Invited Paper

Biomedical Wellness Challenges and Opportunities

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The mission of ONR's Human and Bioengineered Systems Division is to direct, plan, foster, and encourage Science and Technology in cognitive science, computational neuroscience, bioscience and bio-mimetic technology, social/organizational science, training, human factors, and decision making as related to future Naval needs. This paper highlights current programs that contribute to future biomedical wellness needs in context of humanitarian assistance and disaster relief. ONR supports fundamental research and related technology demonstrations in several related areas, including biometrics and human activity recognition; cognitive sciences; computational neurosciences and bio-robotics; human factors, organizational design and decision research; social, cultural and behavioral modeling; and training, education and human performance. In context of a possible future with automated casualty evacuation, elements of current science and technology programs are illustrated.

Introduction

Consistent with the overall Science and Technology strategy[i] of the Office of Naval Research (ONR), the mission of the Human and Bioengineered Systems Division is to direct, plan, foster and encourage science and technology in cognitive science, computational neuroscience, social/organizational science, training, human factors, and decision making as related to future Naval needs. Our goals include sustaining and improving warfighter performance and enhanced decision making in all environments through training and biomedical technologies; creating options for future (perhaps unanticipated) naval technology requirements, based upon fundamental understanding gained from cognitive and neurosciences; and cultivating transition of findings to government and industry, advanced technology development, small business and acquisition projects.

Focus on Biomedical Wellness

While many ONR programs might possibly address issues in biomedical wellness as broadly construed, this paper largely focuses on work supported by the ONR Human and Bioengineered Systems Division that further a specific future capability that many consider exciting and challenging. A future with automated casualty evacuation might enable better medical response in military operations, natural disasters, and evacuation from extreme environments. Enabling such a future capability requires work on a number of technologies that could contribute to casualty care in ways described below. The topics that follow include biometrics and human activity recognition; cognitive sciences; computational neurosciences and biorobotics; human factors, organizational design and decision research; and social, cultural and behavioral modeling; training, education and human performance.

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The elements of a future technology vision outlined below are organized around a notional future capability for automated casualty response and evacuation.

Autonomous Aerial Cargo/Utility System (AACUS)

Supported by the ONR Innovative Naval Prototype (INP) program[ii], the Autonomous Aerial Cargo/Utility System (AACUS) effort explores advanced autonomous capabilities for reliable resupply and, in the long term, casualty evacuation by an unmanned air vehicle under adverse conditions. Key features include a vehicle autonomously avoiding obstacles while finding and landing at an unprepared site in dynamic conditions, with goal-directed supervisory control by a field operator with no special training.

AACUS technologies will be platform agnostic and be transferable to both new and legacy cargo unmanned aerial systems (CUASs). AACUS-enabled CUASs will rapidly respond to requests for support in all weather conditions, be launched from sea and land, fly in high/hot environments, and autonomously detect and negotiate precision landing sites in potentially hostile settings. Such missions could require significant obstacle and threat avoidance, with aggressive maneuvering in the descent-to-land phase.

The AACUS INP represents a substantial leap over both present-day operations as well as other more near-term CUAS development programs because it is focused on autonomous obstacle avoidance and unprepared landing site selection, with precision landing capabilities including contingency management until the point of landing. AACUS includes a goal-based supervisory control component such that any field personnel can request and negotiate a desired landing site. Moreover, this system will communicate with ground personnel for seamless and safe loading and unloading.

Image credit: Design Team, ONR Code 35

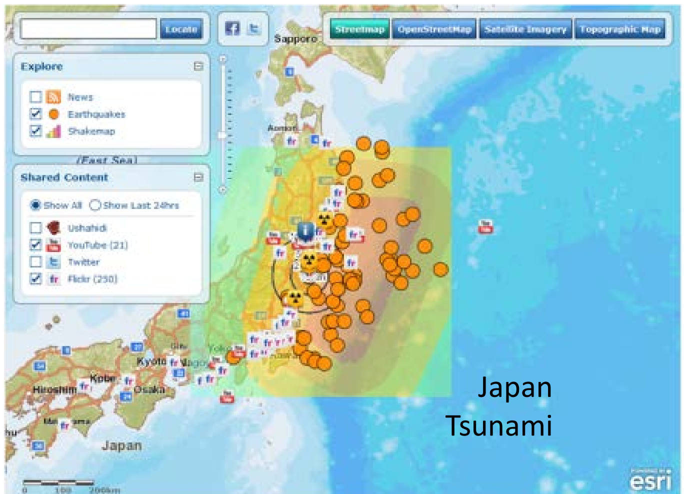
Proposed Autonomous Aerial Cargo/Utility System (AACUS)

Analytics for Humanitarian Assistance and Disaster Response

Mission planners in combined military and civilian missions of disaster response lack a clear understanding of the nature and location of medical needs that might be used better to coordinate responses from various partners in the dynamic crisis situation. This limits the efficiency of provided care.

Humanitarian Assistance / Disaster Relief Crisis Analytics Framework and Tools (HADR-CRAFT) interest within the Social, Cultural, and Behavioral Sciences program[iii] leverages existing cutting edge research and technologies to provide better visualization and rapid, deep understanding of dynamic situations using improved crisis maps, data-mining, models and information discovery tools. ONR is beginning to make investments to provide the technology push to improve information discovery and forecasting models, crisis maps & data mining filters to handle novel data streams, sort, contextualize, and visualize information for crisis sense-making through the analysis of social media and other data.

Planners also require a comprehensive understanding of existing regional capabilities to create effective strategies for coordinated responses. Models and analysis tools are required for understanding the flows of expertise, information, goods and materials. In addition, models and analytical tools are required to understand the command and control architectures of all



Aggregation & Analysis of Social Media

Image credit: Dr. Rebecca Goolsby, ONR Code 341

participating organizations and to develop effective strategies for disaster response.

One approach of current interest involves estimating and displaying biomedical wellness needs based on analysis of social media information.[iv] The ability to better monitor crises as they progress would benefit planners and take advantage of growing use of hand held devices. The opportunity is large and growing. Over 4.1 billion people use cell phones (more than half the world population). More than 90% of populated regions have signal. Over 100,000 phone masts are erected each year. Developing countries account for roughly 2/3 of the mobile phones in use. Technologies for creation and maintenance of "crisis maps" for improved coordination and effectiveness of responders is a significant challenge that requires multi-disciplinary work in social, geospatial, image processing, and linguistic sciences.

Robotics and Human-Robot Interaction

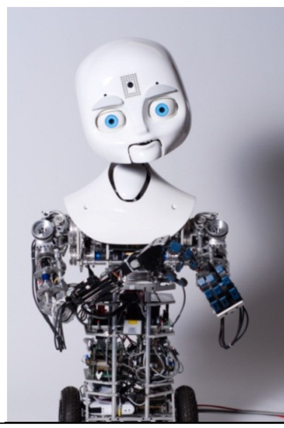
ONR has implemented programs to develop human-centric robot teammates[v] that collaborate with humans in a manner compatible with human cognitive, attentive, and communication capabilities and limitations. Such robots would have the ability to develop gesture and speech based communication with autonomous systems for natural interaction. Also, they are envisioned as capable of both lift and dexterous manipulations of the sort required in medical procedures of the first responder.

The goal of Human-Centric Autonomy program is development of cognitively-compatible intelligent autonomous systems and control interfaces to enable supervisory control and peer to peer collaboration with autonomous systems in order to improve overall system performance, and to enable computers, robots and other autonomous systems to cooperate with people using human natural language.

The related Human Robotic Interaction[vi] program is investing in basic research in areas such as flexible, robust and scalable human-robot teams in dynamic and uncertain environments integration of cognitive models, action schemes and statistical estimation. ONR is also focused on integrating behavior models and distributed control; assigning tasks with different, potentially incompatible goals, and enabling unmanned vehicles to execute them; robust, intuitive, multimodal (e.g., natural language, gestures, pointers, etc.) human-robot dialogue systems; and learning from instruction during task execution.

The Human Robotic Interaction program focuses on the abilities of teams of humans and autonomous systems to: (1) communicate clearly about their goals, abilities, plans and achievements; (2) collaborate to solve problems, especially when situations exceed autonomous capabilities; and (3) interact via multiple modalities both locally and remotely. For effective human-robot interaction, robots must have good models of the humans with whom they interact and effective mechanisms for human-robot interaction and communication. Roles and responsibilities must be assigned according to the capabilities of both the human and the robot. It must be easy for the human to effect control, to assess the situation and to assist the robot. This effort will develop the underlying principles and technology that will enable autonomous vehicles and robots to work with people as capable partners.

Image credit: Mass. Institute of Tech.



Nexi, developed at MIT

Image credit: Naval Research Lab

Octavia, developed at NRL

The main objectives of Activity Recognition & Biometrics[vii] program are automated analysis of human motion for activity recognition, non-verbal communication and advanced human motion and image biometrics for the maritime domain. The goals are to develop principles of machine intelligence, efficient computational methods, algorithms and tools for building versatile smart agents that can perform missions autonomously with minimal human supervision, and collaborate seamlessly with human teams and other agents using words and gestures.

Autonomous agents (cyber or physical) do not yet have the level of intelligence needed to operate in such open, uncertain, and unpredictable environments either independently or alongside warfighters. Building blocks of machine intelligence include: methods for building knowledge bases from diverse sources; reasoning with uncertain and qualitative information, as well as methods for meta-reasoning for self-assessment; planning in large domains in partially known environments and imprecisely modeled goals and assets; learning complex concepts and tasks from examples, instructions, etc.; and intelligent architectures. The Cognitive Sciences program, through investments in representing and reasoning about uncertainty,[viii] provides a computational basis for shared mental models.

The Navy and Marine Corps are currently investing in a variety of heterogeneous naval unmanned systems to be operated from small host platforms. In many cases, significant limitations exist on the manning available for these systems in terms of both numbers and skill types. Increasing the level of automation can have a significant impact on reducing manning requirements, but despite advances in autonomous control technologies, mission management often still requires a human's cognitive skills, judgment, decision-making and tactical understanding.

Applied research efforts are focused on the human interface technology to support small teams of co-located and distributed users in managing larger numbers of unmanned systems and sharing unmanned systems resources, autonomy, decision aids and situational awareness tools to support collaborative decision-making among teams of operators and unmanned systems, mixed-initiative interfaces, and integrating large amounts of data from multiple sources into unmanned system mission displays[ix].

Autonomous Devices for Advanced Personnel Treatment (ADAPT)

The long-term goal of the recently completed ONR Devices for Advanced Personnel Treatment (ADAPT) program was to develop autonomous, in vivo devices that can both detect-and-respond to analytes indicative of trauma or insult (e.g., hemorrhagic shock, infection). A variety of sensing mechanisms have been successfully miniaturized and used in such devices, including optical, electrochemical, antibody, enzymatic, and plasmon resonance. However, nearly all of these devices have an external system to which the device is connected, and which provides feedback to the patient or clinician. For the ADAPT approach we envision the capability to sense and treat a condition, as well as identify the injured person, his status and location to a distant site - using a single, independent device.

ADAPT requires embedded or implanted devices that can detect a physiological change indicative of a specific medical insult (such as hemorrhagic shock) that is severe enough to render the injured individual incapable of performing self-aid. Following detection, the device would then initiate a treatment response. Considering this long-range goal, the objectives of this fundamental research program are to: (1) identify robust biomarkers for injuries and stressors as well as reliable approaches for their detection, and (2) to develop interfaces between the sensor(s) and device control systems that increase fidelity of the diagnosis.

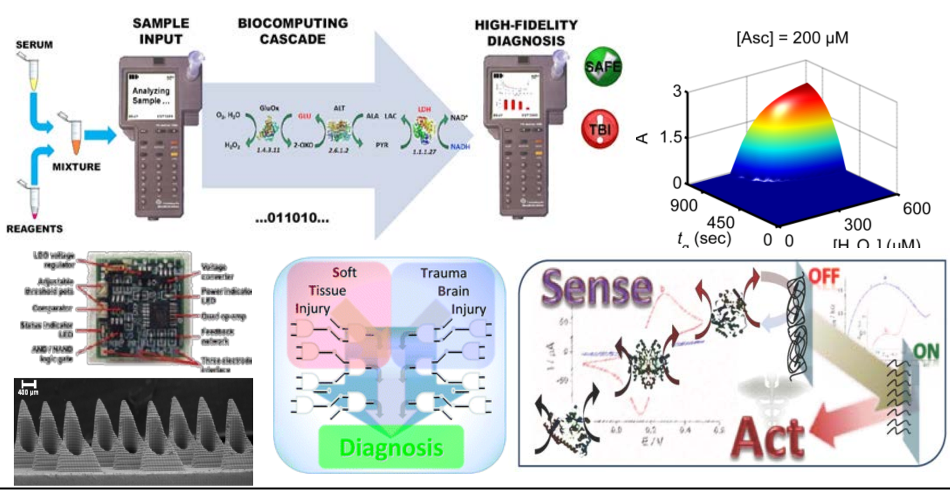


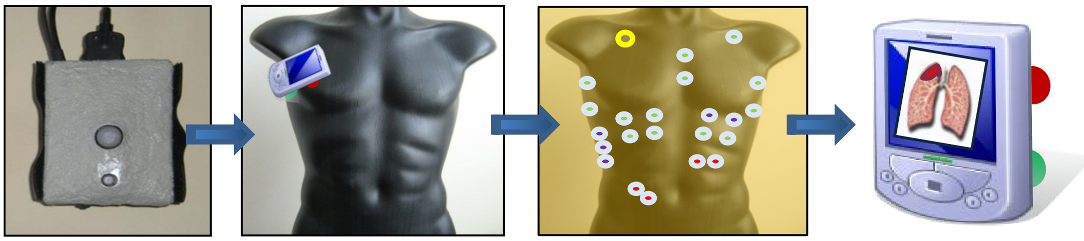
Image credit: Dr. Joseph Wang (University of CA at San Diego) & Dr. Evgeny Katz (Clarkson University)

Autonomous Devices for Advanced Personnel Treatment (ADAPT)

Diagnostic Sensing

In recent years, ONR investments in Biophysics[x] have led to a number of technology demonstrations of possible use in future systems for automated casualty care. These technologies result from multi-disciplinary work, involving engineering and biological sciences, to obtain rapid sensing and diagnosis of blood loss, head injury, and pneumothorax, for example.

A portable pulmonary injury diagnostic device has been demonstrated. It generates mild percussive impulses to the chest, the acoustic response to which is analyzed by the same device for rapid indication of lung abnormality via a displayed image. Clinical evaluation of this device in an urban trauma center is ongoing.



Device Examination Classification Imaging

Image credit: University of Windsor, Canada

The ultrasonic imaging of brain structures and blood vessels through the skull has been demonstrated in a portable device prototype for detection of foreign objects in the brain. This work takes advantage of matched filtering and time reversal algorithms to reconstruct an image from the signals scattered by the skull. Interest in this approach to hand-held diagnostic devices continues.[xi]

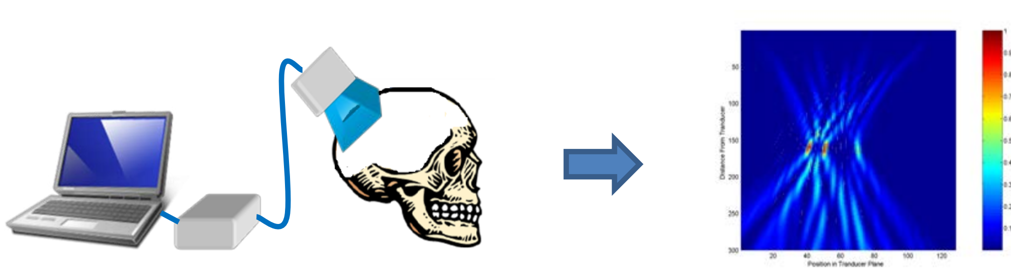


Image credit: Tessonics Inc.

A portable device[xii] for fast, accurate, estimates of heart rate, blood pressure, and hemorrhage has been developed and demonstrated in a clinical setting. This device takes advantage of algorithmic processing of pressure variation at the fingertip. The goal is a device for continuous monitoring of casualty condition during all phases of care.

Image credit: Empirical Technologies Corp

Realistic Simulation for Medical Training

The Office of Naval Research currently develops, deploys, validates, and refines standardized curricula for medical simulation, education, and training. Current programs are composed of three types of simulations: Live, Virtual, and Constructive.

Live Simulations represent the natural physical environment in which individuals or teams operate their systems and platforms for rehearsal and training purposes. Typically, these environments are closely similar to the expected operational environments, with modifications to the systems and platforms that support performance assessment and maintain range safety. Virtual Simulations are synthetic environments that include the replication of equipment and operational environmental conditions; allows for the sharing of a common environment which multiple users can access; and supports interactions with simulated entities (including objects, avatars, and equipment) that match those in the real world. Constructive Simulations are simulated forces that respond to trainee actions. Typically, real human inputs are needed to fully operate these simulated forces which then carry out the resultant actions in a synthetic environment.

Intelligent Tutoring Systems (ITS)

Intelligent tutoring systems have proven themselves in contexts of training, and are being explored as a way to bridge human and machine reasoning for the benefit of both. In the context of biomedical wellness, the ITS technologies may be useful not only to analyze and interpret the performance of human experts but also to help shape the performance of robotic systems.

The ONR has invested in cognitive architectures for ITS for more than 20 years. Among many success stories, cognitive architectures have been broadly applied to training and education in the development of intelligent tutoring technologies used at Department of Defense Dependent Schools. Additionally, validated cognitive models of naval operator performance are currently being applied to human-to-computer interface issues as a cost-effective technique for exploring new concepts in naval displays. Basic research supports autonomous systems that are capable of enhanced coordination with both human and machine teammates; intelligent systems that are capable of natural language interactions through dialogue; systems that are capable of rapid learning via discernment of teacher's intent; and systems that teach more effectively by understanding student intent and comparing against skilled performance.

Image credit: Surface Warfare Officer's School

ITS in action: Students learn advanced shiphandling

The objective for Intelligent Tutoring Systems[xiii] include: aiding students learning in simulators by automating selected instructor feedback and advice; reducing cost of instructor hours without impacting learning; gaining increased student proficiency through more efficient use of simulators; automating performance assessment with objective standards; and retraining of perishable skills while recording proficiency levels. ONR programs have developed ITSs that use dialogue to reduce demand on instructors for routine tutoring while retaining the instructor role in explanation and control of student practice events. In addition, these programs have developed a measurement system for student performance that will support more objective evaluation of proficiency.

Socio-cognitive architectures[xiv] form the basis for software platforms to be installed on adaptable autonomous systems. Socio-cognitive architecture focuses on cognition about other agents, including their beliefs, desires, intentions, and obligations. The associated technology hinges on computationally instantiated theory of the entire cognitive system, including perception, cognition, learning and action, constrained by computational, neural, and psychological findings. These architectures support reasoning directly about the mental states of other agents—either human or non-human—by maintaining "mental models" corresponding to the mental perspectives of those agents.

Socio-cognitive architectures are outfitted with mechanisms corresponding to neural and psychological theories regarding the human ability to reason about the mental states (e.g., beliefs, desires, intentions, etc.) of other humans. Predicting and explaining the behavior of others in terms of their mental states is sometimes called "mind reading." In general, mind readers must be able to construct and maintain two "mental models"—one of the world as it is seen first-person, and one as it is seen from the perspective of the target agent to be predicted.

Common Operating Picture: Logistics Planning and Decision Support Tool

The Office of Naval Research (ONR) Command Decision Making Program[xv] concentrates on the development of models— including cognitive architectures, adaptive command and control architectures, and engineering models— to create human system design standards, human system decision support and new interface technology. It is collection of efforts aimed at developing guidance and engineering tools for human-system interaction that are compatible with human cognitive and physical capabilities. The program is centered on cognitive, science-based tools, models and computational models; design methodologies and tools for command decision making; optimized user interaction for improved operator performance; intuitive displays for uncertain information; and design for realistic combat conditions.

The program has successfully completed task-centered design guidance for manpower reduction and reduced errors, cognitive architectures for human performance prediction and modeling for the design of cognitively compatible systems to improve performance; the development of 3D audio for improved spatial awareness and cueing; and human-centric 360 degree imaging systems for improved situational awareness in cluttered littoral environments. Command decision making tools will enhance the performance of warfighters and improve overall system capability and affordability. This includes user-centered design guidance for systems and team-oriented design of human systems.

This planning and decision support tool will: automate the collection, storage and distribution of defined logistics data; operate in real time and near real time situational awareness of logistics resources and consumption; and enable knowledge creation based on acquired information, provide plan vs. actual assessments, provide analysis for appropriate decision trade spaces and provide recommendations for course of action creation and execution. It provides capability to: assemble, aggregate, parse, infuse context at the Commander's intent, and to distribute and display on demand real/near time information in an open, distributed environment.

Finally, it provides the ability for Commanders and Staffs to accurately assess current execution and future plans with developed metrics based on Task, Purpose and Intent.

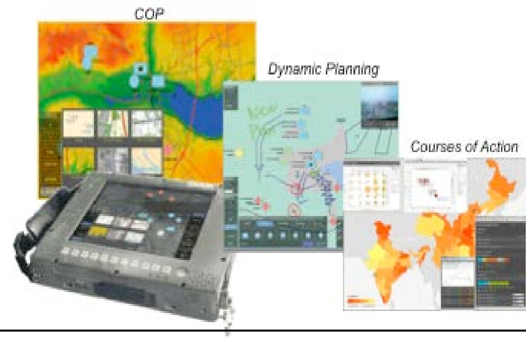


Image credit: Dr. Jeff Morrison, ONR Code 341

Common Operating Picture: Logistics Planning and Decision Support Tool

Summary

As illustrated above, the ONR support for research and technology developments contributing to enhanced biomedical wellness may be found in several of its multi-disciplinary programs. The theme for this paper, a notional future capability for autonomous casualty evacuation, gains support from ONR programs involving autonomous air vehicles for evacuation, humanoid robots for manipulation and intervention, social media analysis for disaster needs estimation and coordination, sensing and signal processing for diagnosis, engagement through natural language and gesture, cognitive models for intelligent tutoring and coordinated planning, and information fusion for decision support.

Most of the ONR programs described involve strong cooperation across disciplines, including the disciplines of interest to members of SPIE. Science and technology of optics and photonics can contribute to the goals of the programs described and discussion is welcome through contacts provided in the material cited.

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[i] http://www.onr.navy.mil/About-ONR/~/media/Files/About%20ONR/Naval-Strategic-Plan.ashx

[ii] http://www.onr.navy.mil/~/media/Files/Funding-Announcements/BAA/2012/12-004.ashx

[iii] http://www.onr.navy.mil/en/Media-Center/Fact-Sheets/Social-Cultural-Behavioral-Sciences.aspx

[iv] http://tweettracker.fulton.asu.edu/

[v] http://www.onr.navy.mil/Science-Technology/Departments/Code-34/All-Programs/human-bioengineered-systems-341/Biorobotics.aspx

[vi] http://www.onr.navy.mil/Science-Technology/Departments/Code-34/All-Programs/human-bioengineered-systems-341/Human-Robot-Interaction.aspx

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[viii] http://www.onr.navy.mil/Science-Technology/Departments/Code-34/All-Programs/human-bioengineered-systems-341/Representing-Reasoning-Uncertainty.aspx

[ix] http://www.onr.navy.mil/Science-Technology/Departments/Code-34/All-Programs/human-bioengineered-systems-341/Perception-Metacognition-Cognitive-Control.aspx

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[xiv] http://www.onr.navy.mil/Science-Technology/Departments/Code-34/All-Programs/human-bioengineered-systems-341/Perception-Metacognition-Cognitive-Control.aspx

[xv] http://www.onr.navy.mil/Science-Technology/Departments/Code-34/All-Programs/human-bioengineered-systems-341/Multi-Echelon-Command-Decision-Making.aspx