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Consortium for Robotics and Unmanned Systems Education and Research

From Technical to Ethical...From Concept Generation to Experimentation

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Special Edition

The Coming Swarm

by Paul Scharre, Director of the 20YY Warfare Initiative at the Center for a New American Security

The unfolding robotics revolution is transforming a range of industries, from manufacturing to transportation, warehouse management, household appliances, toys, elder care and more. Similarly, it will lead to significant and perhaps surprising changes in warfare. Uninhabited vehicles, like the Predator aircraft or the Packbot ground robot, have already proven invaluable in today's conflicts. As uninhabited vehicles incorporate increasing automation and become true robotic systems, they will have tremendous value in future military operations. Untethered from the limits of human endurance, robotic systems will allow military forces to extend their reach into the battlespace, operating with greater range and persistence than would be possible with human-inhabited systems. With no human onboard they can be sent on dangerous or even suicidal missions, allowing more daring concepts of operation. Individually, robotic systems can provide warfighters significant advantages in a range of missions. Collectively, swarms of robotic systems have the potential for even more dramatic, disruptive change to military operations. Swarms of robotic systems can bring greater mass, coordination, intelligence and speed to the battlefield, enhancing the ability of warfighters to gain a decisive advantage over their adversaries.

Secretary of Defense Chuck Hagel has called for a renewed effort to sustain American military technological dominance, and uninhabited and autonomous systems are an important component of such a strategy¹. Today the U.S. military faces a pernicious cycle of ever rising platform costs and shrinking quantities. As a result, the number of combat ships and aircraft in the U.S. inventory has steadily declined, even during periods of significant growth in defense spending. Today's acute fiscal pressures only exacerbate these trends, forcing a crisis not only in military modernization and readiness, but also in the ability to field sufficient quantities to be relevant in future fights. As precision-guided munitions proliferate to other adversaries – both state and non-state actors – the shrinking number of U.S. combat assets becomes a major strategic liability. Adversaries can concentrate their weapons, which are becoming increasingly accurate and capable at ever-longer ranges, on the relatively small number of U.S. ships and bases, overwhelming their defenses. The current trend of attempting to compensate for ever-shrinking numbers of capital assets through increasingly exquisite systems is not sustainable. Clinging to greater quantities by eschewing modernization, however, is not a recipe for success either. A new paradigm is needed, one that sustains the qualitative superiority of U.S. forces in aggregate, but that disperses combat power among a greater number of platforms, increasing resiliency and diversity and imposing costs on adversaries.

Uninhabited systems can help bring mass back to the fight by augmenting human-inhabited combat systems with large numbers of lower cost uninhabited systems to expand the number of sensors and shooters in the fight. Because they can take more risk without a human onboard, uninhabited systems can balance survivability against cost, affording the ability to procure larger numbers of systems. Greater numbers of systems complicates an adversary's targeting problem and allows graceful degradation of combat power as assets are attrited. The disaggregation of combat power into a larger number of less exquisite systems also allows the ability to field a family-of-systems approach, increasing diversity and reducing technology risk, driving down cost. Uninhabited systems

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Cont from page 1 need not be exquisite multi-mission systems, but rather can be purpose-built for specific missions at lower cost. For example, uninhabited missile barges, undersea payload modules, airborne “missile trucks” and robotic appliqué kits for ground vehicles can supplement the striking power of existing manned platforms at relatively low cost. The result can be greater combat power on the battlefield, at the same cost. By embracing uninhabited and autonomous systems, the United States can disperse its combat capabilities, increasing resiliency, and expand its offensive striking capacity, all within realistic budget constraints².

The power of swarming lies in more than just greater numbers, however. Today’s modern military forces fight as a network, with interconnected human-inhabited platforms passing surveillance and targeting data across great distances. Future military forces will fight as a swarm, with greater coordination, intelligence and speed. Autonomous and uninhabited systems will be networked and cooperative with the ability to autonomously coordinate their actions in response to events on the ground. Swarming, coordinated action can enable synchronized attack or defense, more efficient allocation of assets over an area, self-healing networks that respond to enemy actions or widely distributed assets that cooperate for sensing, deception and attack. Harnessing the power of swarming will require new command-and-control models for human supervision of large swarms. This will mean moving beyond existing paradigms where humans directly control a vehicle’s movements to one where human controllers supervise the mission at the command level and uninhabited systems maneuver and perform various tasks on their own.

Increased automation also has the potential to speed up the pace of warfare by helping to shorten decision cycles and, in some cases, remove humans from them entirely. Increased automation can allow humans to process large amounts of data quickly, allowing warfighters to react to changing events on the ground faster than the enemy. In some cases, the fastest reactions might come from removing humans from some tasks entirely, as is already done for some defensive actions like dispensing flares or other countermeasures. While increased automation may have tactical benefits in allowing faster reaction times to enemy actions, it could also have strategic consequences if the speed of action on the battlefield eclipses the speed of decision-making for policymakers. Increased autonomy in the use of force raises the dangerous specter of “flash wars” initiated by autonomous systems interacting on the battlefield in ways that may be unpredictable. While militaries will need to embrace automation for some purposes, humans must also be kept in the loop on the most critical decisions, particularly those that involve the use of force or movements and actions that could potentially be escalatory in a crisis.

Increasingly sophisticated autonomous systems will still fall short of human intelligence in many respects, and uninhabited systems will not be useful or appropriate for all missions. A human-machine teaming approach will be needed to find the optimal mix of human-inhabited and uninhabited platforms and human and machine cognition for various tasks. As one example, the Army has adopted an approach of teaming human-inhabited Apache helicopters with uninhabited Gray Eagle aircraft to perform armed aerial reconnaissance. Developing the doctrine, training, concepts of operation and organization to enable effective human-machine teaming will be critical to leveraging the unique advantages of uninhabited and autonomous systems in a wide range of mission areas.

The introduction of greater numbers of uninhabited and autonomous systems on the battlefield will not lead to bloodless wars of robots fighting robots, but could make more warfare more deadly and dangerous for human combatants. Humans will still fight wars, but new technology will give combatants, as it always has, greater standoff from the enemy, survivability or lethality. Exploiting those advantages will depend principally on the ability to uncover the most innovative applications of robotic swarms, which will require not only increased resources but also an aggressive campaign of experimentation and technology development. Many of the underlying technologies behind increased autonomy are driven by commercial sector innovation, and as a result will be available to a wide range of state and non-state actors. In a world where some of the most game-changing technologies will be available to everyone, uncovering the best uses of that technology – and doing so urgently – will be vital to sustaining American military dominance.

This article is excerpted from CNAS’s recent report, “Robotics on the Battlefield Part II: The Coming Swarm,” available at www.cnas.org/20YY. Follow him on Twitter @paul_scharre.

¹ Chuck Hagel, “Defense Innovation Days Opening Keynote,” (Southeastern New England Defense Industry Alliance, Newport, September 3, 2014), <http://www.defense.gov/Speeches/Speech.aspx?SpeechID=1877>. Deputy Secretary of Defense Bob Work has also expounded on this issue: Bob Work, “National Defense University Convocation,” (National Defense University, Washington, August 5, 2014), <http://www.defense.gov/speeches/speech.aspx?speechid=1873>.

² T.X. Hammes has made a similar, and compelling, argument: T.X. Hammes, “The Future of Warfare: Small, Many, Smart vs. Few and Exquisite?” *Warontherocks.com*, July 16, 2014, http://warontherocks.com/2014/07/the-future-of-warfare-small-many-smart-vs-few-exquisite/#_.

Director's Corner

Lyla Englehorn, CRUSER Director Concept Generation

Happy 2015! Time to mark your calendars as CRUSER has several activities and events planned along our 4th Innovation Thread, "Warfighting in the Contested Littorals." (list on bottom of page 4)

Our March event will explore the operational limits of military robotics during a guided two-day foray into a future scenario employing unmanned systems in a contested littoral environment. The first full week of April is National Robotics Week, and CRUSER will be hosting the first ever "CRUSER Faire" to include three events: our annual technical continuum to explore the potential of concepts generated during the September 2014 workshop, a guided tour of unmanned systems labs for the campus community, and culminating in our annual research fair showcasing the variety of work currently underway across campus.



IED Detector Developed by Sandia Labs being Transferred to Army

for inquiries contact Jon P. Chavez, Airborne ISR, Sandia National Laboratories, jonchav@sandia.gov

Copperhead Synthetic Aperture Radar system helps troops by detecting IEDs day or night, in any weather

ALBUQUERQUE, N.M. — Detecting improvised explosive devices in Afghanistan requires constant, intensive monitoring using rugged equipment like that demonstrated on a modified miniature synthetic aperture radar (MiniSAR) system developed by Sandia National Laboratories.



Sandia's Copperhead — a highly modified MiniSAR system mounted on unmanned aerial vehicles (UAVs) — has been uncovering IEDs in Afghanistan and Iraq since 2009. Now, Sandia is transferring the technology to the U.S. Army.

The technology was developed with the Defense Department's Joint Improvised Explosive Device Defeat Organization (JIEDDO); the U.S. Army Engineer Research and Development Center/Cold Regions Research and Engineering Laboratory (CRREL); the Naval Air Systems Command (NAVAIR); Johns Hopkins University's Applied Physics Laboratory; the Naval Research Laboratory; and Florida-based force protection company AIRSCAN.

"Today, we're acknowledged as the most successful airborne IED detection capability out there," Sandia senior manager Jim Hudgens said.

Department of Energy Secretary Ernest Moniz honored the team that developed Copperhead with an Achievement Award.

Copperhead detects disturbances in the earth, for example, those

made when IEDs are buried. It can find them day or night and in many weather conditions, including fog and dust storms. Extremely fine-resolution images are processed onboard UAVs and transmitted real-time to analysts on the ground. Those analysts pass the information to soldiers charged with destroying IEDs.

MiniSAR, the first system of its size to successfully transmit real-time images from UAVs in 2006, uses small antennae that capture reflections of microwaves returned from objects on the ground, transmitting and receiving many radar pulses as the aircraft flies. The received pulses are integrated by signal-processing techniques to synthesize a fine-resolution image, hence the name "synthetic aperture."

A few different demonstrations and tests were conducted to demonstrate the fundamental capability. In 2007, the Sandia team connected with Mark Moran, director of the special projects office at CRREL. The team showed the value of MiniSAR in a series of scientific investigations Moran's team was running for JIEDDO.

MiniSAR needed a way to keep the entire height of the terrain in an image in focus, for example, the top of a mountain and the valley floor. Sandia researcher Bryan Burns created advanced image-processing algorithms that focused the high and low terrain simultaneously while continuing to provide fine-resolution imagery. The new capability, which has been proven effective on slopes of more than 40 degrees, made Copperhead useful in the wide variety of terrain.

Sandia and its partners had to quickly adapt and enhance the 30-pound MiniSAR so it could fly on NAVAIR's 17-foot Tiger Shark UAV. When the modifications were made, Copperhead's MiniSAR technology weighed about 65 pounds and was about 1 foot wide, it could do its entire image processing on board and was rugged enough for the environments it would face, Hudgens said.

The Copperhead operational system includes hardware and software tools to help radar analysts on the ground understand the data coming from the aircraft and a training program.

"We developed a flight planner and an exploitation tool that the analysts use in the ground station, and we had to develop all the concepts of operations to make it work and tactics, techniques and protocols for utilizing the system," Hudgens said. "While MiniSAR was a radar that we flew and used to collect data, Copperhead is an entire system, everything from communications to analyzing imagery to providing information useful to people who defeat IEDs."

Short Range Wireless Power Transfer (WPT) for UAV/UAS Battery Charging

by Professor David Jenn, NPS Electrical Engineering Faculty, jenn@nps.edu

There are numerous advantages of wireless power transfer (WPT) for many remote energy source and battery charging applications. In a WPT system, power is transmitted wirelessly from a base station to a client. The concept was first demonstrated for vehicle propulsion in the mid 1960s. More recently, WPT has been used for charging wireless devices, and commercial WPT charging technologies have appeared on the market under the names Witricity and Energous.

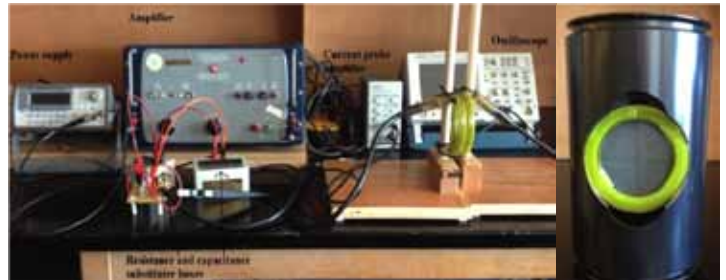
In a typical WPT system, prime power is provided by the base station, converted to radio frequency, and then transferred through space to a receiving coil or antenna. On the client side the received power is filtered, transformed in voltage, and subsequently delivered to the battery or power plant.

Inductive systems use two coils with one located in the charging station and the second in the device. Energy is transferred by the magnetic fields linking the coils. At the receiving coil, circuits are required to rectify and condition the output voltage for charging the battery. Inductive systems generally operate at low frequencies (< 10 MHz). Efficiencies greater than 95% have been achieved, but only at very short distances (a maximum of several cm) and alignment of the coils is critical.

Radiative WPT systems use two antennas rather than coils, and the energy is transferred by a propagating wave. The receiving antenna has an integrated rectifier, and is called a rectenna. Radiative systems operate at higher frequencies than inductive systems (> 1 GHz), and suffer a $(1/\text{distance})^2$ propagation loss. High gain antennas can be used to increase the received power, but they become physically large. The use of antennas has advantages though. Solid state arrays allow full control of the antenna excitation, which permits scanning and focusing of the beam. This capability relaxes the alignment requirements between the two antennas. Radiative systems can be designed to operate at distances of tens of meters or more.

A disadvantage of radiative systems is that they are more susceptible to environmental conditions. To minimize loss, a clear line-of-sight in air is desirable. Therefore, this approach cannot be used for

vehicles submerged in water or buried in wet ground. However it can be used for ground vehicles, air vehicles on the ground, or even warfighter packed equipment.



Measurement setup used to obtain efficiency and coil installed in a UAV hull

Other issues that must be considered when using electromagnetic energy are safety and interference. Because of the short ranges and relatively low power involved, safety should not be an issue and the interference introduced by a practical WPT system will be limited to same platform (self) interference.

In Phase I of the study (completed in FY14) both approaches were simulated using commercial software. For the inductive case, working at 100 kHz, efficiencies over 90% were achieved at short ranges (less than 30 mm). A frequency of 100 kHz was used to allow the system to operate in seawater without suffering decreased efficiency due to the water resistance. For the radiative approach, the transmission loss between antennas was less than 1 dB at ranges less than 3 m when near field focusing was employed. The results are important because they demonstrate that efficient transmission of energy can take place between the WPT ground station and a client for both approaches.

The next phase in the research is to demonstrate efficient rectifying and battery charging circuits. It includes the design of a practical interface between the coils, and optimization of the rectifying and charging circuit. The demonstration of an inductive system is planned in FY15.

Full Report: <https://calhoun.nps.edu/handle/10945/44092>

Librarian's Corner

The latest issue of *Journal of Strategic Security* (Winter 2014, v. 7, no. 4) is a special issue – “Future Challenges in Drone Geopolitics”

<http://scholarcommons.usf.edu/jss/vol7/iss4>

Unmanned Aerial Vehicles in Humanitarian Response

<https://docs.unocha.org/sites/dms/Documents/Unmanned%20Aerial%20Vehicles%20in%20Humanitarian%20Response%20OCHA%20July%202014.pdf>

CRUSER Calendar of Events

Monthly Meeting: 9 Feb, 1200-1250 (PST)

JIFX: 9-13 Feb 2015 at Alameda, CA

Robo-Ethics: 3-4 March 2015

CRUSER TechCon: 7-8 April 2015

CRUSER Tech Expo: 9 April 2015

Robots in the Roses: 9 April 2015

details at: <http://CRUSER.nps.edu>

NPS Student Participation in Experiment at JIFX 14-4 in Alameda, CA, August 2014

by LT Daniel Lee, USCG, NPS Information Sciences Student, dlee1@nps.edu

The objectives of the experiment I attended at JIFX 14-4 was three-fold: establish and test Cutter-to-Boarding team network, establish and test boarding Team on-the-move Network and integrate Maritime Interdiction Operations (MIO) and counter weapons of mass destruction (WMD)/intelligence, surveillance and reconnaissance (ISR) techniques. We created a scenario for this experiment and based our work off that scenario as a guide.

To establish communication links between the experiment location and the NPS CENETIX servers, a VPN gateway was installed between the Coast Guard Base in Yerba Buena Island (YBI), San Francisco Bay and NPS CENETIX operations center. In addition, a portable network operations center was established on board USNS Cape Orlando to coordinate efforts and to observe/manage experiments. Sector Antenna Arrays were mounted on YBI tower, onboard SFPD boats, and a Coast Guard Cutter to act as a network extension. SFPD Boats were deployed to act as a relay communication between us and YBI, with unique IP's assigned to all nodes. Additionally the YBI tower node was configured to be the gateway for all distributed nodes. A quad radio router with its omni directional sector antenna provided robust connectivity between mobile nodes.



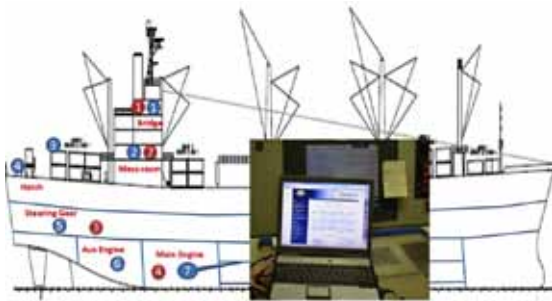
The Wave Relay Mobile Ad-Hoc System is designed and developed by Persistent Systems as a solution for communication between on-the-move nodes. It provides peer-to-peer scalable networks that enables data, voice and video communication between on-the-move nodes. Man Portable Unit 4 (MPU4) provides connectivity by seamless OSI Layer-2 Ethernet which enables plug-and-play cameras, video recorders, IP sensors and various devices. The radios in our lab have 2.3-2.5 GHz frequency range. Wave relay radios can be configured through an interface in a web browser.

The second commercial mobile ad-hoc radio that we used was Cheetah Net's tactical network radio TW220. It is a handheld portable unit designed to establish a voice/video/data network with up to 8 point-to-point nodes.

Virtual Extension's VEmesh network is a low power, low frequency wireless mesh network (VMN) that is designed for sensor networking. VEmod with its RF part communicates with the network via RS232, RS485 or DALI interface. According to Virtual Extensions' data sheet, VEmesh is optimized for wireless mesh networks via "synchronized-flooding" technology that enables nodes to retransmit every message they receive. In order to send a message, an initiating node sends it to all neighbor nodes, and all nodes retransmit the message until all nodes have received it. Essentially, all nodes are covered without any excessive routing process that consumes energy and processing time. This multi-path propagation maximizes network throughput against interference. There is no theoretical limitation for the number of nodes in WMN.

A Solar Winds Network Management and Performance tool, Qcheck Network Performance Measurement tool, and two laptops each with two Ethernet cards to host two local area networks were used to capture the data. Additionally, a Node Ping Graph tool which is an interface that provides pings concurrently to multiple IP's with their response time, was used to observe instant changes in connectivity of nodes.

We mounted one Trailles Ware node and one Wave Relay node to two laptops on each side. We created a common background domain to merge these



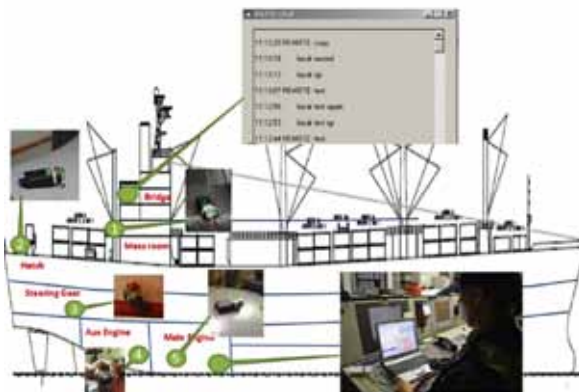
Wave Relay (blue), Trailles Ware(red) Networks

two local area networks. The plan was to capture the measurement of the first phase of boarding to secure the ship. To observe behavior of on-the-move nodes we measured TCP, UDP throughputs, SNR, Upload and Download Bandwidths of nodes in between stations and recorded the values. We set bridge, mess room, hatch to second deck, steering gear compartment, auxiliary engine compartment and main engine compartment as our stations respectively from upper decks to lower decks. We extended the network down to the engine room via deployable nodes and measured the network metrics to have a better understanding of communication below the main deck.

A total of 5 nodes were deployed for the wave relay in between the bridge and main engine compartment in order to maintain data communication. As a result, the boarding team member was able to download the CENETIX website and establish communication to the server from the main engine compartment. We deployed our nodes close to entrances within the ship due to the higher frequency used by Wave Relay nodes and propagation of waves within ship compartments. We deployed only two TW-220 radios to keep voice communication alive between the far edge nodes.

For the Virtual Extension Mesh Network, 5 lightweight easily carried nodes were deployed to maintain communication. Boarding team members on-the-move below main deck were able to confirm communication through a command and control channel with the boarding team leader. We tested the system in all parts of steering gear, auxiliary and main engine room.

With only five relay nodes, boarding team members on the move had the flexibility to move around without any interference.



Virtual Extension Mesh Network

STUDENT CORNER

STUDENT: LCDR JAMES CENA, USN

TITLE: Power Transfer Efficiency of Mutually Coupled Coils in an Aluminum AUV Hull

CURRICULUM: ELECTRICAL ENGINEERING

LINK TO COMPLETED THESIS: [HTTP://CALHOUN.NPS.EDU/HANDLE/10945/38895](http://calhoun.nps.edu/handle/10945/38895)

ABSTRACT:

To charge the United States Navy's Remote Environmental Measuring Units (REMUS) autonomous undersea vehicle (AUV) in situ requires the REMUS to mate with a docking station. There are two problems with this docking station. The docking system requires the REMUS to make electrical contact with the dock, which can lead to electrical shorting in an undersea environment. The dock is also designed to fit a single type of AUV. AUVs of different sizes require a new docking system. A different means of power transfer is required that can be used in a universal docking station. An inductive power transfer (IPT) system can be used in a universal docking station. In this report, we calculated the power transfer efficiency of an IPT system operating at 100 kHz using circular coils. These calculated results were then compared to three sets of measured efficiency data: an IPT system without ferrite tiles; an IPT system with the receiving coil attached to ferrite tiles; and an IPT system with the receiving coil/ferrite tile combination placed inside an aluminum AUV hull. Efficiency was poor, less than 10 percent with an air gap of 55 mm, when the receiving coil was placed inside the aluminum hull.

Representation of Unmanned Systems in Naval Analytical Modeling and Simulation: What are we really simulating?

by Professor Curtis Blais, NPS MOVES Institute Faculty, clblais@nps.edu

Combat models are used in major assessments such as Quadrennial Defense Reviews for Naval system acquisition and future force structure decisions. For several years, the Navy has been adding capabilities to the Synthetic Theater Operations Research Model (STORM) originally developed by the U.S. Air Force. Similarly, the Army and Marine Corps employ a specific analytical model called the Combined Arms Analysis Tool for the 21st Century (COMBATXXI) to evaluate major proposed changes in materiel and associated warfighting operations and tactics. The CRUSER Charter identifies numerous Naval initiatives for study and development of unmanned systems, such as the Unmanned Carrier Launched Airborne Surveillance and Strike (UCLASS) squadron, Large Diameter Unmanned Undersea Vehicles (LDUUVs), and an integrated Family of Robotic Systems to augment the capabilities of the Marine Air Ground Task Force (MAGTF) / Fleet. The Unmanned Systems Integrated Roadmap FY2013-2038 indicates the Presidential Budget for Fiscal Year 2014 was over four billion dollars (covering research, development, test, and evaluation, procurement, and operations and maintenance). With such current initiatives and high-valued expenditures occurring with respect to unmanned systems, there is concern that expected improvements to warfighter effectiveness, through tactics, techniques, or procedures, are not well supported by analytical processes and findings. Initial investigation of models such as STORM and COMBATXXI that support studies for major decisions indicates that these simulations are largely deficient in representations of such emerging systems. Without such representations, it is not possible to conduct studies investigating future force structures (e.g., 2020 and beyond) involving significant employment of unmanned systems. Instead, it appears that decisions are being made without an analytical basis that can show the benefits, limitations, and challenges (manpower, training, logistics, combat service support, vulnerabilities, etc.) of introduction of such systems into the battlespace.

Starting in late 2014, we began investigating capabilities of these critical Naval analytical models to identify improvements needed in representations of unmanned system capabilities that can improve the scope and value of studies conducted using such tools. This is an initial effort to bring improved representations of unmanned systems into analytical environments, recognizing that it is part of a larger need to bring such representations into gaming environments for concept exploration, into constructive simulations for experimentation and mission planning, and into training environments for low-level (operator) to high-level (staff) skill development.

Interestingly, the initial research is raising a new thesis—that current analytical models actually possess, though unintentionally, a higher fidelity representation of autonomous systems than they do of human-operated systems! If this is true, users of current models must change their perspectives considerably. It is well recognized that a major challenge in modeling and simulation is representation of the human element in combat, reflecting human characteristics such as training, fatigue, unit cohesion, intuition, etc. The lack of such modeling extends to the operation of systems by humans, including the operation of robotic systems (teleoperated). In many respects, it may be argued that current models of the battlespace provide a reasonably accurate depiction of diverse land, air, sea autonomous systems interacting in the battlespace, while poorly representing the human element in the operation of warfare systems. How this change in perspective in understanding the capabilities and validity of current models will affect the modeling & simulation and analytical communities remains to be seen but clearly needs further study. A key issue becomes determining how to better distinguish humans and human-operated systems from autonomous systems so that the models can more correctly represent all of these systems, and their interactions, in the battlespace.

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