DARPA and APL—Technology Innovation and Transition: Guest Editor's Introduction

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The Defense Advanced Research Projects Agency (DARPA) was created in 1958 to ensure technological superiority for U.S. military forces by fostering innovation and pursuing high-payoff, high-risk projects. DARPA started life as the Advanced Research Projects Agency (ARPA) with an early focus on space research as a result of a presidential directive following the surprise launching of *Sputnik*. Over the years, the Agency has vigorously pursued a broad range of research and development efforts relevant to more than one service in order to address capabilities for future military systems. ARPA/DARPA was also chartered to address worthwhile developments that entailed too much risk for others to pursue.[1]

The success of ARPA/DARPA has been significant since its inception. Technological innovations such as the internet, stealth technology, and the space program all began as DARPA-sponsored activities. The first DARPA program was established to develop a rocket booster with clustered engines to enable the heavy lifting needed to put a man on the moon. DARPA investment in packet-switching technology and the invention of the TCP/IP protocol gave birth to ARPANet, the father of the internet, which is now ubiquitous and has changed the way we live. In Operation Desert Storm, revolutionary capabilities such as the F-117 stealth fighter, the Joint Surveillance and Target Attack Radar System (JSTARS), and Precision Guided Munitions were the direct result of DARPA initiatives in the preceding years.[2] Other notable developments and transitions include the M-16 high-velocity rifle, phased array radars, ballistic missile defense, and head-mounted displays.[3] DARPA investments in the fundamental bases of information technology, microelectronics, and materials have affected most military systems and have resulted in significant improvements in our warfighting capability.

The APL–DARPA collaboration goes back to 1958, when the Laboratory brought the idea for the world's first satellite navigation system (Transit) to the agency. Under ARPA sponsorship, the Laboratory built the Transit satellite and accompanying ground stations,[4] with the first successful launch in 1960. The feasibility having been dramatically demonstrated, the Navy (the Strategic Systems Program Office) assumed funding responsibilities in the early 1960s, and the full Transit constellation was in place by 1968. Transit solved the Navy's need for precise navigation for its nuclear-powered Fleet Ballistic Missile submarines.[5]

APL has supported DARPA through the development of technology that has produced many successful transitions to the services, including

- *The High Performance Distributed (HiPer-D) Computing Project.* APL, under joint sponsorship from DARPA and the Navy (PMS 400), conceived and developed a distributed computing architecture for surface ship combat systems. The development effort was done jointly with the Naval Surface Weapons Center (NSWC), Dahlgren, and Lockheed Martin to support future Aegis combat systems.
- *The Long-Term Mine Reconnaissance Unmanned Undersea Vehicle (UUV).* DARPA funded the development of UUV prototypes that have successfully transitioned to the Navy.
- *The flexible fabrication of titanium.* DARPA investment in the versatile, rapid prototyping of titanium alloy has resulted in transition to the U.S. Army for tank armor, helicopter conformal armor, and soldier systems development.
- *The Ship Systems Automation (SSA) Program.* This program demonstrated the feasibility and vision for significant manning reduction for Navy combatants through the application of automation technology. Various technologies and architectures have transitioned to submarine combat system development, but the vision of automation has been most significant in the DD21 Program, where manning reduction has been one of the primary metrics.

APL activity for DARPA has increased in the past decade, particularly through key contributions to technology development and transition support. The Laboratory is now actively involved in a wide range of DARPA-funded projects, and this issue of the *Technical Digest* covers many of them. The topics, in order of appearance, are information technologies; advanced submarine technology; space systems; chemical/biological, mine, and environmental hazard detection systems; hypersonic missiles; undersea warfare; logistics technology; and synthetic environments for advanced simulation. The first article by the Director of DARPA, Dr. Frank Fernandez, reinforces the high-risk, high-payoff vision of DARPA, and compares the evolutionary innovation supported by the services and revolutionary innovation, the primary goal for DARPA.

The next series of articles focus on information technologies. To begin, Sheffer and Vaughan discuss the recent development of the Tactical Scene Operator Associate (TSO/A) and the cognitive modeling used to produce an advanced, intelligent human systems interface. This effort, as part of the SSA Program, focused on the affordability of naval ships and submarines by the application of manning reduction technologies that were in part conceived by APL. The Laboratory had a lead role in the integration of all the associates developed in the SSA Program through its work for DARPA's Tactical Technology Office (TTO). The resulting information systems architectures and interfaces are currently in transition to the Navy.

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The second article describes ongoing research at APL to fabricate biological neuronal networks as part of the Ultrascale Computing Program in the Information Technology Office (ITO). Matsuzawa et al. examine biological intelligence and its implications for future neural network concepts. These concepts exemplify far-reaching research that could dramatically increase computing performance levels. To conclude this series of articles, Wang and Jones describe an effort that has just begun in support of the Agile Information Control Environment (AICE) Program in the Information Systems Office (ISO). The goal of the AICE Program is to produce a more efficient and faster level of information control in Joint command and control systems. Future work at APL in this arena will focus on the development of an intelligent MetaNet controller as well as novel adaptive information control techniques.

Submarine technology is the focus of the next two articles. The history of DARPA-sponsored advanced submarine technology at APL is long, with the Laboratory playing a number of roles as technology developer, program concept developer, government honest agent, and transition support agent. Recent activities in this area are the Advanced Subtech Program, Advanced Technologies for Submarines Operating in the Littoral (ATSOL), and the Signature Management System. In the first two cases, APL worked with other submarine technology organizations and DARPA in developing the programs and conducting demonstrations of advanced prototypes. In the last case, APL was the primary technology developer.

The first article on advanced submarine technology, by Watson, describes the Integrated Vulnerability Management System, which was part of the ATSOL

Program sponsored by TTO. APL was the primary technology developer for the program, which is now in transition to the Navy. The prototype was a real-time decision support system that provided an assessment of current ship stealth and an estimation of the threat counterdetection capability. The second article, by Thompson et al., chronicles the development of an antenna technology that will provide two-way communications for a submarine at speed and depth, thereby preserving the submarine's stealth. This ongoing project, sponsored by TTO, is part of a joint Navy/DARPA effort to examine advanced submarine antenna technologies and is a good example of how APL supports DARPA technology developed elsewhere by fitting the technology into the warfighter's domain, ensuring the utility of the product, and easing its transition.

The domain of space applications is covered by the following two articles. As previously stated, DARPA had its start in space technology development. After many years of successful investment in this arena, the Agency has only recently ventured back to it. The Discoverer II Program, under sponsorship with DARPA-TTO, the National Reconnaissance Office, and the Air Force, is a technology demonstration program showing the feasibility for a constellation of satellites that will perform ground-moving target indication and synthetic aperture radar (SAR). The system would provide near–real-time support to the warfighter on the ground an order of magnitude faster than is currently provided, thus enabling new capabilities for indication and warning, precision engagement, and battlefield surveillance.

Roth summarizes a project conducted for TTO that surveys the applicability of current research for space-based high-resolution interferometric SAR (IFSAR). The second article, written by Gilreath et al., highlights a study that examined the technical and economic feasibility of launching small satellites with a distributed-injection, light-gas gun. The study, also conducted for TTO, exemplifies the preprogram work that APL is called on to do for DARPA before a large-scale technology investment is begun. In this particular case, the study, which provides a roadmap for a potential program, shows that the satellite gun concept is feasible, provided certain technologies are developed. Additionally, a cost analysis demonstrated that under particular conditions, the launching of satellites by a light-gas gun could be an excellent economic alternative, paving the way for eventual transition.

Dr. Fernandez has articulated DARPA's current focus, with respect to national security priorities, to include the development of technology and systems that will allow protection from biological attack. Following the early developments at JHU in this area, APL and DARPA have been jointly developing sensors and their associated systems to detect, characterize, and respond to chemical and biological attack. The next series of articles describe efforts at both APL and JHU that focus on this important problem.

The first article in this series was written by Donlon and Jackman. Dr. Donlon sponsored development of the miniaturized mass spectrometer at the Johns Hopkins School of Medicine (SOM) and APL. That tool is the foundation for the systems currently under development at the Laboratory. The article describes the overall sensor program at the DARPA Special Projects Office (SPO) in the area of chemical and biological counterproliferation and sets the context for the APL-specific developments described in subsequent articles.

The miniature time-of-flight (TOF) mass spectrometer is the centerpiece for APL and SOM efforts in chemical and biological defense. McLoughlin et al. describe the development of this sensor and its associated subsystems that will support a field-portable version of the detection system in the near future. Applications focus on battlefield protection for the warfighter, but can be easily extended to support counterterrorism, domestic preparedness, and law enforcement applications. The effort is part of a 3-year advanced technology demonstration jointly funded by DARPA-SPO and the Defense Threat Reduction Agency Chem/Bio Directorate. McLoughlin et al. also describe the significant advances in technology that will enable maximum utility and protection for the warfighter of the future.

The next four articles detail the development of the miniature TOF spectrometer. Cornish and Bryden, writing about the pseudo-tandem TOF mass spectrometer, discuss the operating principles of the mass analyzer, its miniaturization, and mass spectral biosignatures. Scholl et al. describe the matrix-assisted laser desorption/ionization (MALDI) method used in the detection system, and show how the MALDI process (as incorporated into the TOF mass spectrometer) helps to characterize the properties of chemical and biological weapons. Anderson and Carlson next present details of the automatic aerosol collector, a sample processor, and the vacuum chamber load lock parts of the overall system. They describe a unique approach to the problem that has resulted in a fully automated system for combining sample collection, preparation, measurement, and analysis.

Hayek et al. describe the analysis part of the mass spectrometer system. The observed mass spectra of the samples normally require extensive work to extricate signatures from the noise. This article examines algorithms that have been developed to automatically interpret mass spectra, both from known and partially known signatures. Frank Fernandez, in a statement before the Senate Subcommittee on Emerging Threats and Capabilities on 20 April 1999, hailed the development of the miniaturized mass spectrometer as "already demonstrating substantial success."

An effort to develop a handheld sensor for the detection of aflatoxins is the subject of the next article about detection systems. This project was sponsored by DARPA-SPO and the Nonproliferation Center in response to the weaponization of aflatoxins during the Gulf War. Carlson et al. report on the rapid prototyping of a fully automated and highly sensitive device that operates on the principles of immunoaffinity for specificity and fluorescence for a quantitative assay. The sensor system is also easily extended to support the detection and characterization of other chemical and biological agents. The project is an excellent example of the combined abilities of APL and DARPA to quickly leverage state-of-the-art technology, integrate it into a working system, and provide the warfighter (or weapons inspector) a portable capability in short order.

Recent advances in membrane material science are presented next. These advances will allow for greatly enhanced detection of chemical agents in water. Morgan et al. describe membrane-introduction mass spectrometry (MIMS) and how it has been used to detect volatile organic compounds in aqueous matrices at the parts-per-trillion level. They detail how advances in membrane materials, combined with the miniaturized mass spectrometer, will enable the development of a portable detection system to support counterproliferation, treaty verification, and infrastructure protection.

A related subject, mine detection, has been an urgent problem for many years. Warfighters, as well as civilian populations, have suffered many casualties owing to the lack of a good detector of buried explosive ordnance. Dogs using olfactory detection of the vapor from explosives serve as excellent sensors, but they are in short supply, and the training time is an issue. The Electronic Dog's Nose Program at DARPA is examining technologies that would replicate the canine's capability, and the APL effort in this program is described in another article by Morgan et al. APL has focused on the momentary increase of the explosive vapor pressure in the headspace over the target produced by the use of laser thermal desorption. Early results, described in the article, show that the technique has merit.

The monitoring of fish to detect toxins in water is the topic of the article by Sarabun et al. The U.S. Army Center for Environmental Health Research and APL, with DARPA-SPO support, have initiated exploratory work for monitoring fish ventilatory systems for early detection of toxins. From a series of experiments, APL recorded data and is conducting time and frequency domain analyses. The results show promise for the application of these techniques to the early detection of toxic substances.

An effort to develop a framework for evaluating environmental health risks is described next. This capability could affect warfighters deployed overseas who may be exposed to environmental contamination from deliberate adversary action or by routine industrial operations or accidents. The article by Tran et al. describes the development of the framework, which is based on quantitative risk assessment and risk prioritization originally designed by JHU for urban environments. The work, performed by the JHU School of Hygiene and Public Health, was sponsored by the Defense Intelligence Agency Environmental Health Branch with support from DARPA-SPO.

APL's domain expertise in many areas has been leveraged by DARPA in support of technology development projects. The next article is an example of how APL has used its knowledge in the area of advanced missile technology to support a DARPA Project in TTO. The Affordable Rapid Response Missile Demonstrator Program (ARRMD) will develop a concept for an affordable hypersonic long-range cruise missile and demonstrate it in flight. This program will facilitate the vision for fast strike capabilities against moving targets. White and Price (the latter is the DARPA Program Manager for ARRMD) describe the overall goals and approach of the program as well as the enabling technology required for the development of the hypersonic missile.

APL and DARPA have also been working on antisubmarine warfare (ASW) for many years. During the Cold War, ASW was a top priority as the former Soviet Union deployed advanced nuclear submarines as its first line of attack against our Fleet Ballistic Missile submarines and our aircraft carrier battle groups. Now, with the fall of the Berlin Wall, third world nations could deploy very quiet diesel submarines that may preclude our Navy's ability to operate in the littorals. DARPA-TTO has developed advanced active acoustic source technology for single-ping detection against diesel submarines operating in shallow water, and APL has contributed to this effort by analyzing test results and providing general technical support. The article by Bowen and Mitnick describes a methodology developed to predict multistatic active performance, a capability that was used to demonstrate the operational utility of the DARPA-developed sources. APL supported both the DARPA and Navy developments in multistatic active sonar and was able to show the value added for each approach to the problem.

DARPA-ISO has been investing in technology development to resolve the critical problem of logistics support. The Gulf War demonstrated the need for significant improvements to ensure that supplies were delivered to the warfighter on time and in correct numbers, and that excessive waste caused by over-ordering particular items was avoided. DARPA has sponsored a system-of-systems effort in the logistics support area through its Advanced Logistics Program. The article by Perdomo et al. describes tasking from DARPA to determine a viable concept of operations for a future system of small, expendable tags. These tags, which could be attached to virtually every item in the inventory, would allow for total asset visibility and tracking of all items in the logistics chain "from factory to foxhole." The study focused on the in-theater logistics problem and was the beginning of a future DARPA tag technology program.

The final article reports on the latest APL contribution in support of DARPA-sponsored simulation technology development. The Advanced Simulation Technology Thrust in ISO has sponsored APL to assist in development of a synthetic natural environment that will provide the domain in which synthetic forces can operate. The APL effort, described by Newman et al., is the Multiresolution Interaction Validity (MIV) Project, which is aimed at more efficient methodologies for employing environmental models. These methodologies will aid in the development of synthetic forces and enable consistent environmental treatment with multiple models. The article provides an overview of the program and addresses recent accomplishments.

APL and DARPA have formed a synergistic and effective relationship in which the Laboratory continues to support the agency through the development of revolutionary innovation, through technical support as an honest agent and domain expert, and as a transition agent to facilitate the impedance matching between the Agency and the services. The collection of articles presented here shows the breadth and depth of these activities across many domains of interest. I believe that this relationship will continue into the future, for although DARPA and APL will undoubtedly change over time, the need for both revolutionary innovation and effective transition of that innovation will be critical to achieve our national and defense goals and requirements.

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