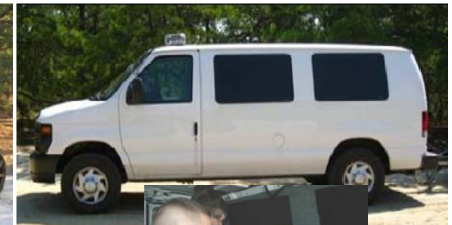

Manufacturer's Specs:

- Width: 118 in (300 cm)
- Length: 72 in (183 cm)
- Height: 74 in (188 cm)
- Weight: 2420 lbs (1097 kg)
- Turning Dia: 0in (0 cm)
- Max Speed: 28 mph, 41 fps (12.5 mps)
- Power Source: 34 hp turbo Diesel
- Endurance: 12 hours, 720 min
- Tether: none
- Control: remote teleop or waypoint with obstacle avoidance
- Sensors: Velodyne LIDAR, 2 SICK LMS, Omni-directional color camera, GPS, INS
- Payload: 1500 lb (680 kg)
- Manipulator: none, 4' x 4' bed for mounting

Radio TX: tethered or RF
Radio RX: tethered or RF

Centaur

The MITRE Corporation
www.mitre.org
rbolling@mitre.org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- Length: 72 in (183 cm)
- Height: 74 in (188 cm)
- Weight: 2420 lbs (1097 kg)
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- Power Source: 34 hp turbo Diesel
- Endurance: 12 hours, 720 min
- Tether: none
- Control: remote teleop or waypoint with obstacle avoidance
- Sensors: Velodyne LIDAR, 2 SICK LMS, Omni-directional color camera, GPS, INS
- Payload: 1500 lb (680 kg)
- Manipulator: none, 4' x 4' bed for mounting

Radio TX: tethered or RF
Radio RX: tethered or RF

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BOZ I

BOZ Robotics
www.bozrobot.com
847-574-0168/Jamie Alvarez


Ground Robots

Manufacturer's Specs:

- Width: 26.4 in (67 cm)
- Length: 67.3 in (171 cm)
- Height: 53.2 in (135 cm)
- Weight: 1,300 lbs (600 kg)
- Turning Dia: 360 degrees
- Max Speed: 6.7 km/h
- Power Source: battery
- Endurance: 3 - 4 hrs to continuous w/generator
- Tether: 100 meter; 1 km remote los
- Control: computer w/case and joystick
- Sensors: ultra sound distance sensors (to the cm) 5 cameras; 3 infrared
- Payload: 265 lb (120 kg) lifting capacity w/arm straight; 441 lbs (200 kg) arm bent
- Manipulator: Hydraulic gripper w/12,717 lbs (5,770 kg) of opening force, reach 11.5 ft (350 cm) and four joints independently operated to tear off car doors, trunks, & dexterity to pour a soda bottle in a glass

Radio TX: 2400 MHz
Radio RX: 2400 MHz

BOZ I

BOZ Robotics
www.bozrobot.com
847-574-0168/Jamie Alvarez


Ground Robots

Manufacturer's Specs:

- Width: 26.4 in (67 cm)
- Length: 67.3 in (171 cm)
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Radio TX: 2400 MHz
Radio RX: 2400 MHz

Wall Climbers

Wall Climbers

Wall
Climbers

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VMRP

Vortex HC LLC.
www.vortexhc.com
919-462-8828

Manufacturer's Specs:

- Width: 8.5 in (21.5 cm)
- Length: 6.5 in (16.5 cm)
- Height: 4 in (10 cm)
- Weight: 1.87 lbs (.84kg)
- Turning Dia: TBD
- Max Speed: 6 in/sec. (.154m/sec)
- Power Source: battery
- Endurance: 20- 40 minutes
- Tether: none
- Control: teleoped
- Sensors: 2 color camera (boom pan drive camera)
- Payload: 1 lbs (.45kg) (scalable)
- Manipulator: n/a

Radio TX: 2400 MHz (Bluetooth) video 1200 MHz
Radio RX: 2400 MHz (Bluetooth)

VMRP
Vortex HC LLC.
www.vortexhc.com
919-462-8828

Manufacturer's Specs:
- Width: 8.5 in (21.5 cm)
- Length: 6.5 in (16.5 cm)
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- Endurance: 20- 40 minutes
- Tether: none
- Control: teleoped
- Sensors: 2 color camera (boom pan drive camera)
- Payload: 1 lbs (.45kg) (scalable)
- Manipulator: n/a

Radio TX: 2400 MHz (Bluetooth) video 1200 MHz
Radio RX: 2400 MHz (Bluetooth)

194

NanoMag

Inuktun
www.inuktun.com/
1-877-468-5886

Manufacturer's Specs:

- Width: 17 in (43.1cm)
- Length: 12 in (30.4 cm)
- Height: 3.5 in (8.8 cm)
- Weight: 5 lbs (2.26kg)
- Turning Dia: TBD
- Max Speed: 0-5 ft/min (0-1.5 m/min)
- Power Source: TBD
- Endurance: TBD
- Tether: 100ft (30m)
- Control: teleoped
- Sensors: TBD
- Payload: TBD
- Manipulator: n/a

Wall Climbers

Radio Tx: (tether only)
Radio Rx: (tether only)

NanoMag

Inuktun
www.inuktun.com/
1-877-468-5886

Manufacturer's Specs:

- Width: 17 in (43.1cm)
- Length: 12 in (30.4 cm)
- Height: 3.5 in (8.8 cm)
- Weight: 5 lbs (2.26kg)
- Turning Dia: TBD
- Max Speed: 0-5 ft/min (0-1.5 m/min)
- Power Source: TBD
- Endurance: TBD
- Tether: 100ft (30m)
- Control: teleoped
- Sensors: TBD
- Payload: TBD
- Manipulator: n/a

Wall Climbers

Radio Tx: (tether only)
Radio Rx: (tether only)

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Aerial Robots

Aerial Robots

Aerial Robots

Aerial Robots

197

Nighthawk

Applied Research Associates, Inc
www.ara.com
Adam Sloan/asloan@ara.com

Manufacturer's Specs:

• Wingspan:	2.2 ft (0.66 m)
• Length:	1.7 ft (0.51 m)
• Weight:	1.65 lbs (0.750 kg)
• Range:	6.2 miles (10 km)
• Speed:	28 mph (44 kmph)
• Launch:	hand
• Recovery:	skid land
• Propulsion:	electric motor
• Altitude:	100-500 ft (30.48m-152.4m) AGL
• Endurance:	60-90 min
• Control:	auto waypoint following
• Payload:	color camera, infrared

Radio TX:915-928 MHz / 650 mW/2409-2469 MHz / 600 mW
Radio RX:

Nighthawk

Applied Research Associates, Inc
www.ara.com
Adam Sloan/asloan@ara.com

Manufacturer's Specs:

• Wingspan:	2.2 ft (0.66 m)
• Length:	1.7 ft (0.51 m)
• Weight:	1.65 lbs (0.750 kg)
• Range:	6.2 miles (10 km)
• Speed:	28 mph (44 kmph)
• Launch:	hand
• Recovery:	skid land
• Propulsion:	electric motor
• Altitude:	100-500 ft (30.48m-152.4m) AGL
• Endurance:	60-90 min
• Control:	auto waypoint following
• Payload:	color camera, infrared

Radio TX:915-928 MHz / 650 mW/2409-2469 MHz / 600 mW
Radio RX:

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Raven

AeroVironment Inc.
www.avsuav.com
626-357-9983

Manufacturer's Specs:

- Wingspan: 4.5 ft (1.4 m)
- Length: 3 ft (0.9 m)
- Weight: 4.2 lbs (1.9 kg)
- Range: 6.2 miles (10 km)
- Speed: 20-50 mph (32-82 km/hr)
- Launch: hand
- Recovery: deep stall vertical
  Propulsion: electric motor
- Altitude: 100-500 ft (30.48m-152.4m) AGL
- Endurance: 80-110 min
- Control: auto waypoint following
- Payload: color camera, infrared

Aerial Robots

Radio TX:
Radio RX:

Raven

AeroVironment Inc.
www.avsuav.com
626-357-9983

Manufacturer's Specs:

- Wingspan: 4.5 ft (1.4 m)
- Length: 3 ft (0.9 m)
- Weight: 4.2 lbs (1.9 kg)
- Range: 6.2 miles (10 km)
- Speed: 20-50 mph (32-82 km/hr)
- Launch: hand
- Recovery: deep stall vertical
  Propulsion: electric motor
- Altitude: 100-500 ft (30.48m-152.4m) AGL
- Endurance: 80-110 min
- Control: auto waypoint following
- Payload: color camera, infrared

Aerial Robots

Radio TX:
Radio RX:

Dragon Eye

AeroVironment Inc.
www.avsuav.com
626-357-9983

Manufacturer's Specs:

- Wingspan: 3 ft (0.9 m)
- Length: 3 ft (0.9 m)
- Weight: 5.9 lbs (2.7kg)
- Range: 3.1 mile (5 km)
- Speed: 21.7 mph (35 km/hr
  Launch: bungee
- Recovery: horizontal landing
- Propulsion: electric motor
- Altitude: 100-500 ft (30.48m-152.4m) AGL
- Endurance: 45-60 min
- Control: auto waypoint following
- Payload: color camera, infrared

Radio TX:
Radio RX:

Dragon Eye

AeroVironment Inc.
www.avsuav.com
626-357-9983

Manufacturer's Specs:

- Wingspan: 3 ft (0.9 m)
- Length: 3 ft (0.9 m)
- Weight: 5.9 lbs (2.7kg)
- Range: 3.1 mile (5 km)
- Speed: 21.7 mph (35 km/hr
  Launch: bungee
- Recovery: horizontal landing
- Propulsion: electric motor
- Altitude: 100-500 ft (30.48m-152.4m) AGL
- Endurance: 45-60 min
- Control: auto waypoint following
- Payload: color camera, infrared

Radio TX:
Radio RX:

Cyberbug

CyberDefense Systems
www.cyberdefensesystems.com/
Billy Robinson/727-577-0878

Manufacturer's Specs:

• Wingspan:	3.5 ft (1.1 m)
• Length:	3.5 ft (1.1 m)
• Weight:	7 lbs (3.2 kg)
• Range:	6.2 miles (10 km)
• Speed:	24.85 mph (40 km/hr)
• Launch:	hand
• Recovery:	horizontal landing
• Propulsion:	electric motor
• Altitude:	100-500 ft (30.48m-152.4m) AGL
• Endurance:	45 min
• Control:	auto waypoint following
Payload:	color camera, infrared

Aerial Robots

Radio TX: 900 MHz – 2400 MHz
Radio RX:

Cyberbug

CyberDefense Systems
www.cyberdefensesystems.com/
Billy Robinson/727-577-0878

Manufacturer's Specs:

• Wingspan:	3.5 ft (1.1 m)
• Length:	3.5 ft (1.1 m)
• Weight:	7 lbs (3.2 kg)
• Range:	6.2 miles (10 km)
• Speed:	24.85 mph (40 km/hr)
• Launch:	hand
• Recovery:	horizontal landing
• Propulsion:	electric motor
• Altitude:	100-500 ft (30.48m-152.4m) AGL
• Endurance:	45 min
• Control:	auto waypoint following
Payload:	color camera, infrared

Aerial Robots

Radio TX: 900 MHz – 2400 MHz
Radio RX:

201

Evolution-XTS

BAI Aerosystems
Kirk Jenkins/ 410-820-8500

Manufacturer's Specs:

- Wingspan: 5.4 ft (1.6 m)
- Length: 3.2 ft (1.0 m)
- Weight: 8.2 lbs (3.7 kg)
- Range: 10000 m LOS
- Speed: 30-50mph (48-81 kmph)
- Launch: hand
- Recovery: horizontal landing
- Propulsion: electric motor
- Altitude: 100-500 ft (30.48m-152.4m) AGL
- Endurance: 90 min
- Control: auto waypoint following
- Payload: color camera, infrared bio/chemical

Radio TX: 399.37 MHz / 1500 mW
Radio RX:

Evolution-XTS
BAI Aerosystems
Kirk Jenkins/ 410-820-8500

Manufacturer's Specs:
- Wingspan: 5.4 ft (1.6 m)
- Length: 3.2 ft (1.0 m)
- Weight: 8.2 lbs (3.7 kg)
- Range: 10000 m LOS
- Speed: 30-50mph (48-81 kmph)
- Launch: hand
- Recovery: horizontal landing
- Propulsion: electric motor
- Altitude: 100-500 ft (30.48m-152.4m) AGL
- Endurance: 90 min
- Control: auto waypoint following
- Payload: color camera, infrared bio/chemical

Radio TX: 399.37 MHz / 1500 mW
Radio RX:

202

Micro-Drone 200

BCB International, Ltd.
www.taccsc4i.com/www.bcbin.com
Barry Davies/Edward J. Schmitt


Manufacturer's Specs:

- Width: 36 in (95 cm)
- Weight: 1.5 lbs (680 gm)
- Range: 1.5 mi (3 km) Radius of Operation
- Avg Speed: 15 mph (35kmph)
- Launch: VTOL
- Recovery: deep stall vertical
- Propulsion: electric motors
- Altitude: 0-1500 ft (30-500 m)
- Orbit Direction: Left
- Orbit Diameter: @200ft AGL= <3 ft, @400ft AGL= <3 ft
- Endurance: 20 min
- Sensors: fwd/side color, zoom, Night Vision, Thermal Imaging, chem
- Payload: .44 lbs (200g)
- Other Features: waypoint following, Autonomous flight. Hi-Res Photo cameras, Infrared Camera, Thermal Camera, Laser rangefinder, GSM Jammer, IED detection, CBRN detection, Communication (repeater), RFID Long Range detection
- Payload: small camera

* Has not attended any exercises to date

Radio TX: 2.3-2.5 GHz / 10 mW (video), 2.3-2.5GHz / 10 mW (audio), 2.3-2.5 GHz / 200 mW (commands), 2.4 GHz / xxx mW (other),

Aerial Robots

Micro-Drone 200

BCB International, Ltd.
www.taccsc4i.com/www.bcbin.com
Barry Davies/Edward J. Schmitt


Manufacturer's Specs:

- Width: 36 in (95 cm)
- Weight: 1.5 lbs (680 gm)
- Range: 1.5 mi (3 km) Radius of Operation
- Avg Speed: 15 mph (35kmph)
- Launch: VTOL
- Recovery: deep stall vertical
- Propulsion: electric motors
- Altitude: 0-1500 ft (30-500 m)
- Orbit Direction: Left
- Orbit Diameter: @200ft AGL= <3 ft, @400ft AGL= <3 ft
- Endurance: 20 min
- Sensors: fwd/side color, zoom, Night Vision, Thermal Imaging, chem
- Payload: .44 lbs (200g)
- Other Features: waypoint following, Autonomous flight. Hi-Res Photo cameras, Infrared Camera, Thermal Camera, Laser rangefinder, GSM Jammer, IED detection, CBRN detection, Communication (repeater), RFID Long Range detection
- Payload: small camera

* Has not attended any exercises to date

Radio TX: 2.3-2.5 GHz / 10 mW (video), 2.3-2.5GHz / 10 mW (audio), 2.3-2.5 GHz / 200 mW (commands), 2.4 GHz / xxx mW (other),

Aerial Robots

203

AirRobot

AirRobot GmbH
www.AirRobot.com
49 2932 54 77 40/info@airrobot.de


Manufacturer's Specs:

- Rotor span: 36 in (1097 cm)
- Length: 36 in (1097 cm) diameter
- Weight: less than 2.2 lbs (less than 1 kg)
- Range: up to 1640 ft (up to 500 m)
- Speed: approximate 25 mph
- Launch: vertical
- Recovery: vertical
- Propulsion: electric, LiPo Battery 14.8 V, 2.05 Ah
- Altitude: up to 492 ft (150m)
- Endurance: 20-25 min
- Control: video glasses or Tablet PC
- Payload: 0.44 lb (0.2 kg)

Radio TX: 35 MHz (200 mW)
Radio RX: 35 MHz Video 1420 MHz

AirRobot

AirRobot GmbH
www.AirRobot.com
49 2932 54 77 40/info@airrobot.de


Manufacturer's Specs:

- Rotor span: 36 in (1097 cm)
- Length: 36 in (1097 cm) diameter
- Weight: less than 2.2 lbs (less than 1 kg)
- Range: up to 1640 ft (up to 500 m)
- Speed: approximate 25 mph
- Launch: vertical
- Recovery: vertical
- Propulsion: electric, LiPo Battery 14.8 V, 2.05 Ah
- Altitude: up to 492 ft (150m)
- Endurance: 20-25 min
- Control: video glasses or Tablet PC
- Payload: 0.44 lb (0.2 kg)

Radio TX: 35 MHz (200 mW)
Radio RX: 35 MHz

Flying Bassett

University of Alabama in Huntsville (UAH)
Gary Maddux/gary.maddux@us.army.mil

Manufacturer's Specs:

- Rotor span: 6 ft (1.8 m)
- Length: 7 ft (2.13 m)
- Weight: 45 lbs (20.4 kg)
- Range: 0.5 mi (0.81km) LOS, Further with GCS
- Speed: 5 mph (8.1km/hr)
- Launch: vertical takeoff
- Recovery: vertical landing
- Propulsion: Zenoah 80cc 8 hp Twin ylinder, Gasoline
- Altitude: 500 ft (152 m)
- Endurance: 20 min
- Control: auto waypoint following
- Payload:

Aerial Robots

Radio TX: 72.230 MHz / 100 mW
Radio RX:

Flying Bassett

University of Alabama in Huntsville (UAH)
Gary Maddux/gary.maddux@us.army.mil

Manufacturer's Specs:

- Rotor span: 6 ft (1.8 m)
- Length: 7 ft (2.13 m)
- Weight: 45 lbs (20.4 kg)
- Range: 0.5 mi (0.81km) LOS, Further with GCS
- Speed: 5 mph (8.1km/hr)
- Launch: vertical takeoff
- Recovery: vertical landing
- Propulsion: Zenoah 80cc 8 hp Twin ylinder, Gasoline
- Altitude: 500 ft (152 m)
- Endurance: 20 min
- Control: auto waypoint following
- Payload:

Aerial Robots

Radio TX: 72.230 MHz / 100 mW
Radio RX:

Yamaha Helicopter

SkeyesUnlimited Inc.
www.skeyesunlimited.com/index.html
412-661-0292

Manufacturer's Specs:

- Rotor span: 10.2 ft (3.1 m)
- Length: 11.8 ft (3.6 m)
- Weight: 207 lbs (94 kg)
- Range: 492 ft (150 m) LOS
- Speed: TBD
- Launch: vertical takeoff
- Recovery: vertical landing
- Propulsion: 21 hp, 246 cc, 2-stroke, gas/oil mix
- Altitude: TBD
- Endurance: 60 min
- Control: auto waypoint following
- Payload: 3-D laser scanner

Radio TX: TBD
Radio RX: TBD

Yamaha Helicopter

SkeyesUnlimited Inc.
www.skeyesunlimited.com/index.html
412-661-0292

Manufacturer's Specs:

- Rotor span: 10.2 ft (3.1 m)
- Length: 11.8 ft (3.6 m)
- Weight: 207 lbs (94 kg)
- Range: 492 ft (150 m) LOS
- Speed: TBD
- Launch: vertical takeoff
- Recovery: vertical landing
- Propulsion: 21 hp, 246 cc, 2-stroke, gas/oil mix
- Altitude: TBD
- Endurance: 60 min
- Control: auto waypoint following
- Payload: 3-D laser scanner

Radio TX: TBD
Radio RX: TBD

206

Blimp

ARACAR
www.aracar.org/index.html
985-845-3774


Manufacturer's Specs:

- Length: 10’ -20’ (3 m-6 m)
- Weight: < 0! lbs (< 0! kg)
- Range: 150 ft (50 m) tethered
- Speed: 0 km/hr (or tether vehicle speed)
- Launch: vertical pay out of tether
- Recovery: vertical retrieval of tether
- Propulsion: none
- Altitude: 150 ft (50 m)
- Endurance: TBD
- Control: none
- Payload: small camera

Aerial Robots

Radio TX:
Radio RX:

Blimp

ARACAR
www.aracar.org/index.html
985-845-3774


Manufacturer's Specs:

- Length: 10’ -20’ (3 m-6 m)
- Weight: < 0! lbs (< 0! kg)
- Range: 150 ft (50 m) tethered
- Speed: 0 km/hr (or tether vehicle speed)
- Launch: vertical pay out of tether
- Recovery: vertical retrieval of tether
- Propulsion: none
- Altitude: 150 ft (50 m)
- Endurance: TBD
- Control: none
- Payload: small camera

Aerial Robots

Radio TX:
Radio RX:

207

Aquatic Robots

Aquatic Robots

Aquatic Robots

209

VideoRay Pro 3

VideoRay
www.videoray.com/index.htm

Manufacturer's Specs:

- Width: 9 in (22.5 cm)
- Length: 12 in (30.5 cm)
- Height: 8.5 in (21 cm)
- Weight: Submersible: 8.4 lbs (3.8 kg), Total System: 90 lbs
- Depth Rating 500 ft (152 m)
- Max Speed: 2.6 knots
- Power Source: Battery Pack
- Endurance: xx
- Tether: power, comms, 250 ft (75 m)
- Control: remote teleop
- Sensors: front/rear camera, scanning sonar (seasprite)
- Payload: xxx
- Manipulator: 10 in (25 cm) gripper accessory

VideoRay Pro 3

VideoRay
www.videoray.com/index.htm

Manufacturer's Specs:

- Width: 9 in (22.5 cm)
- Length: 12 in (30.5 cm)
- Height: 8.5 in (21 cm)
- Weight: Submersible: 8.4 lbs (3.8 kg), Total System: 90 lbs
- Depth Rating 500 ft (152 m)
- Max Speed: 2.6 knots
- Power Source: Battery Pack
- Endurance: xx
- Tether: power, comms, 250 ft (75 m)
- Control: remote teleop
- Sensors: front/rear camera, scanning sonar (seasprite)
- Payload: xxx
- Manipulator: 10 in (25 cm) gripper accessory

210

LBV200L2

SeaBotix Inc.
www.SeaBotix.com
Sean Newsome

Manufacturer's Specs:

- Width: 9.65 in (245 cm)
- Length: 21 in (530 cm)
- Height: 10 in (254 cm)
- Weight: 24.25 lbs (11 kg)
- Locomotion: 4 Brushless Thrusters (1 vertical, 1 lateral & 2 forward/reverse)
- Steering: Joystick w/ various knob control
- Turning Diam: 24 in (61 cm)
- Max Speed: 5 fps (1.54 mps)
- Power Source: 110V/220V
- Tether: Power, Data & Communication
- Control: Integrated Control Console with Handheld Controller
- Sensors: Standard: Color and Black/White Cameras, Depth, Heading, Water Temperature Optional: Grabber Attachment, Multi-beam Sonar, Scanning Sonar, Navigation System (USBL), Zoom Camera, High-Definition (HD) Camera, Scaling Lasers, Radiation Detector, Thickness Gauge, Altimeter, LYYN Video Enhancement
- Payload in water: 1 lb (0.45 kg), (additional floats can accommodate more weight)
- Manipulator: Grabber (3 jaw, interlocking, parallel & cutting), reach 10 in (25.4 cm)

Aquatic Robots

LBV200L2

SeaBotix Inc.
www.SeaBotix.com
Sean Newsome

Manufacturer's Specs:

- Width: 9.65 in (245 cm)
- Length: 21 in (530 cm)
- Height: 10 in (254 cm)
- Weight: 24.25 lbs (11 kg)
- Locomotion: 4 Brushless Thrusters (1 vertical, 1 lateral & 2 forward/reverse)
- Steering: Joystick w/ various knob control
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- Power Source: 110V/220V
- Tether: Power, Data & Communication
- Control: Integrated Control Console with Handheld Controller
- Sensors: Standard: Color and Black/White Cameras, Depth, Heading, Water Temperature Optional: Grabber Attachment, Multi-beam Sonar, Scanning Sonar, Navigation System (USBL), Zoom Camera, High-Definition (HD) Camera, Scaling Lasers, Radiation Detector, Thickness Gauge, Altimeter, LYYN Video Enhancement
- Payload in water: 1 lb (0.45 kg), (additional floats can accommodate more weight)
- Manipulator: Grabber (3 jaw, interlocking, parallel & cutting), reach 10 in (25.4 cm)

Aquatic Robots

211

LBV150SE-5

SeaBotix Inc.
www.SeaBotix.com
Sean Newsome


Manufacturer's Specs:

	LBV w/CSA	LBV only
• Width:	19.7 in (50 cm)	19.7 in (50 cm)
• Length:	20.5 in (52 cm)	20.5 in (52 cm)
• Height:	15.75 in (40 cm)	8.7 in (22 cm)
• Weight:	61.7 lbs (28 kg)	28.6 lbs (13 kg)

- Locomotion: Standard 4-axis in-water flight without CSA Attached or combo of wheeled drive with Vortex attach. 5-axis in-water flight in Crawler mode
- Steering: Joystick/var. knob control/Skid
  Turning Diam: ~20 in (51 cm)
- Max Speed: Water: 3 knots/crawler:1.64 fps(0.5 mps)
- Power Source: AC power via shore power, generator, inverter w/true sign wave.
- Endurance: Indefinitely with power applied.
- Tether: Yes
- Sensors: Video, sonar, depth, temp, heading.
  Optional: Grabber Attachment, Multi-beam Sonar, Scanning Sonar, Navigation System (USBL), Zoom Camera, Scaling Lasers, Rad.Detector, Thickness Gauge, Altimeter, LYYN Video Enhancement
- Payload: 3.3 lb (1.5 kg) in water.
- Manipulator: Single function 3-jaw standard (open/close) w/ optional attachments for cutting, parallel, and interlocking.

LBV150SE-5

SeaBotix Inc.
www.SeaBotix.com
Sean Newsome


Manufacturer's Specs:

	LBV w/CSA	LBV only
• Width:	19.7 in (50 cm)	19.7 in (50 cm)
• Length:	20.5 in (52 cm)	20.5 in (52 cm)
• Height:	15.75 in (40 cm)	8.7 in (22 cm)
• Weight:	61.7 lbs (28 kg)	28.6 lbs (13 kg)

- Locomotion: Standard 4-axis in-water flight without CSA Attached or combo of wheeled drive with Vortex attach. 5-axis in-water flight in Crawler mode
- Steering: Joystick/var. knob control/Skid
  Turning Diam: ~20 in (51 cm)
- Max Speed: Water: 3 knots/crawler:1.64 fps(0.5 mps)
- Power Source: AC power via shore power, generator, inverter w/true sign wave.
- Endurance: Indefinitely with power applied.
- Tether: Yes
- Sensors: Video, sonar, depth, temp, heading.
  Optional: Grabber Attachment, Multi-beam Sonar, Scanning Sonar, Navigation System (USBL), Zoom Camera, Scaling Lasers, Rad.Detector, Thickness Gauge, Altimeter, LYYN Video Enhancement
- Payload: 3.3 lb (1.5 kg) in water.
- Manipulator: Single function 3-jaw standard (open/close) w/ optional attachments for cutting, parallel, and interlocking.

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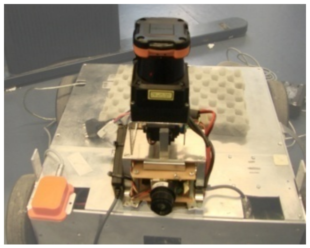
Sensors

Sensors

Sensors
213

dcMap

University of Freiburg
www.informatik.uni-freiburg.de/~kleiner
kleiner@informatik.uni-freiburg.de



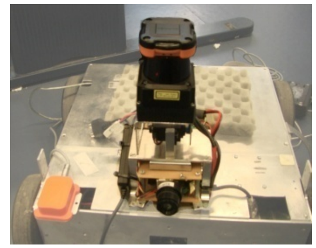

Manufacturer's Specs:

- Width: 3.92 in (10 cm)
- Length: 4.3 in (11 cm)
- Height: 9.06 in (23 cm)
- Weight: 1.76lbs (0.8 kg)
- Power Source: Lith.Polymer battery,
- Endurance: 120 min
- Control: remote teleop
- Sensors: Hokuyo UTM30 Laser Range Finder, ThermalEye thermo cam, Xsens IMU

•The sensor head can be mounted on any robot system
•without requiring data from the robot, such as wheel
•odometry data.

dcMap

University of Freiburg
www.informatik.uni-freiburg.de/~kleiner
kleiner@informatik.uni-freiburg.de




Manufacturer's Specs:

- Width: 3.92 in (10 cm)
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- Weight: 1.76lbs (0.8 kg)
- Power Source: Lith.Polymer battery,
- Endurance: 120 min
- Control: remote teleop
- Sensors: Hokuyo UTM30 Laser Range Finder, ThermalEye thermo cam, Xsens IMU

•The sensor head can be mounted on any robot system
•without requiring data from the robot, such as wheel
•odometry data.

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GammaRAE II Responder

RAE Systems, Inc
www.raesystems.com

Manufacturer's Specs:

- Width: 2.7 in(6.8 cm)
- Length: 4.9 in (12.5 cm)
- Height: 1.4 in(3.5 cm)
- Weight: 0.625 lbs (0.24 kg)
- Sensitivity: (Cs-137, Co-60, Am-241)
- Energy range: 60 keV to 3.0 MeV
- Exposure rate range: 1 μR/h to 10 R/h
- Response with angle if incidence: ±20% from 0° for -45° to 45° (Cs-137)
- Type of detector: CsI(Tl)+photodiode & energy-compensated
- Data transmission type: Bluetooth
- Battery type and lifetime: 2xAA alkaline, 500hr
- Display type: Backlit LCD
- Alarm type: Audible, Visual LEDs, Built-in vibration
- Control: Manual
- Radio frequency immunity:
- Radiated emission: omplies with FCC Part 15
- Shock resistance: Passes drop tests from 59 in (1.5 m)

Sensors

GammaRAE II Responder

RAE Systems, Inc
www.raesystems.com

Manufacturer's Specs:

- Width: 2.7 in(6.8 cm)
- Length: 4.9 in (12.5 cm)
- Height: 1.4 in(3.5 cm)
- Weight: 0.625 lbs (0.24 kg)
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- Energy range: 60 keV to 3.0 MeV
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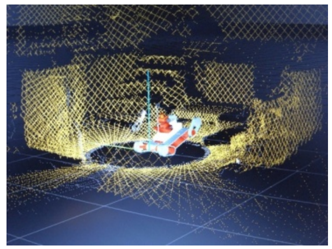
- Response with angle if incidence: ±20% from 0° for -45° to 45° (Cs-137)
- Type of detector: CsI(Tl)+photodiode & energy-compensated
- Data transmission type: Bluetooth
- Battery type and lifetime: 2xAA alkaline, 500hr
- Display type: Backlit LCD
- Alarm type: Audible, Visual LEDs, Built-in vibration
- Control: Manual
- Radio frequency immunity:
- Radiated emission: omplies with FCC Part 15
- Shock resistance: Passes drop tests from 59 in (1.5 m)

Sensors

215

High Speed 3D Scanner

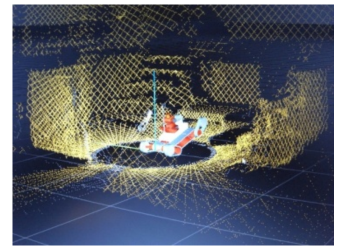
School of Information Sciences, Tohoku University / IRS
: Kazunori Ohno/kazunori@rm.is.tohoku.ac.jp



Manufacturer's Specs:

- Width: 5.1 in (13.0 cm)
- Length: 4.1 in (10.5 cm)
- Height: 8.8 in (22.4 cm)
- Weight: 11 lbs (5.0 kg)
- Max Speed: .1fps (Frame Per Second)
- Power Source: battery
- Endurance: N/A
- Tether: LAN
- Control: N/A
- Sensors: 2D LRF + Pan Tilt base
- Payload: N/A
- Manipulator: N/A
- Radio Tx: Tethered
- Radio Rx: Tethered

High Speed 3D Scanner
School of Information Sciences, Tohoku University / IRS
: Kazunori Ohno/kazunori@rm.is.tohoku.ac.jp



Manufacturer's Specs:

- Width: 5.1 in (13.0 cm)
- Length: 4.1 in (10.5 cm)
- Height: 8.8 in (22.4 cm)
- Weight: 11 lbs (5.0 kg)
- Max Speed: .1fps (Frame Per Second)
- Power Source: battery
- Endurance: N/A
- Tether: LAN
- Control: N/A
- Sensors: 2D LRF + Pan Tilt base
- Payload: N/A
- Manipulator: N/A
- Radio Tx: Tethered
- Radio Rx: Tethered

ICS-4000 Radionuclide Identifier

XRF Corporation
www.xrfcorp.com / www.laurussystems.com

Manufacturer's Specs:

• Width:	3.4 in
• Length:	10.2 in
• Height:	1.2 in
• Weight:	1.75 lbs
• Sensitivity:	Cs-137: 90 cps/mR/h, Co-60: 25 cps/mR/h, Am-241: 2900 cps/mR/h
• Energy range:	10 keV – 2 MeV
• Exposure rate range:	50 mR/h – 1 R/h
• Response with angle if incidence:	-3.3% 0° for -45° to 45° (Cs-137)
• Type of detector:	Solid state CdTe for dose rate & radionuclide ID
• Data transmission type:	Bluetooth
• Battery type and lifetime:	24 hours
• Display type:	LCD w LED backlight
• Alarm type:	Audible & visual
• Control:	Remote / manual
• Radio frequency immunity:	Class A per standard EN 61326 (1997) + A1 (1998) + A2 (2001)
• Radiated emission:	Class B per standard EN 61326 (1997) + A1 (1998) + A2 (2001)
• Shock resistance:	Conditional per ANSI N42.34

ICS-4000 Radionuclide Identifier

XRF Corporation
www.xrfcorp.com / www.laurussystems.com

Manufacturer's Specs:

• Width:	3.4 in
• Length:	10.2 in
• Height:	1.2 in
• Weight:	1.75 lbs
• Sensitivity:	Cs-137: 90 cps/mR/h, Co-60: 25 cps/mR/h, Am-241: 2900 cps/mR/h
• Energy range:	10 keV – 2 MeV
• Exposure rate range:	50 mR/h – 1 R/h
• Response with angle if incidence:	-3.3% 0° for -45° to 45° (Cs-137)
• Type of detector:	Solid state CdTe for dose rate & radionuclide ID
• Data transmission type:	Bluetooth
• Battery type and lifetime:	24 hours
• Display type:	LCD w LED backlight
• Alarm type:	Audible & visual
• Control:	Remote / manual
• Radio frequency immunity:	Class A per standard EN 61326 (1997) + A1 (1998) + A2 (2001)
• Radiated emission:	Class B per standard EN 61326 (1997) + A1 (1998) + A2 (2001)
• Shock resistance:	Conditional per ANSI N42.34

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Inspector-1000

Canberra Industries
www.canberra.com

Manufacturer's Specs:

- Width: 7.5 in (19 cm)
- Length: 6.5 in (16.5 cm)
- Height: 2.5 in (6.4 cm)
- Weight: 2.2 lbs (1.0 kg)
- Sensitivity: (Cs-137, Co-60, Am-241)
- Energy range: 50-3000 keV
- Exposure rate range: 1000 mR/h
- Response with angle if incidence: 95% from 0° for -45° to 45° (Cs-137)
- Type of detector: GM + (either NaI(Tl) or LaBr) with radionuclide ID
- Data transmission type: USB
- Battery type and lifetime: 12, hours
- Display type: LCD 320 x 200 Hi-res color display
- Alarm type: audible, visual
- Control: eyes-on, manual
- Radio frequency immunity: yes
- Radiated emission: yes
- Shock resistance: yes

Inspector-1000

Canberra Industries
www.canberra.com

Manufacturer's Specs:

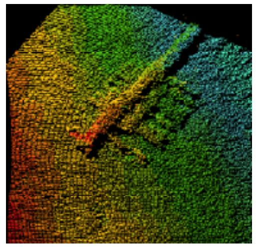
- Width: 7.5 in (19 cm)
- Length: 6.5 in (16.5 cm)
- Height: 2.5 in (6.4 cm)
- Weight: 2.2 lbs (1.0 kg)
- Sensitivity: (Cs-137, Co-60, Am-241)
- Energy range: 50-3000 keV
- Exposure rate range: 1000 mR/h
- Response with angle if incidence: 95% from 0° for -45° to 45° (Cs-137)
- Type of detector: GM + (either NaI(Tl) or LaBr) with radionuclide ID
- Data transmission type: USB
- Battery type and lifetime: 12, hours
- Display type: LCD 320 x 200 Hi-res color display
- Alarm type: audible, visual
- Control: eyes-on, manual
- Radio frequency immunity: yes
- Radiated emission: yes
- Shock resistance: yes

Multibeam Imaging Sonar

MBI350-45

BlueVeiw Technologies

www.blueveiwtech.com



Manufacturer's Specs:

- **Specifications**
  - Field of View: 45˚x 1°
  - Max Range: 90 ft
  - True Beam Width: 1˚x 1˚
  - Number of Beams: 256
  - Beam Spacing: 0.18°
  - Range Resolution: .016 in
  - Update Rate: Up to 40 Hz
  - Frequency: 1.35 MHz

- **Mechanical Specifications**
  - Weight in Air: 12.0 lb
  - Weight in Water: 3.2 lb
  - Depth Rating: 1000 ft
  - Size: 10.5 in x 9.2 in x 5.3 in

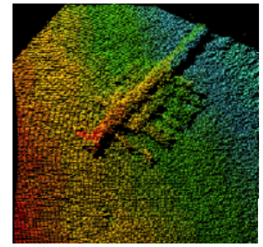
- **Interface Specifications**
  - Coms: Ethernet
  - Voltage: 12-48 VDC
  - Power: 15 Watts

Multibeam Imaging Sonar

MBI350-45

BlueVeiw Technologies

www.blueveiwtech.com

Manufacturer's Specs:

- **Specifications**
  - Field of View: 45˚x 1°
  - Max Range: 90 ft
  - True Beam Width: 1˚x 1˚
  - Number of Beams: 256
  - Beam Spacing: 0.18°
  - Range Resolution: .016 in
  - Update Rate: Up to 40 Hz
  - Frequency: 1.35 MHz

- **Mechanical Specifications**
  - Weight in Air: 12.0 lb
  - Weight in Water: 3.2 lb
  - Depth Rating: 1000 ft
  - Size: 10.5 in x 9.2 in x 5.3 in

- **Interface Specifications**
  - Coms: Ethernet
  - Voltage: 12-48 VDC
  - Power: 15 Watts

Sensors

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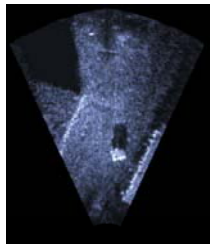
Multibeam Imaging Sonar

P450E-15

BlueVeiw Technologies

www.blueveiwtech.com



Manufacturer's Specs:

- **Specifications**
  - Field of View: 45˚x 15°
  - Max Range: 450 ft
  - True Beam Width: 1˚x 15˚
  - Number of Beams: 256
  - Beam Spacing: 0.18°
  - Range Resolution: 2 in
  - Update Rate: Up to 10 Hz
  - Frequency: 450 kHz

- **Mechanical Specifications**
  - Weight in Air: 5.7 lb
  - Weight in Water: 1.4 lb
  - Depth Rating: 1000 ft
  - Size: 9.6 in x 6.9 in x 4 in

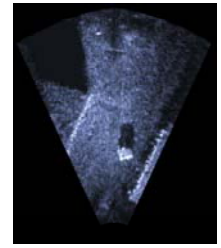
- **Interface Specifications**
  - Coms: Ethernet
  - Voltage: 12-48 VDC
  - Power: 10 Watts

Multibeam Imaging Sonar

P450E-15

BlueVeiw Technologies

www.blueveiwtech.com

Manufacturer's Specs:

- **Specifications**
  - Field of View: 45˚x 15°
  - Max Range: 450 ft
  - True Beam Width: 1˚x 15˚
  - Number of Beams: 256
  - Beam Spacing: 0.18°
  - Range Resolution: 2 in
  - Update Rate: Up to 10 Hz
  - Frequency: 450 kHz

- **Mechanical Specifications**
  - Weight in Air: 5.7 lb
  - Weight in Water: 1.4 lb
  - Depth Rating: 1000 ft
  - Size: 9.6 in x 6.9 in x 4 in

- **Interface Specifications**
  - Coms: Ethernet
  - Voltage: 12-48 VDC
  - Power: 10 Watts

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Multibeam Imaging Sonar

P900E-20
BlueVeiw Technologies
www.blueveiwtech.com
206-545-7260

Manufacturer's Specs:

- **900 kHz Head Specifications**
  - Field of View: 45˚x 20°
  - Max Range: 180 ft
  - True Beam Width: 1˚x 20˚
  - Number of Beams: 256
  - Beam Spacing: 0.18°
  - Range Resolution: 1 in
  - Update Rate: Up to 10 Hz
  - Frequency: 900 kHz

- **Mechanical Specifications**
  - Weight in Air: 4.0 lb
  - Weight in Water: 1 lb
  - Depth Rating: 1000 ft
  - Size: 7 inx 4 in OD

- **Interface Specifications**
  - Coms: Ethernet
  - Voltage: 12-48 VDC
  - Power: 10 Watts

Multibeam Imaging Sonar

P900E-20
BlueVeiw Technologies
www.blueveiwtech.com
206-545-7260

Manufacturer's Specs:

- **900 kHz Head Specifications**
  - Field of View: 45˚x 20°
  - Max Range: 180 ft
  - True Beam Width: 1˚x 20˚
  - Number of Beams: 256
  - Beam Spacing: 0.18°
  - Range Resolution: 1 in
  - Update Rate: Up to 10 Hz
  - Frequency: 900 kHz

- **Mechanical Specifications**
  - Weight in Air: 4.0 lb
  - Weight in Water: 1 lb
  - Depth Rating: 1000 ft
  - Size: 7 in x 4 in OD

- **Interface Specifications**
  - Coms: Ethernet
  - Voltage: 12-48 VDC
  - Power: 10 Watts

Multibeam Imaging Sonar

BlueVeiw Technologies
www.blueveiwtech.com
206-545-7260

Manufacturer's Specs:

- **900 kHz Head Specifications**
  - Field of View: 45˚x 20°
  - Max Range: 180 ft
  - True Beam Width: 1˚x 20˚
  - Number of Beams: 256
  - Beam Spacing: 0.18°
  - Range Resolution: 1 in
  - Update Rate: Up to 10 Hz
  - Frequency: 900 kHz
- **2.25 MHz Head Specifications**
  - Field of View: 45˚x 20°
  - Max Range: 15 ft
  - True Beam Width: 1˚x 20˚
  - Number of Beams: 256
  - Beam Spacing: 0.18°
  - Range Resolution: 0.4 in
  - Update Rate: Up to 10 Hz
  - Frequency: 2.25 MHz
- **Mechanical Specifications**
  - Weight in Air: 6.0 lb
  - Weight in Water: 1.5 lb
  - Depth Rating: 1000 ft
  - Size: 8.3 in x 5.0 in OD
- **Interface Specifications**
  - Coms: Ethernet
  - Voltage: 12-48 VDC
  - Power: 15 Watts

Multibeam Imaging Sonar

BlueVeiw Technologies
www.blueveiwtech.com
206-545-7260

Manufacturer's Specs:

- **900 kHz Head Specifications**
  - Field of View: 45˚x 20°
  - Max Range: 180 ft
  - True Beam Width: 1˚x 20˚
  - Number of Beams: 256
  - Beam Spacing: 0.18°
  - Range Resolution: 1 in
  - Update Rate: Up to 10 Hz
  - Frequency: 900 kHz
- **2.25 MHz Head Specifications**
  - Field of View: 45˚x 20°
  - Max Range: 15 ft
  - True Beam Width: 1˚x 20˚
  - Number of Beams: 256
  - Beam Spacing: 0.18°
  - Range Resolution: 0.4 in
  - Update Rate: Up to 10 Hz
  - Frequency: 2.25 MHz
- **Mechanical Specifications**
  - Weight in Air: 6.0 lb
  - Weight in Water: 1.5 lb
  - Depth Rating: 1000 ft
  - Size: 8.3 in x 5.0 in OD
- **Interface Specifications**
  - Coms: Ethernet
  - Voltage: 12-48 VDC
  - Power: 15 Watts

Radiogem

Canberra Industries
www.canberra.com

Manufacturer's Specs:

Width:	5.9 in (15.0 cm)
Length:	3.3 in (8.5 cm)
Height:	1.8 in (4.5 cm)
Weight:	.66 lbs(0.300 kg)
Sensitivity:	yes (Cs-137, Co-60, Am-241)
Energy range:	30 - 2000 keV (probe dep.)
Exposure rate range:	0.03-10,000mR/h
Response with angle if incidence:	95% from 0° for -45° to 45° (Cs-137)
Type of detector:	GM, or NaI, Plastic
Data transmission type:	RS-232
Battery type and lifetime:	80 hours
Display type:	LCD display
Alarm type:	audible, visual
Control:	eyes-on, manual
Radio frequency immunity:	yes
Radiated emission:	yes
Shock resistance:	yes

Radiogem

Canberra Industries
www.canberra.com

Manufacturer's Specs:

Width:	5.9 in (15.0 cm)
Length:	3.3 in (8.5 cm)
Height:	1.8 in (4.5 cm)
Weight:	.66 lbs(0.300 kg)
Sensitivity:	yes (Cs-137, Co-60, Am-241)
Energy range:	30 - 2000 keV (probe dep.)
Exposure rate range:	0.03-10,000mR/h
Response with angle if incidence:	95% from 0° for -45° to 45° (Cs-137)
Type of detector:	GM, or NaI, Plastic
Data transmission type:	RS-232
Battery type and lifetime:	80 hours
Display type:	LCD display
Alarm type:	audible, visual
Control:	eyes-on, manual
Radio frequency immunity:	yes
Radiated emission:	yes
Shock resistance:	yes

Sensors

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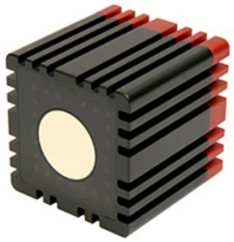
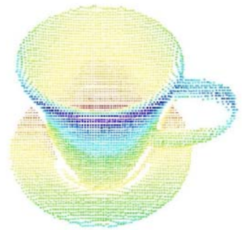
Swiss Ranger 4000

Mesa Imaging AG/Acroname Inc.
www.acroname.com (US) / www.mesa-imaging.ch (Switzerland)
Steve Richards (steve@acroname.com)

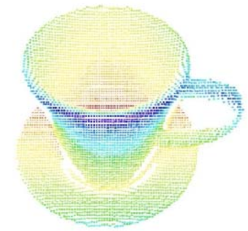




Manufacturer's Specs:

- Width: 2.6 in (6.5 cm)
- Length: 2.6 in (6.8 cm)
- Height: 2.6 in (6.5 cm)
- Weight: 1.05 lbs (470 g)
- Locomotion: None
- Steering: None
- Turning Diam: None
- Max Speed: 54 fps
- Power Source: battery (12V)
- Endurance: None
- Tether: USB or Ethernet
- Control: Mac, Linux, Windows Drivers
- Sensors: 3D Depth Imaging (176x144) pixel, 0.3 to 5.0 meter
- Payload: None
- Manipulator: None

Swiss Ranger 4000



Manufacturer's Specs:

- Width: 2.6 in (6.5 cm)
- Length: 2.6 in (6.8 cm)
- Height: 2.6 in (6.5 cm)
- Weight: 1.05 lbs (470 g)
- Locomotion: None
- Steering: None
- Turning Diam: None
- Max Speed: 54 fps
- Power Source: battery (12V)
- Endurance: None
- Tether: USB or Ethernet
- Control: Mac, Linux, Windows Drivers
- Sensors: 3D Depth Imaging (176x144) pixel, 0.3 to 5.0 meter
- Payload: None
- Manipulator: None

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UltraRadiac

Canberra Industries
www.canberra.com

Manufacturer's Specs:

- Width: 2.61 in (6.6 cm)
- Length: 3.95 in (10.0 cm)
- Height: 1.14 in (2.9 cm)
- Weight: .6 lbs (0.269 kg)
- Sensitivity: yes (Cs-137, Co-60, Am-241)
- Energy range: 60 - 1300 keV
- Exposure rate range: 0.001 – 500,000 mR/h
- Response with angle if incidence: 45° to 45° (Cs- 95% from 0° for - 137)
- Type of detector: GM
- Data transmission type: RS-232
- Battery type and lifetime: 150 hours
- Display type: LCD display
- Alarm type: audible, visual, vibration
- Control: yes-on, manual
- Radio frequency immunity: yes
- Radiated emission: yes
- Shock resistance: yes

Sensors

UltraRadiac

Canberra Industries
www.canberra.com

Manufacturer's Specs:

- Width: 2.61 in (6.6 cm)
- Length: 3.95 in (10.0 cm)
- Height: 1.14 in (2.9 cm)
- Weight: .6 lbs (0.269 kg)
- Sensitivity: yes (Cs-137, Co-60, Am-241)
- Energy range: 60 - 1300 keV
- Exposure rate range: 0.001 – 500,000 mR/h
- Response with angle if incidence: 45° to 45° (Cs- 95% from 0° for - 137)
- Type of detector: GM
- Data transmission type: RS-232
- Battery type and lifetime: 150 hours
- Display type: LCD display
- Alarm type: audible, visual, vibration
- Control: yes-on, manual
- Radio frequency immunity: yes
- Radiated emission: yes
- Shock resistance: yes

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