*A Timeline of NRL's*

AUTONOMOUS SYSTEMS
Research

The Naval Research Laboratory has been actively involved in research in unmanned and autonomous systems since its opening in 1923. From one of the first unmanned ground vehicles to the development of more than 200 prototype air, ground, underwater, and space platforms, and from smart sensors to smart batteries to robots that reason like humans, NRL's research has been at the forefront. In January 2012, NRL completed construction on its new Laboratory for Autonomous Systems Research. This Laboratory provides specialized facilities to support highly innovative research in autonomous systems, including intelligent autonomy, sensor systems, power and energy systems, human–system interaction, networking and communications, and platforms. The Laboratory capitalizes on the broad multidisciplinary character of NRL, bringing together scientists and engineers with disparate training and backgrounds to tackle common goals in autonomy research at the intersection of their respective fields. The Laboratory provides simulated environments (littoral, desert, tropical) and instrumented reconfigurable high bay spaces to support integration of science and technology components into research prototype systems. The objective of the Laboratory is to enable continued Navy and DoD scientific leadership in this complex, emerging area and to identify opportunities for advances in future defense technology. In the following pages, we present a timeline of NRL's research in unmanned and autonomous systems from 1923 to the present.

1923 Electric Dog

NRL devised a control switch with a vertical handle, similar to the control stick of an aircraft, which could operate selective relays simultaneously to provide for the several controls necessary to the flight of aircraft. It was first applied
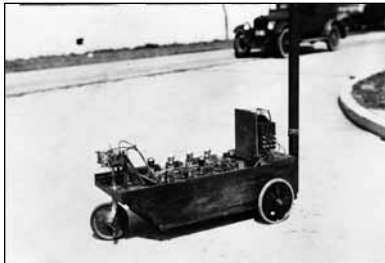
to a three-wheel cart system, the "electric dog," which could be seen wandering about on NRL's driveways.

### 1924 Remote-Controlled Pontoon Plane

NRL developed the control system for the first U.S. flight of a radio-controlled pilotless aircraft. Remotely controlled from the ground, the N-9 float plane took off from the Potomac River, followed a triangular course, executed

glides and climbs, and landed on the river.

1926 Joystick Remote Control Circuit Patent

NRL's C.B. Mirick patented his system for remote radio control of pilotless aircraft (or of "any circuits or objects which are to be controlled at a distance") using a "'joy stick' identical with the 'joy stick' provided in aircraft." U.S. Patent no. 1,597,416, "Electrical Distant-Control
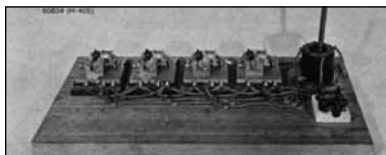
System," Aug. 24, 1926. "My invention relates broadly to distant control systems, and more particularly to a control

circuit for a radio transmitter, and a selectively responsive circuit for a radio apparatus whereby particular controls may be caused to function individually or simultaneously."

1930s Remote-Controlled Decoy Battleships

For exercises to test the vulnerability of ships to air bombing, NRL devised a radio remote control system to maneuver the warships USS *Stoddert* and USS *Utah,* which had been converted to target ships. The steering and throttle controls were operated through selector

switches based on the teletype mechanism using the Baudot code.

1936–WWII
Anti-Aircraft Target Drones

The Navy needed more realistic anti-aircraft practice targets than target sleeves towed by piloted aircraft, so NRL developed the radio-control system for an unmanned aircraft that, in demonstration, could be controlled by a "mother plane" 25 miles away. Target "drones" became widely used and led to rapid improvement in fire-control systems. Hundreds of F6F and other type aircraft were converted to drones for gunnery training, evaluation of defense procedures, and to carry out simulated "Japanese suicide" attacks.

1942 Assault/Guided Missile Drones

The first complete simulation of a guided missile was demonstrated using an unmanned type BG-1 aircraft equipped as an assault drone with NRL's radio-command guidance system and remote observation by television. The drone crashed through a towed battle raft, proving the capabilities as a weapon.

1945 Aircraft Carrier Traffic and Landing Control

NRL developed a radar carrier-controlled approach system that allowed aircraft to land on a carrier in complete darkness. It was first demonstrated on USS *Solomons* (CVE 67).

1946 Bikini Atoll Test Observation by Drones

Radio-guided drones collected data on nuclear explosions during the Bikini tests in the Pacific, telemetering it to safe observation points aboard ship.

1947 Loon Ship-to-Surface Guided Missile System

The Loon, with the guidance system developed by NRL, provided the first successful demonstration of a surface-to-surface guided missile and the first guided missile to be launched from a submarine, USS *Cusk*. NRL contributions included tracking by radar and steering by radio remote control.

1955 Polaris

NRL participated extensively in the conceptual planning and development of the submarine-launched Polaris missile.

1957 Blossom Point Satellite Tracking and Command Facility

NRL developed the first operational U.S. satellite tracking station at Blossom

Point, Maryland. Still in operation, Blossom Point pioneers automated ground commanding of satellites.

1958 Vanguard Solar Power System

Vanguard I proved that solar cells could be used for several years to power satellite radio transmitters. Vanguard's solar cells operated for about 7 years, while conventional batteries powering another onboard transmitter lasted only 20 days.

1960 GRAB

The Galactic Radiation and Background satellite was America's first electronic intelligence (ELINT) satellite. GRAB's ELINT antennas collected each pulse of a Soviet radar signal in a specified bandwidth, and a larger and separate

turnstile antenna transponded a corresponding signal to NRL receiving and control huts.

1964 Gravity Gradient Stabilization Experiment Satellites

NRL pioneered the gravity-gradient system for stabilizing the attitude of satellites with respect to Earth. This system is widely used in present-day satellites.

1976 MSD/Titan Launch Dispenser

NRL conceived and built the Multi-Satellite Dispenser (MSD), later modified

as the Titan Launch Dispenser (1990), a booster stage that goes through a

preprogrammed sequence of tasks to deposit multiple satellites from low shuttle orbits into their respective orbits, with or without real-time guidance from Earth.

1977 Nickel Hydrogen Battery on Navigation Technology Satellite-2

This was the first use of an NiH_2 battery as the primary energy source on a satellite, instead of nickel cadmium, for higher power and longer life.

1979 Unmanned Free-Swimming Submersible (UFSS)

NRL developed a long-range autonomous submersible to demonstrate (1) autonomy obtained by an OMEGA navi-

gator and a preprogrammed command and control microcomputer, and (2) high endurance (25 hr at 5 kt) attained with a low-drag hull and inexpensive battery energy source.

1981 NCARAI Established

Realizing the importance of artificial intelligence to the development of more intelligent autonomous and human-centered systems, NRL created the Navy Center for Applied Research in Artificial Intelligence.

1985 Cluster-based Routing

NRL conducted seminal work on distributed, self-organizing routing protocols for autonomous networking based upon clustering concepts. The novel concept of automated, dynamic structural formation amongst network nodes allowed improvements in mobile organization and wireless channel access coordination in self-forming networks.

1985 Fault Isolation Shell (FIS)

This tool captures device-specific knowledge to build expert systems to autonomously determine the causes of the breakdown of complex electro-mechanical-optical equipment, to aid maintenance and troubleshooting.

1986 Navy Message Understanding

This robust natural language processing system enabled automatic processing and summarizing of Navy Casualty Report (CASREP) messages, reducing the dependence on time-consuming human analysis.

1988 Low Altitude/Airspeed Unmanned Research Aircraft (LAURA)

This highly instrumented testbed aircraft was developed to address operational requirements of UAVs for Fleet EW missions. Its modular fuselage accepted the

installation of several wing/tail combinations for comparative aerodynamic testing. Other requirements driving UAV research included long flight endurance at ship-like speeds, flying in gusts, and storage in a protective canister prior to launch.

1990 Automated Weapon Assignment Algorithms for SDI Mid-Course Battle Management

NRL developed weapon allocation algorithms for the defense of selected assets against a MIRV ballistic missile threat based on a tracking and correlation algorithm. The software continually reassessed the threat and reassigned weapons to targets not previously engaged based on new situational assessment.

1990 NAUTILUS

The Navy Automated Intelligent Language Understanding System incorporates both robust natural language processing and semantic interpretation, providing greater ease of user interaction with autonomous systems. The system was used in the speech controller for the VIEWER immersive virtual reality tactical warfare simulation display system and an interface to a cartographic database with graphical map display.

1991 Tripod Operators for Recognizing Objects

NRL developed this class of feature extraction operators for range images which facilitate the automated recognition and localization of objects.

1992 Anytime Learning

NRL developed an "anytime learning" algorithm that allows a robot to adapt in near real time to a changing environment.

1993 Samuel: Evolutionary Approach to Learning in Robots

NRL developed Samuel, a learning system based on evolutionary algorithms, to explore alternative robot behaviors within a simulation model, as a way of reducing the overall knowledge engineering effort. Behaviors for collision avoidance navigation were learned and then successfully demonstrated on real ground robots.

1993 FLYRT

The FLYing Radar Target RF-distraction decoy flew at ship-like speeds following launch from a shipboard chaff launcher.

The fiber optic gyroscope provided highly accurate angle rate data.

1994 Clementine

NRL built and operated the first spacecraft known to conduct autonomous operations scheduling. The Spacecraft Command Language (SCL) became a widely used standard for automating spacecraft.


1995 Adaptive Testing

NRL developed a system that applies learning techniques to the general problem of evaluating an intelligent controller for an autonomous vehicle, searching for combinations of conditions and faults the controller is unable to handle. The system was successful in finding faults in two domains, an aircraft landing autopilot and an underwater autonomous vehicle controller.

1995 Heterogeneous Ad Hoc Network with Collaborative Data Streaming

In the Data and Voice Integration Advanced Technology Demonstration, NRL demonstrated one of the first working
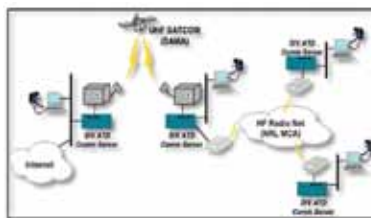
mobile ad hoc networking systems providing secure, mobile self-organization

and routing across heterogeneous radio technologies. The system also provided compressed and optimized Internet interoperability and demonstrated early forms of network-centric collaborative applications including compressed VoIP, reliable file dissemination, multicast situational awareness, and electronic whiteboarding.

1995 Multicast Dissemination Protocol (MDP)

The MDP framework was developed to provide reliable data transport improvements within autonomous collaborative groups that are often formed at the forward edge of a Navy or military communication network. This work introduced a novel information coding approach for network parity encoding and repairing in multicast networks.

1995 Non-Linear Discrete Event Tracking

NRL developed a multiple-target, multiple-sensor, automated data fusion algorithm based on ambiguous sensor reports to track land, sea, and undersea objects. The solution is provided in a unique set of probability maps and velocity probability wheels. The probability maps process both negative and positive information to create an area map of likely location of the object.

1996 Mobile Ad Hoc Networking (MANET)

NRL co-founded an Internet-standards working group to develop ad hoc routing technologies for self-organizing mobile Internet wireless infrastructures. This work stimulated extensive applied research activity and open standard designs that can be adapted and applied to military self-organizing wireless network technology.

1996 Robo-Shepherd

NRL demonstrated the ability for a robot to learn adversarial behaviors, in this case "herding" other robots into a "corral." This work showed that for tasks that are too expensive or dangerous to learn from experience, behaviors can be learned in simulation and then transferred into the real world.

1997 Hors d'Oeuvres, Anyone?

NRL's robot Coyote placed first in technical achievement at the 1997 AAAI Mobile Robot Competition. In developing a robot to serve hors d'oeuvres at

the conference reception, the research investigated several issues important to autonomous systems: navigating in a crowded space, being assertive without being intimidating or dangerous, human–robot interaction in noisy environments, and tracking of resources.

1998 Analyte 2000 Fiber Optic Biosensor

As payload on the Swallow UAV, NRL's biosensor provided one of the first demonstrations of the identification of

aerosolized bacteria by a sensor flown on a remotely piloted plane, with data transmitted to a ground station.

1998 ARIEL Frontier-based Exploration

For robotic mapping of unknown environments, it is useful for the robot to concentrate on areas at the edge of its knowledge, in order to expand that

knowledge. The ARIEL algorithm analyzes the robot's map, identifies frontier regions where known empty space borders unsensed space, and directs the robot to examine these areas in order to improve its ability to map unknown environments.

1998 Constrained Routing for Aircraft

NRL developed algorithms for computing least cost paths for multiple aircraft involved in strike missions. These included taking into account turn constraints, threat (no-fly) areas, goals, and efficient computing.

1998 Interbot

To reduce the warfighter's cognitive load, NRL developed natural interfaces that integrate the use of spoken natural language and hand/arm gestures for interacting with autonomous robots.

1998 Optical Flow for Control

NRL's novel sensor for detecting optical flow was mounted on a mobile robot and used to develop controls for steering the robot to avoid obstacles.

1998 DC-ARM: Damage Control Automation for Reduced Manning

Addressing the Navy's need to reduce manning aboard ships, the DC-ARM program shifts both routine and hazardous manpower-intensive manual damage control operations to survivable automation. The program reduces manning requirements while improving surface ship survivability. From 1998 to 2001, DC-ARM demonstrated Smart Valves, the Early Warning Fire Detection System, the Area-wide Water Mist Fire Protection System, the Smoke Ejection System, and a Supervisory Control System. DC-ARM combines a multi-criteria (sensor array) approach with sophisticated data analysis methods and improved organization and procedures.

1998 ORCA

NRL adapted the semi-submersible ORCA (Oceanographic Remotely Controlled Automaton), a diesel-powered, unmanned survey vehicle, to collect

oceanographic data at a fraction of the cost of a survey ship.

1998 SENDER

The man-portable Self-Navigating Drone, Expendable/Recoverable provided advanced technology in a

simple and affordable platform. Flown autonomously or under radio control, it featured electric propulsion, advanced composite structure, digital microprocessor autopilot, GPS navigator, and lithium propulsion batteries.

1999 Dynamic Autonomy

Intelligent mobile robots that interact with humans must be able to dynamically adjust their level of autonomy depending on the current situation. NRL demonstrated the ability for an autonomous robot to be able to interact with, or be interrupted by, a human, and then smoothly return to its earlier goals.

1999 Integrating Exploration, Localization, Navigation, and Planning with a Common Representation

This research demonstrated a novel approach to the common SLAM (simultaneous localization and mapping) problem that was able to work in dynamic environments, and also showed the utility of using a unifying representation. Experiments with indoor ground robots

showed only 13.6 cm of error over a half-mile traverse without the use of GPS.

2000 ADAPTING TO SENSOR FAILURES

NRL demonstrated the ability for a ground robot to adapt to failures in its sensors, learning to use its remaining sensors to perform its mission. This research explored autonomous systems that can continue to learn throughout their lives, adapting to changes in the environment and in their own capabili-

ties. While operating in the real world, the vehicle is always exploring different strategies via an internal simulation model; the simulation, in turn, is changing over time to better match the world.

2000 DarkHORSE/ WAR HORSE

The DarkHORSE project demonstrated that a hyperspectral sensor could be used for autonomous detection of air and ground targets. WAR HORSE demonstrated the first autonomous, real-time, visible hyperspectral target detection system flown aboard a Predator UAV. The system provides the ability to detect manmade objects in areas of natural background, for reconnaissance and surveillance.

2000 EXTENDER

This 10-ft-wingspan, air-drop-deployable UAV for electronic warfare missions had

a battery-powered electric motor and 7.5-lb payload capacity. It could perform

an entirely autonomous mission or be directed in real time through an RF link. It was designed to glide for 77 miles from a 5-mile release altitude.

2000 NAVY SMART VALVE

As part of the DC-ARM program, NRL developed Smart Valves embedded with
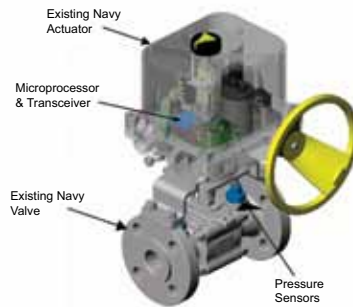
pressure sensors and processors that allow the valve to identify fire main ruptures, and thereby automate opening or closing of the valve as appropriate.

2001 AN/WLD-1 RMS(O)

NRL developed and transitioned this oceanographic variant of the Remote

Minehunting System semi-submersible UUV by developing a swappable center section equipped with hydrographic survey sensors.

2001 MOBILE NETWORK SYSTEM EMULATION

NRL developed sophisticated mobile ad hoc network emulation systems and analysis tools to support the design, development, and testing of distributed autonomous networking protocols. This capability helped bridge the gap between simulation and expensive, limited field testing of self-organizing network systems.

2001 HYBRID COGNITIVE/ REACTIVE AUTONOMOUS SYSTEM

To create more intelligent autonomous systems, NRL developed a hybrid control system that combined process models of human cognition for performing high-level reasoning, with evolved reactive behaviors for low-level control of an autonomous system.

2002 COEVOLUTION OF FORM AND FUNCTION

For an autonomous micro air vehicle, NRL developed a system that used simulation to evolve both an optimal minimum sensor suite, and reactive strategies for navigation and collision avoidance using data from the evolved sensor suite.

2002 CFD SIMULATIONS OF UAVs

Aerodynamic characterization and performance assessment of micro air vehicles via computational fluid dynamics (CFD) led to the controller development for the MITE and Dragon Eye vehicles.

2002 FINDER

This long-endurance UAV (Flight Inserted Detector Expendable for Reconnaissance) can carry payloads including chemical sensors, high-resolution battle damage assessment imagers, GPS jammer homing sensors, and SIGINT sensors. Launched from a Predator UAV, it can report its findings in near real time


through the Predator to a ground control station for distribution to the warfighter, and can retrieve samples for laboratory testing.

2002 FLAPPING FOIL PROPULSION IN INSECTS AND FISHES

Computations at NRL have provided insights into unsteady force production in nature that guide the design of

insect-like autonomous air vehicles and fish-like autonomous undersea vehicles. Flapping foil propulsion has many applications, such as submersible propulsion, maneuvering and flow control, and aerodynamics of unconventional micro air vehicles (MAVs). The Biplane
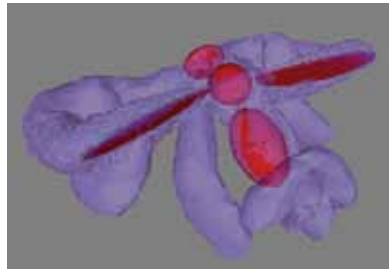
Insectoid Travel Engine (BITE) MAV and a pectoral fin–driven UUV make use of these bio-inspired mechanisms for propulsion.

2002 GRACE

A joint project with academic and corporate partners, GRACE was an autonomous robot system entered in the 2002 AAAI Robot Challenge. GRACE acted


autonomously to travel, without a map, from the front floor of a convention center to the registration desk by interacting with people and reading signs, then registered, made its way to an assigned location, presented a talk, and answered questions about itself.

2002 MITE

The Micro Tactical Expendable micro air vehicle is designed to be the smallest practical aircraft that can still perform useful Navy missions, such as over-the-hill reconnaissance, surveillance, and electronic warfare. Different wingspans (10–24 in.) are used depending on the payload and endurance required. Several very low cost autonomous flight control

systems have been demonstrated on the vehicle.
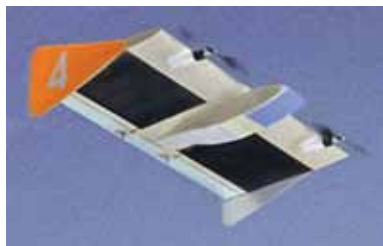
2003 DRAGON EYE

This lightweight, backpackable UAV is an affordably expendable sensor platform launched with a "slingshot." It provides real-time reconnaissance, battle


damage assessment, and threat detection through a miniature ground control station. Dragon Eye has provided critical intelligence in the Iraq and Afghanistan conflicts.

2003 FINDING HIDDEN PEOPLE (HIDE AND SEEK)

NRL scientists extended their models of visual perspective-taking to address the problem of searching for people who are trying to hide (e.g., snipers). Using a cognitive process model of how people hide, they developed a cognitive model for determining likely hiding places in the environment, and integrated this high-level reasoning with a reactive robot controller. The same model could be used to reason about what makes a good hiding place, and resulted in a robot that could play "hide and seek" with a human.

2003 MULTICAST FORWARDING IN MOBILE AD HOC NETWORKS

NRL produced the first draft Internet specification for simplified, self-organizing mobile multicast. Simplified Multicast Forwarding (SMF) is useful for autonomous group data forwarding since
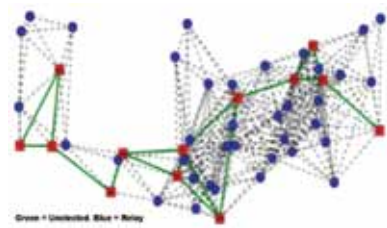
it is a highly distributed and resilient protocol approach that can adapt to change with minimized control signaling and can operate with a variety of optimized network relay set algorithms.

2004 ANALOGICAL HYPOTHESIS ELABORATOR FOR ACTIVITY DETECTION (AHEAD)

NRL developed a software system that uses computational analogy to assess the support that a given hypothesis has in a given body of evidence. The system demonstrated its utility to perform this task for simulated terrorist activities, where the evidence would include facts such as specific actions by specific people who have known organizational, family, or other types of relationships.

2004 BUG

The Benthic Unattended Generator persistently generates electrical power in marine environments from oxidation of sediment organic matter with oxidants in overlying water. The BUG enables very long-term use of autonomous marine deployed scientific and surveillance instruments that are presently limited in duration by batteries.

2005 AutoSurvey®

NRL-patented AutoSurvey® autonomous line running software, originally developed for the ORCA unmanned vehicle,

was transitioned to all NAVOCEANO TAGS 60 class survey ships. AutoSurvey provides up to 60% reduction in survey time in areas with rough terrain.

2005 Dragon Warrior/ Vantage™

Originally developed with the Marine Corps Warfighting Laboratory for reconnaissance and communications relay

missions, this vertical take-off and landing UAV resembles a small helicopter and can be transported in a Humvee. It features fully autonomous flight operation, a 44-hp heavy-fuel engine, and a ducted electric tail rotor.

2005 Scalable Robust Self-Organizing Sensors (SRSS)

NRL designed multiple-function sensor devices capable of self-organizing, autonomous network formation and data routing. This capability enabled distributed sensors and other devices to form a distributed data network when deployed in an ad hoc manner with minimum planning and management. Both autonomous mobile and non-mobile devices (e.g., distributed cameras) could discover distributed sensor events, collaborate over the network, and take appropriate action with minimal human interaction.

2005 Visual–Spatial Perspective Taking

An important aspect of human–human interaction is visual-spatial perspective-taking, in which one participant is able

to interpret a scene from the other's point of view. NRL developed a computational cognitive process model for perspective-taking and integrated it with a robot. The robot successfully solved a series of perspective-taking problems and was able to resolve different frames of reference to facilitate collaborative problem solving with a person.

2006 Control of a Team of Robots

NRL developed a sketch-based interface and algorithms that allow one operator, using a tablet PC, to manage a team of robots performing tasks such as surveillance, reconnaissance, damage assessment, and search and rescue. A precise map of the environment is not required. Rather, the user sketches a qualitative map of a live scene and directs the team using the interface.

2006 Swarm Control with Physicomimetics

Advantages of swarm intelligence include robustness to uncertainty and change, the ability to self-organize, and a decentralized nature which makes the population less vulnerable. One method of implementing swarm intelligence is the artificial physics representation of physicomimetics, in which agents behave as point-mass particles and respond to artificial forces generated by local interactions with nearby particles. NRL is taking a multitiered approach to the design and real-time control of physicomimetics swarms that includes machine learning techniques for the acquisition of swarm behavior modes and a human–swarm interface to dynamically influence swarm behavior.

2007 Cooperative Multi-Agent Systems in Mobile Ad Hoc Networks

This project developed and demonstrated various multi-agent systems that autonomously self-organized and communicated teamwork information using NRL-based ad hoc networking technology. The agents were capable of seamlessly fragmenting and coalescing topologically as network and mobility conditions varied. Agents could autonomously take on and optimize various mission roles but could also view their network function as a role and participate in sustaining the network by dynamically positioning themselves as relays within a distributed, mobile scenario.

2007 Coping with Information Overload

NRL developed methods to automatically accelerate multiple acoustic channels and prioritize message trafficking. This research allows watchstanders to process the ever-increasing amounts of information generated and exchanged in combat information centers aboard Navy ships, thereby reducing workloads and the errors resulting from the simultaneous transmission of aural messages.

2008 Embodied Cognition

NRL developed the first cognitively plausible robot architecture, ACT-R/E. Based on what is known about human reasoning and memory (from both psychological studies and fMRI data), ACT-R/E, using the robot's perceptual inputs, performs reasoning and decision making in a way that is similar to how people reason, and allows the robot to interact naturally with people.

2008 FREND: Autonomous Rendezvous and Docking

NRL developed and ground-demonstrated guidance and control algorithms

to allow a robotic servicing vehicle to autonomously rendezvous and dock with satellites not pre-designed for docking. The demonstration was completed in a realistic spaceflight environment under full autonomy with no human-in-the-loop assistance.

2008 Gaze Following

NRL developed a system that uses a combination of visual perception algorithms and computational cognitive models to allow a robot to track a person's head movements and understand that person's focus of attention. This allows the robot to work well in joint tasks with people.

2008 Gesture Recognition

NRL's system for learning and recognizing static and dynamic hand gestures (both one-handed and two-handed) allows autonomous systems to understand a person's communicative intent, improving human–robot interaction in joint tasks.

2008 Tracking Conversation with Vision and Audition

One of the goals of human–robot interaction research is to have natural dialog, which requires conversation tracking. NRL developed a system that uses sound localization to guide the robot's vision system to find the speaker. The audition and visual streams are integrated to form a coherent representation of the speaker. This system allowed a robot to correctly track conversations.

2008 UUV Mission Planner

Demonstrated during RIMPAC 08, the UUVMP provides automated planning and monitoring for fleets of unmanned underwater gliders on long-endurance (months) missions. An advanced vehicle motion model allows simulation using forecast currents to predict trajectory.

2009 XFC

The eXperimental Fuel Cell unmanned aerial system is a fully autonomous, affordably expendable surveillance plat-

form. The folding-wing UAV ejects from a transport tube, unfolds to its X-shaped configuration, and can fly for 6 hours. The hydrogen fuel cell provides power for electric propulsion, command and control, avionics, and payload operation. XFC is being modified for launch from a submarine.

## 2009 Automated Image Understanding for Maritime Threat Analysis

NRL developed an integrated video processing and learning system for object identification, maritime vessel behavior recognition, and threat analysis from land-based optical video cameras. Previous approaches were limited to perimeter defense penetration alerts.

2009 InterTrack

NRL collaborated to develop a user interface to a video surveillance system that permits easier natural interaction with the video output. InterTrack also provides an automatic inferencing capability that removes some of the burden of users' surveillance tasks and creates more autonomous or system-generated analyses.

2009 Optimization of ISR Platforms to Improve Signal Collection in Maritime Environments

NRL developed intelligence, surveillance, and reconnaissance (ISR) optimization algorithms for tracking targets of interest in the maritime domain. The algorithms simultaneously optimize over several measures of interest (e.g., suspicious vessel movements, cargo, ports, piracy areas), "difficulty" measures (e.g., meteorological conditions), and ISR
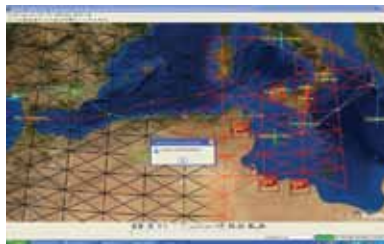
performance characteristics to improve signal collection for maritime domain awareness.

2009 Predicting and Preventing Procedural Errors

Using a combination of theories of human memory (memory for goals) and an eyetracker, NRL created a system that can predict when an operator is about to make a post-completion error before the error actually occurs, and give a just-in-time cue to prevent the error from being made.

2009 Self-Organizing Airborne Networking Backbones

NRL collaborated to develop and demonstrate technology for hybrid air/surface (ground) networks that self-organize and adapt to both gateway and legacy network infrastructures. NRL multicast routing and distributed applications were critical to the success of the field demonstration of multiple UAVs and surface nodes in the same mobile network.

2009 Ion Tiger

This UAV flew for 26+ hours with a 5-lb payload by using a high-energy hydrogen fuel cell system for electric propulsion, exceeding by 6× the endurance provided by batteries. With this demonstration, NRL created a new class

of stealthy, small, unmanned air vehicles capable of "big vehicle missions." A new liquid hydrogen fuel tank may extend the UAV's endurance to 72 hours.

2010 Assessing Translation Memory Technology

NRL teamed with the National Virtual Translation Center to evaluate the effectiveness of Translation Memory technology, which provides automated assistance to human translators for timely and cost-effective translations of documents related to military strategy and national security.

2010 Automatic Face Recognition

NRL developed an algorithm to perform automatic face recognition that has an extremely low false positive rate and that can work in a wide variety of environments with a minimal number of photos of the target subject.

2010 Bio-Inspired Deformable Fin UUV

This unmanned undersea vehicle is propelled and controlled using fish-like, bio-robotic fins inspired by the bird wrasse, a coral reef fish. Actuation of individual ribs within each fin creates the curvatures necessary to generate the high-

magnitude, variable-direction forces that enable precise, low-speed maneuvering in highly dynamic environments such as nearshore and cluttered areas with currents and waves.

2010 Dynamic Goal Management

NRL developed methods for goal-driven autonomy that permit agents to automatically self-select their goals. These are particularly valuable for unmanned systems on long-duration deployments in complex environments.

2010 Flow Immunosensor Payload

NRL demonstrated its flow immunosensor payload on a Hydroid REMUS 100 AUV. Low parts-per-billion levels of

TNT were detected in a simulated plume while underway, and data acquisition was observed remotely in real time over a Web-based interface.

2010 Foundations of Collective Classification

NRL developed and evaluated methods for leveraging relations among instances in supervised learning (classification) tasks.

2010 Serverless Messaging Systems

NRL designed and developed serverless messaging systems that effectively operate in highly distributed and disruptive network environments. This system also supports proxy interfaces to standards-based clients and servers that cannot normally operate without server centralization. A serverless messaging system extension allows more autonomous operations by combining effective group discovery and collaboration among multiple communication nodes.

2010 Shibboleth

NRL developed automatic procedures for determining the native language of non-native speakers of English, lessening the burden on warfighters and security personnel in sensitive environments such as border patrols, VBSS (visit, board, search, and seizure) operations, and foreign countries.

2010 Theory of Mind

NRL developed a system that, when an anomaly is discovered, runs multiple simulations to determine the most likely reason for that anomaly. The anomaly can then be pointed out to a person along with a possible (most likely) solution.

2010 Volume Sensor

This multisensor shipboard detection system provides early warning detection of flames, smoke, thermally hot objects, pipe rupture, and gas leaks through improved situational awareness. Based on data fusion, the system combines video image detection and machine vision software with spectral sensors and acoustic data inputs to correctly identify damage

control events and discriminate against false positives.

2010 Unmanned Semi-Submersible (USS)

NRL demonstrated this vehicle for shallow-water (2 m to 200 m) bathymetry and sidescan surveying. It provides vastly superior coverage rates (2× or greater) compared to unmanned surface

or underwater vehicles, and is excellent for rapid response in hostile environments (combat, disasters).

2011 Low Frequency Broadband Sonar

NRL's AUV-based broadband active sonar system for the high-performance detection and identification of underwater mines was transitioned to production. The "squint capable" synthetic aperture sonar measures scattering cross-sections very precisely for identification based on

structural acoustic features. The sonar is configured on a long-endurance, quiet AUV that navigates using a fusion of Doppler velocity measurement, fiber-optic gyroscope inertial navigation, and GPS. Deployment is anticipated on the Littoral Combat Ship and other platforms of opportunity. NRL is extending the technology to longer ranges and exploring the applicability to antisubmarine warfare.

2011 Behavior Recognition and Threat Analysis for Unmanned Sea Surface Vehicles

NRL is developing and testing methods for automatically recognizing behaviors of maritime vessels and assessing their threat, using sensor data from unmanned sea surface vehicles.

2011 Evaluating Deep Learning Technology

NRL is evaluating novel methods for automatic feature extraction for event detection from optical videos, sentiment analysis from text documents, surveillance, and other complex classification tasks.

2011 Facilitating Resumption After an Interruption

NRL developed a computational cognitive model that can help people resume a task after being interrupted. The model can understand the effect of an interruption on a person, and offer help so the person can continue the task with less error.

2011 Highly Distributed Networked Services Discovery

NRL developed working prototypes of highly distributed network service discovery that operates across self-organizing networks in the absence of any hierarchy or server availability. This technology allows more distributed systems to be deployed hosting services and applications that can more effectively self-organize and adapt at the middleware and application layer.

2011 RAFT Robotic Boat Refueling

NRL demonstrated the first autonomous boat-to-boat refueling system, capable of mating a refueling fitting with an autonomous surface vehicle fuel tank in sea states exceeding 3 ft maximum wave height.

2011 Supervisory Control of Multiple Autonomous Vehicles

A single operator controlling multiple autonomous vehicles can experience cognitive overload. NRL built a model that predicts when human performance limits have been reached, in order to provide automatic alerts to direct the operator's attention to critical events.

2011 Autonomous Network Modeling Framework

NRL developed a framework for rapidly constructing distributed wireless network protocol test cases for controlled, repeatable, emulation- and simulation-based experimentation. The resulting capability is being used to plan and execute complex mobile network scenarios involving large numbers of heterogeneous wireless links and nodes operating in challenging environmental conditions. Instrumentation and visualization tools provide an observable and interactive experimentation environment in real time.
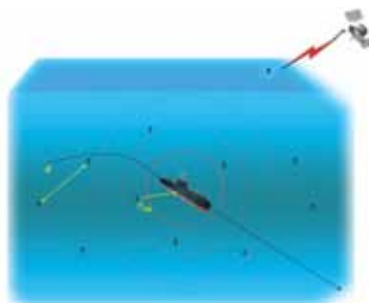
2011 Damage Control Technologies for the Twenty-First Century

The DC-21 program is developing humanoid robotic systems to support future shipboard firefighting operations. Advanced human–system interfaces will enable natural human–robot interactions and supervisory control. The program consists of four highly integrated elements: Shipboard Autonomous Firefighting Robot (SAFFiR), Human–Robot Interaction for Autonomous Firefighting Robots, Fire Suppression Methodologies and Real-Scale Demonstrations, and Robotic Firefighter Sensor Development.

2011 Sea Nimbus

With a goal of improving detection of the very quietest underwater threats in shallow water environments, NRL created an autonomous distributed sensing and identification technology for short- (<1 month) and long- (2 to 10 months) duration monitoring over a wide area. This approach deploys large numbers of small, inexpensive, power-efficient/harvesting, intercommunicating but otherwise unconnected underwater sensor nodes which through their own cooperative decision making rise to the surface and RF-link contact information and then re-submerge to continue monitoring. The principal focus is antisubmarine warfare in littoral ocean areas, with applications in other environments including rivers and harbors.

2011 Robotic Materials Testing System

NRL's robotic system provides high-rate, fully automated testing to generate large quantities of response data for characterizing the behavior of complex materials.
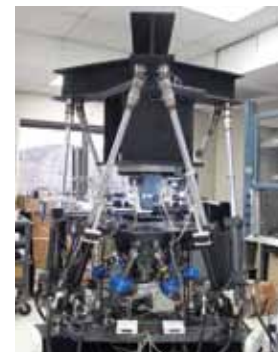
It features six-degree-of-freedom multi-axial loading, a wireless sensor network infrastructure, and a whole-field 3D optical method for measuring displacement and strain fields. Such a system is expected to influence the design, certification, and qualification methodologies used for sea and aerospace platforms built from high-performance composite and other anisotropic materials.

2012 Laboratory for Autonomous Systems Research

NRL opened the LASR to become a nerve center for autonomous systems research for the Navy and Marine Corps.