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PORTABLE DEEP-ULTRAVIOLET RAMAN SPECTROSCOPY FOR

STANDOFF THREAT DETECTION

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MESSAGE FROM THE EDITOR

ERIC FIORE

Recently, I had the good fortune to witness a live demonstration of the threat detection technology featured on this issue's cover. The man-Portable Raman Improvised Explosives Detector (PRIED) is a derivative of a larger Checkpoint Explosive Detection System (CPEDS) currently protecting a critical asset in the Middle East. PRIED provides dismounted troops the ability to rapidly (in a matter of seconds) interrogate suspicious items, including people, to determine if they contain or have recently handled dangerous materials. The system, which is starting to get a lot of attention from the Unified Combatant Commands, holds great promise as a portable, lightweight, short-range, multithreat, detection system. Luisa Profeta's article on PRIED discusses how Raman spectroscopy is being applied to detect pervasive chemical and energetic threats in the field. The simplicity in operation to make real-time threat determinations is perhaps one of the greatest advantages of this technology.

Optical systems are used throughout the Services for surveillance, rifle scopes, laser weapons, laser designators, and night vision goggles. However, in many cases, the manufacture of high-precision optics is extremely expensive, as achieving the high precision required for the desired optical performance often requires increased manufacturing time. In Justin Mansell's article on adaptive optics, he discusses how industry has been developing technology to combat the performance limitations by enabling these aberrations to be dynamically corrected and significantly reduce the costs of complex optical systems.

In Capt. Anthony Ripley's article on persistent intelligence, surveillance, and reconnaissance (ISR), he discusses how the Marine Corps Expeditionary Energy Office and a team of scientists and engineers from government, academia, and industry are collaborating to demonstrate an innovative energy-harvesting approach using a solar-powered unmanned aerial vehicle (UAV). By integrating the latest technologies in photovoltaics, autonomous soaring, high-energy density storage, maximum power point tracking, and cooperative flight, the project team plans to deliver a long-sought-after persistent ISR capability. In fact, the technology looks so promising that the Marine Corps may well be on its way to having a next-generation persistent ISR capability on a platform that requires no operating fuel at all.

And finally, Bruce Simon (whose biography is shown on right) discusses testimony presented at a recent hearing of the House Armed Services Committee (HASC) Emerging Threats and Capabilities Subcommittee, where senior DoD leaders discussed how Better Buying Power 3.0 is integral to the FY17 S&T Plan. As a new member of the DSIAC team, Mr. Simon will be monitoring, capturing, and reporting news and successes associated with the Better Buying Power 3.0 initiative, particularly as it relates to DSIAC and the DoD Information Analysis Center enterprise. It is my pleasure to introduce Bruce. ■

Bruce Simon is a Senior Advisor at the SURVICE Engineering Company. As a new member of the DSIAC team, Mr. Simon is responsible for increasing Department of Defense (DoD) and public awareness of Information Analysis Center contributions and successes resulting from implementation of the DoD Better Buying Power 3.0 initiative. Prior to his work at SURVICE, Mr. Simon conducted legislative and policy research and (through SAIC) served as a legislative liaison for the Joint Improvised Explosive Device Defeat Organization, and supported congressional reporting responsibilities of the Director of Operational Test and Evaluation in the Office of the Secretary of Defense. He has also served as a congressional staffer and worked in President George H. W. Bush's administration. Mr. Simon holds a master's in political science from George Washington University and a bachelor's in political science from the University of Rochester.

PORTABLE DEEP-ULTRAVIOLET RAMAN SPECTROSCOPY FOR STANDOFF THREAT DETECTION

By Luisa T. M. Profeta, Adam J. Hopkins, Justin L. Cooper, and Col. (R) C. M. Ferguson, Jr.

INTRODUCTION

The growing proliferation of concealed improvised threats (e.g., explosives and chemical warfare agents [CWAs]) has created a critical international need for systems and devices that can rapidly identify unknown, hidden, or camouflaged hazardous materials. Military, federal, and state organizations require instrumentation that can be easily carried by personnel who are monitoring or investigating a location or scene. Operations for such scenarios are generally more interested in the qualitative—“Is a threat material present?”—rather than the quantitative aspect. Knowledge of the presence of a hazardous material is critical for determining the appropriate response. Covert threat analysis operations often involve conducting rapid material analysis (in a 1- to 5-minute time frame), testing samples with less than adequate protection (e.g., little to no personal protective equipment [PPE]), and having to avoid drawing unnecessary attention to the site of a potential hazard.

The current collection/analysis tools of choice for these activities include colorimetric test kits, hand-held optical spectrometers, and miniaturized mass spectrometry systems. Even with recent technology advances in some of these areas, threat sampling is a proximity problem for the majority of them. An investigator must get close to, or even touch, a suspect item, which further exposes the investigator to the threat and requires additional time to investigate. The use of standoff vibrational spectroscopy (e.g., Raman or infrared [IR]) as a rapid method for uniquely identifying suspicious materials from a safe distance (>3 ft) has thus been a focus in academia and laboratories for many years [1]. Recently, however, Alakai Defense Systems (ADS) has developed a standoff solution, the man-Portable Raman Improvised Explosives Detector (PRIED), to get this technology out of the laboratory and into the field.

PRIED combines all the capabilities of a high-sensitivity bench-top Raman system into a compact, ruggedized package that can be worn and employed by a single operator. The device can detect and identify bulk and high-trace levels of substances of interest from several meters in a few seconds using

U.S. Air Force Photo
(Computer-Generated Scenario)

deep-ultraviolet (DUV) illumination. This article describes key aspects of PRIED and characterizes employment of the instrument for pharmaceutical and counter-narcotics applications. Though these applications are likely to be of greater interest to the domestic law enforcement and first responder community, the principles are transferable to those involved in explosives detection operations.

PRIED DESIGN AND OPERATION

PRIED is a revolutionary improvement of the Checkpoint Explosive Detection System (CPEDS). CPEDS, now in its third generation after 8 years of development sponsored by the U.S. Army Research Laboratory (ARL), is a 248-nm Raman system that is transportable by vehicles such as Utility Terrain Vehicles (UTV). CPEDS has been tested extensively in government trials and has demonstrated Raman detection of bulk explosives and explosive residues at ranges in excess of 25 m. The results of this testing are not publically available, but they confirm that DUV Raman is able to identify high-trace concentrations of materials at standoff ranges [2]. ADS's patented stimulated aversion eye-safety technology gives CPEDS a nominal ocular hazard distance (NOHD) of 0 m. PRIED's engineering and design captures both the close-range performance and the eye-safety feature of CPEDS, while reducing the weight and power consumption from 650 lbs and 1.6 kW to 130 W and being man-portable. Figure 1 provides a visual perspective of the size of a PRIED system in use by an adult male.

The PRIED backpack, which weighs 31 lbs, contains the thermal and power management system, computer, iCCD camera, and spectrometer. The backpack is connected to the hand-held sensor head, referred to as a "wand," via an umbilical cord. The wand, which weighs less than 7 lbs, contains the 262-nm laser, visible camera, range finder, eye-safety subsystem, and optics. The wand can be operated in the hand-held mode or attached to a monopod, tripod, or vehicle mount for increased stability when making long-range acquisitions.

PRIED is designed for use in harsh, austere operational environments. Its operation is initiated by a simple manual trigger on the wand. Partially depressing the trigger, similar to the functioning of a single-lens reflex (SLR) camera, activates a green laser pointer/designator and the range-finding subsystem. Fully depressing the trigger initiates data collection, which proceeds until a threat material is detected or a system-specified timeout is reached (typically 10 s). While the laser is firing, a blue light-emitting diode (LED) on the top of the hand piece blinks, indicating emission of invisible DUV radiation. At the conclusion of a scan, a simple threat/no threat indicator is presented to the operator by illuminating either a red or a green LED.

Additional information is available to the operator or anyone monitoring the system via an integrated Bluetooth transmitter (or other suitable wireless communication) on an Android® device. Screenshots of the PRIED application are pictured in Figure 2. The main application screen (Figure 2a) displays the measurement history, with a summary result of each measurement. Detected materials are classified as threats, suspicious, or nonthreats via simple icons. In the sample screen, RDX and ammonium nitrate are shown with red octagons indicating known threat materials. Materials not of interest, or nondetects, are displayed with a green circle. Suspicious materials, such as triethylphosphate (TEPO), that have legitimate manufacturing uses

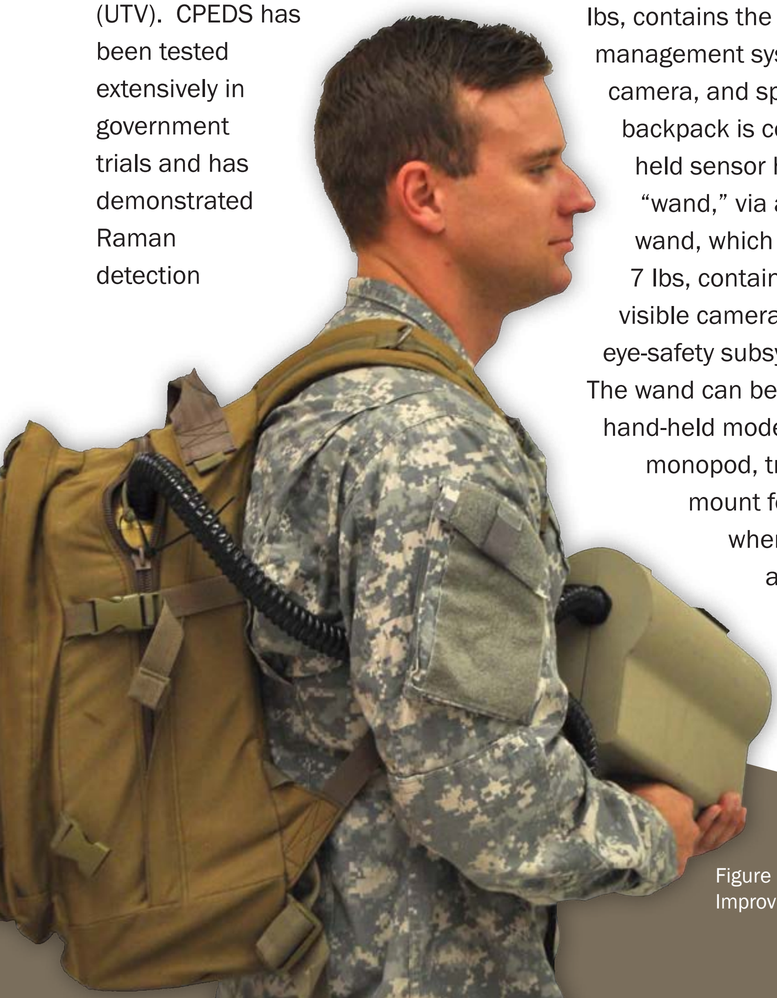
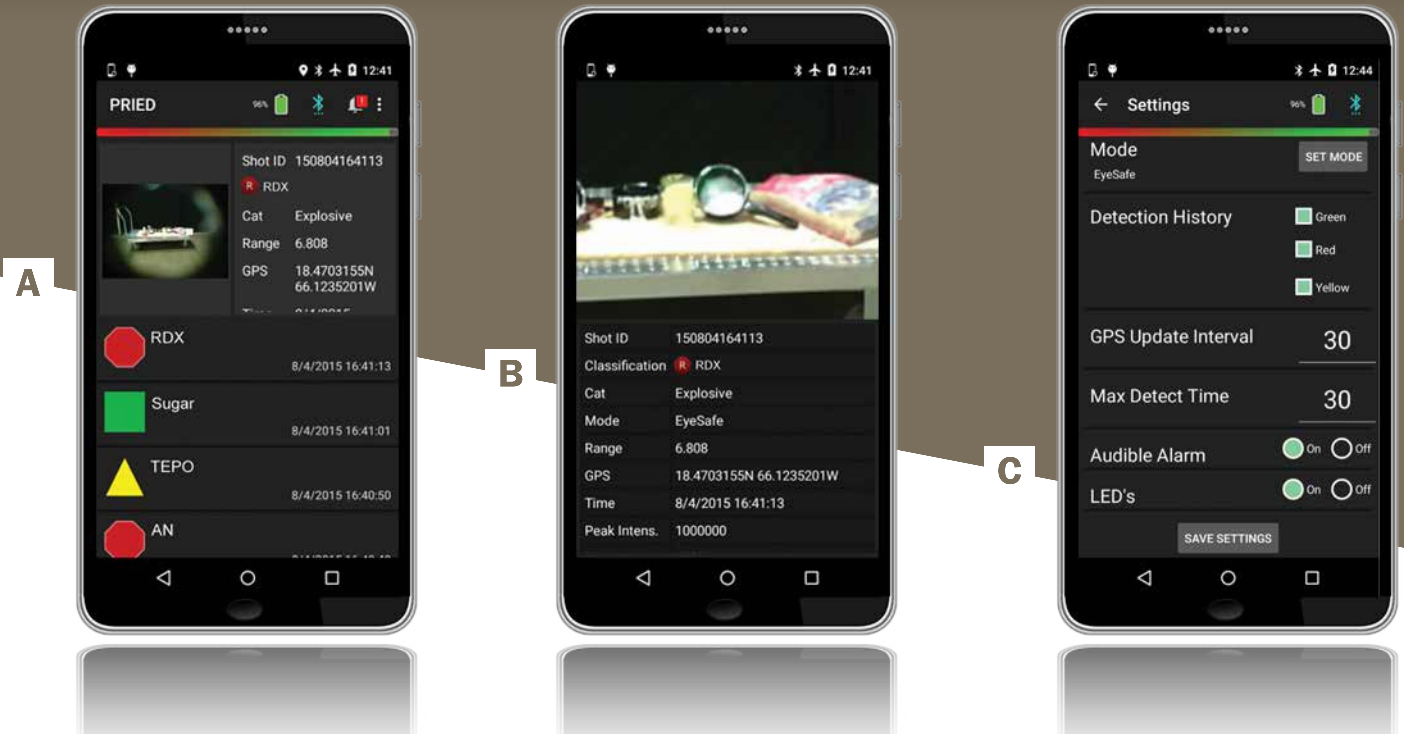


Figure 1: Man-Portable Raman Improvised Explosives Detector (PRIED).



PRIED

Shot ID 150804164113
R RDX
Cat Explosive
Range 6.808
GPS 18.4703155N 66.1235201W

RDX 8/4/2015 16:41:13
Sugar 8/4/2015 16:41:01
TEPO 8/4/2015 16:40:50
AN

Shot ID 150804164113
Classification R RDX
Cat Explosive
Mode EyeSafe
Range 6.808
GPS 18.4703155N 66.1235201W
Time 8/4/2015 16:41:13
Peak Intens. 1000000

Settings
Mode EyeSafe SET MODE
Detection History ☑ Green ☑ Red ☑ Yellow
GPS Update Interval 30
Max Detect Time 30
Audible Alarm ● On ○ Off
LED's ● On ○ Off
SAVE SETTINGS

Figure 2: PRIED Android Application (a) Measurement History, (b) Measurement Details With Zoomed-In Image of Sampled Location, and (c) System Settings.

but can also be used for narcotics or CWA manufacture are indicated with a yellow triangle. Each measurement can be further investigated on any of the connected devices by viewing a high-resolution recorded image that indicates the target being interrogated and uses global positioning system (GPS) to show exactly where the measurement was performed (Figure 2b). From here, the recorded spectrum can be viewed for quick assessment of data quality. Finally, the PRIED application (Figure 2c) displays system status information, indicating such information as the location of electronic faults, system temperature, and battery lifetime. All data, information, and imagery associated with each detection acquired by PRIED are archived in the system for upload to an incident command system or for later forensic use.

Remotely located command/supervisory personnel can access the advanced control software directly via network connection to the backpack and modify the instrument settings, or they can enter changes directly into the application by providing appropriate credentials (Figure 2c). Changeable operating parameters include, but are not limited to, the PRIED application behavior at the end of scan, the maximum allowable scan time, and the ability to change between eye-safe and max detect (not eye-safe) collection mode.

DUV ADVANTAGES

PRIED uses DUV illumination, which has four major advantages over near-IR Raman wavelengths for standoff applications.

1. Raman material cross sections increase with decreasing wavelength by 1/λ^4. The cross sections measured by PRIED at 262 nm are about 80 times larger than the average hand-held Raman instrument at 785 nm and 272 times larger than some specialized hand-helds that lase at 1,064 nm [3–8].
2. DUV excitation results in Raman spectra that are collected in the solar blind region and are nearly fluorescence free (see Figure 3). Solar background is known to cause interference with Raman using visible and near-IR (NIR) lasers [9].
3. Inherent material fluorescence is largely suppressed with DUV excitation as many materials encountered in forensic

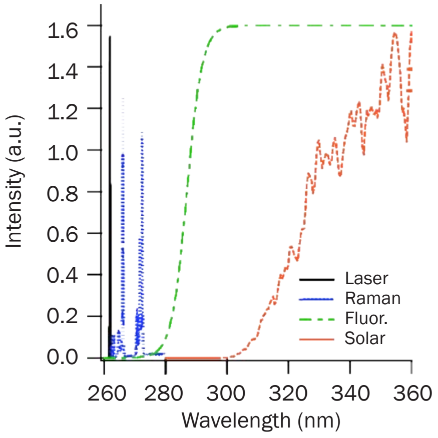


Figure 3: PRIED Raman Spectra in the Fluorescence-Free and Solar-Blind Region.

investigations exhibit strong fluorescence when excited with 785 nm, the most commonly used wavelength for portable Raman systems. To overcome fluorescence, manufacturers are now offering 1,064-nm systems. DUV excitation provides approximately the same level of fluorescence reduction over 785 nm as 1,064-nm excitation, but at more than 200 times the signal strength.

4. DUV Raman has reduced detonation probability of explosives. It is known that certain Raman systems using tightly focused 785-nm or 1,064-nm sources can cause deflagration or detonation of explosive materials. DUV Raman systems have been extensively tested on an array of energetic materials, such as C-4 (RDX), ammonium nitrate/fuel oil (ANFO), and primary explosives (mercury fulminate), and they have not experienced a single initiation or detonation.

EYE SAFETY

The ADS-developed patented eye-safe technology [10] allows for operators to have robust performance without sacrificing eye safety. PRIED is currently awaiting certification by the Army Public Health Command as an eye-safe explosive detection system. Confidence is high that this certification will be achieved because PRIED employs the same patented eye-safe technology developed for use in CPEDS (see Figure 4) that has previously been certified as completely eye safe, even if viewed through magnifying optics. In addition, an operational benefit of this eye-safe technology is that the coordinating visible light co-illuminating the DUV beam acts as a pointer beam for a mission operator. If a truly covert operation is desired, the DUV beam is completely invisible to the eye, night observable devices (NODS), or even thermal viewers.

> DUV excitation provides approximately the same level of fluorescence reduction over 785 nm as 1,064-nm excitation, but at more than 200 times the signal strength.

A collimated UV beam is encased in a slightly diverging green beam. The green beam induces a blink response and causes onlookers to turn away within 0.25 s, preventing UV exposure and allowing increased energy on target. Beyond the range of the intended target, both beams diverge. The technology can be combined with range interruption sensing to shut off the system if a bystander crosses the beam.

ALGORITHM SPECIFICATIONS

PRIED provides identification of an unknown material using built-in spectral libraries and a proprietary algorithm to return a clear, unambiguous answer to a soldier in the field. The algorithm answers the question, “Is a threat material present, even if there are other nonthreat materials present too?” In focusing on the presence or absence of a threat, PRIED is able to achieve much greater sensitivity to threat materials than currently fielded hand-held Raman instrumentation. As with other Raman instruments, PRIED’s search libraries can be customized and narrowed by mission commanders to limit irrelevant results. PRIED is equipped with colored LEDs on the wand, providing a red (threat) or green (nonthreat) response to the operator immediately upon final identification of an unknown. A typical unknown acquisition time at <10 m is 15 s or less.

Within 1 min of identification, additional sample information (including a picture of the scene, National Fire protection Association [NFPA] information, etc.) can be transmitted to an Android™-enabled device, allowing a secondary user or leader to view the results and make appropriate mission decisions. The system of a threat/no-threat notification on board PRIED simplifies site exploitation missions and does not require a soldier to know extensive

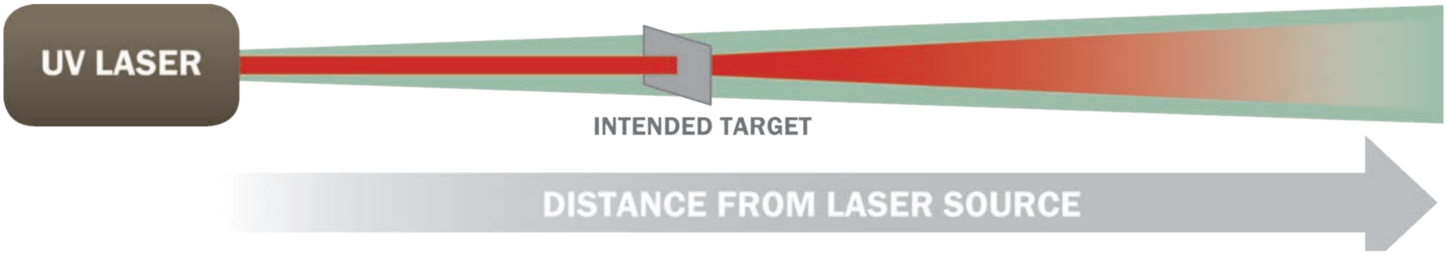


Figure 4: Operating Principle of ADS’s Stimulated-Aversion Eye-Safety Technique.

chemistry to appropriately classify if an identified material is considered a mission hazard. As PRIED is deployed in additional operational scenarios, library growth will continue and further chemometric development for mixture analysis will be implemented.

EXPERIMENTAL

To test the effectiveness of PRIED, a series of experiments was performed on industry standards. All laboratory chemicals were sourced from Sigma-Aldrich (in St. Louis, MO). Narcotics were provided by the National Forensic Science Technology Center, in Largo, FL. Surrogate analytes in the form of locally procured consumer substances were purchased from local retail outlets.

Samples were measured in bulk or near-bulk amounts. We define this amount as a quantity of sample that is sufficiently thick to be seen with the unaided eye and that fills more than three-quarters of the beam footprint at the desired distance. Liquid materials were held in a DUV-transparent sample cell, and solid sample configurations include those similar to the one shown in Figure 5a, in which a few granules of analyte were placed on an unglazed ceramic tile. The samples were typically mounted vertically, so that PRIED could be mounted on a table and normal beam incidence ensured for maximum reproducibility. Integration times were intentionally varied with range to target. Measurements longer than a few seconds were accomplished by supporting the PRIED wand with a monopod or securing it to an optical bench.

In addition to its obvious military benefits, PRIED was also designed with standoff detection in mind for law enforcement and first responders. The system has been evaluated against a number of materials expected to be present in a clandestine narcotics laboratory for a range of distances and investigation times. Materials that are naturally highly fluorescent have been of particular interest, with evaluators comparing the results obtained from PRIED with those of a commercial hand-held 785-nm Raman system.

RESULTS

Bulk Detection Performance

PRIED testing results discussed here fall into three categories: (1) bulk detection performance, (2) algorithm performance, and (3) narcotic and excipient detection. For the characterization of system performance against bulk common cutting agents, sucrose (granulated table sugar), sodium bicarbonate (commercial baking soda), and acetaminophen (Sigma-Aldrich) were selected. Baseline corrected spectra of these bulk materials collected at 3 m are shown in Figure 6. All of the Raman spectral features of sodium bicarbonate reasonably match those in the literature [11]. The relative intensities of the peaks, however, are different, which is attributable to the difference in excitation wavelength.

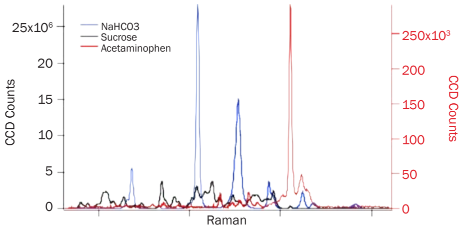


Figure 6: 3-m Data for $NAHCO_3$ (Blue), Sucrose (Black), and Acetaminophen (Red). Acetaminophen Y-Axis Is Approximately 100 Times Smaller Than the Other Two Analytes.

ADS collected spectra of table sugar as a function of range and average power to coarsely evaluate the signal falloff. Figure 7 presents data collected at 2- and 10-m standoff in both max detect (Figure 7a) and eye-safe modes (Figure 7b) after 10 s of measurement. At both 2- and 10-m standoff, the max detect operation gives a strong table sugar spectrum in 1 s. The difference in spectral intensity is a factor of 2.5 for these two ranges in both modes. The intensity difference relates to how the iCCD in PRIED automatically increases sensitivity with increasing range. Eye-safe operation reduces the energy by a factor of approximately 7, so a longer acquisition time is necessary to obtain a spectrum with the same signal intensity as high-power operation. Despite the signal reduction, high-quality spectra are still generated for this material within a few seconds at both ranges.

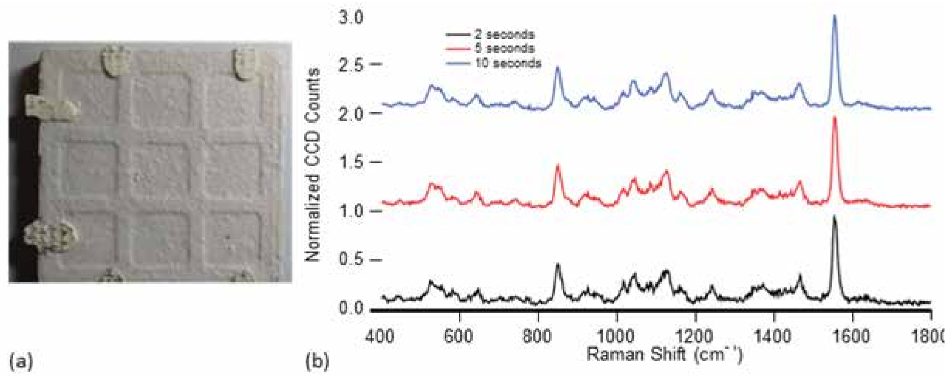


Figure 5: (a) Photograph of 1 mg/cm^2 of Table Sugar on 40-mm-Wide Ceramic Coupon; (b) Normalized Spectra of Sugar at 2-, 5-, and 10-s Integration Times. Spectra Are Normalized to the Oxygen Peak at 1,554 cm^{-1} and Offset for Clarity.

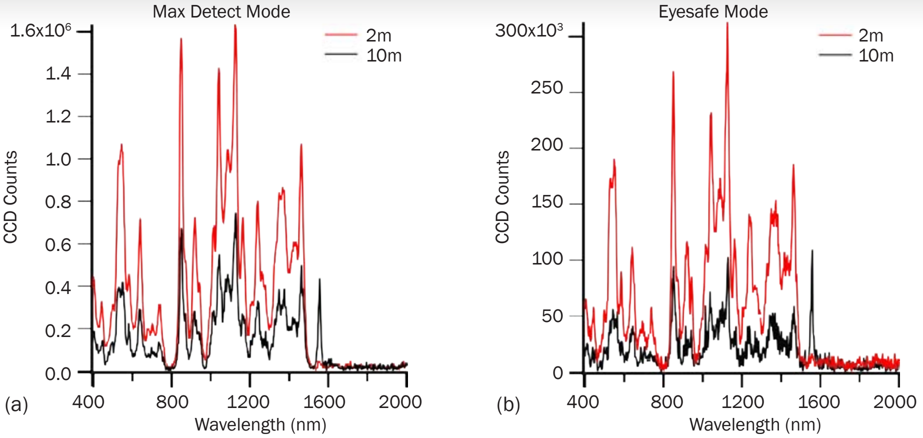


Figure 7: (a) Max-Detect and (b) Eye-Safe Raman Spectra of Table Sugar After 10 s of Collection.

The acetaminophen Raman spectrum in Figure 6 (red trace) is approximately 1,300 times weaker than the sodium bicarbonate spectrum collected under the same conditions. The strongest peak in the spectrum arises from the O_2 vibration at 1,554 cm^{-1}, which has the same intensity as in the bicarbonate and sucrose data. The intensity differences seen with acetaminophen sampled with PRIED vs. other Raman instruments likely arise from the difference in excitation wavelength. The 262-nm light is strongly absorbed by the aromatic moiety, which leads to changes in electron distribution and the molecular polarizability.

> One important fact that is often overlooked by typical end-users is that, after some amount of time for any instrument, there is no major benefit in continuing to measure.

The lower-than-expected signal could occur from self-absorption of Raman shifted photons. A recent analysis by Hong and Asher suggests that self-absorption reduces the Raman intensity faster than resonance enhances it if an impurity is present that resonantly absorbs the Raman photons [12]. ADS measurements were performed on bulk reagent grade material, and it is unlikely that impurities contributed significantly to the spectrum. Photochemical degradation is also known to affect DUV Raman spectra of materials that have high DUV absorption. If the sample were photodegrading, one would expect to have seen decreasing signal over time while illuminating the same area of the sample. The same location of the sample was shot 10 times for 30 s each time in maximum detection mode, and no trend in the signal intensity was found. In addition, no sample discoloration, which is typical of photodegradation, was observed. Further addressing these observations is beyond the scope of this work, but this area will be the target of future research.

Algorithm Performance

Library entries for sucrose, acetaminophen, and baking soda were created using bulk materials at close range. These library elements were added to PRIED to explore algorithm performance. All shown instrument detection performance is based on live instrument results, not reprocessing of data after further analysis. Typical of field samples encountered by first responders, law enforcement, and military personnel will be mixtures or visible residues on surfaces (sometimes called “high-trace” or “near-bulk”). In these cases, the algorithm will have to handle multiple components with Raman signals, fluorescent backgrounds, and discriminate materials of interest (threats) from nonthreats.

To demonstrate high-trace detection capability, data were collected from a several samples with a small amount (approximately 1 mg/cm^2) of table sugar placed in the center of a ceramic tile without adhesive at 1-m standoff. A photograph of one such sample is shown in Figure 5a. Figure 5b shows representative Raman spectra of the sample at 2, 5, and 10 s of analysis time, all normalized to the height of the O_2 peak for ease of intensity comparison. At 2 s, the presence of sugar is unmistakable to the unaided eye. Ten independent measurements were made of these samples, and the algorithm was instructed to identify the material at 2, 5, and 10 s. At 2 s, the algorithm correctly identified the material 90% of the time; at 5 and 10 s, sucrose was correctly identified in each measurement. An estimate of the signal-to-noise ratio (SNR) for the instrument can be instructive in understanding the overall performance. The SNR for these measurements increases from 13 to 19 to 25, with increasing measurement time. These SNR estimates are not fully reflective of detection performance, as a value of 13 suggests that a positive identification should have been made in every 2-s measurement. A full discussion on the relationship between the SNR and the detection performance is beyond the scope of this text but will be the subject of future research.

One behavior characteristic of most Raman systems points to an important fact that is often overlooked by typical end-users; after some amount of time for any instrument, there is no major benefit in continuing to measure. The detection performance reaches 100% or some other maximum value. Early generation hand-held systems, in our experience, will attempt to measure for several minutes to try and make an identification. However, this reduces the operational tempo and does not typically provide improved results. A newer commercially available Raman instrument with which we have experience times out after approximately 120 s.

PRIED was tested against two mixtures to identify "threat" components. Our initial testing was on a 10:1 mole fraction mixture of baking soda ($NaHCO_3$) and calcium sulfate ($CaSO_4 \cdot 2H_2O$). Both of these materials fluoresce visibly when excited at 262 nm and are encountered as narcotics fillers. Additionally, they are fine white powders that are not easily distinguished by eye when separate and cannot be readily separated when mixed. Figure 8a shows a representative spectrum of this mixture overlaying the two components. Both materials have clearly visible peaks in the mixture spectrum. Despite the strength of the baking soda signal, in all 20 measurements, PRIED identified both of the materials in 1 s. At 5-mole-percent $CaSO_4$, additional measurement time is required to correctly identify the minor material.

BENGAY® is a common topical pain reliever containing 30% methyl salicylate (MES), 10% menthol, and 4% camphor as active ingredients, along with nine inactive ingredients. This formulated product was expected to have a high fluorescence background and many features that would obscure the MES, a common chemical warfare agent simulant. However, the PRIED spectra of BENGAY® displayed minimal visible fluorescence (Figure 8b), and MES was correctly identified as in all of the 1-s measurements. Both the BENGAY® and baking soda/calcium sulfate tests indicate that even with current programming, PRIED could be helpful for determining threat materials in mixtures.

Narcotics

Three reagent-grade narcotic samples were measured: cocaine hydrogen chloride (HCl), heroin HCl, and methamphetamine HCl. Figure 9 presents the spectra of a few milligrams of cocaine HCl and heroin HCl collected at 1 m with PRIED and with a 785-nm system. The tallest peaks with intensity 1 in the 262-nm spectra are from atmospheric oxygen. Cocaine HCl and heroin HCl have measurable spectra in less than 10 s with PRIED and have nearly no fluorescence background. The 785-nm instrument identified cocaine in 12 s and was unable to identify heroin. The heroin HCl spectrum is particularly weak due to rapid photodegradation of the material. A fresh sample exposed to the ADS Raman laser lost well-defined spectral features within 15 s of exposure; however, short integration times should present spectra with sufficient SNR to detect once a library

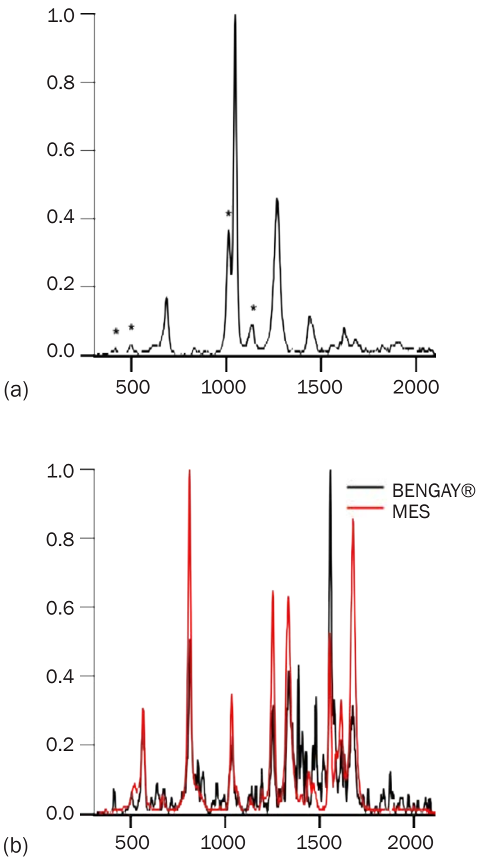


Figure 8: (a) Spectrum of 90:10 $NaHCO_3$:$CaSO_4 \cdot 2H_2O$; Sulfate Features Noted with *; (b) Spectrum of "BENGAY®" Compared with MES.

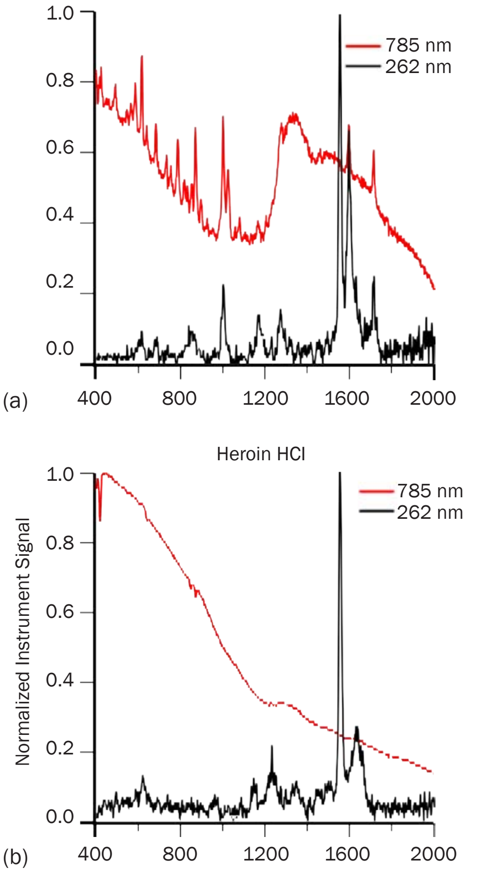


Figure 9: PRIED (1 m) and 785 nm Spectra of (a) Cocaine HCl and (b) Heroin HCl. All the Spectra Have Been Normalized to 1. The PRIED Spectra Were Collected in 30 s.

element is constructed. Cocaine HCl matches well with the data from the 785-nm system, although many modes appear to be broader. This fact may arise from a combination of the instrument response function and UV absorption effects that are either thermal or electronic. ADS was unable to obtain any meaningful data on methamphetamine HCl due to high fluorescence. It is unknown currently if the observed high levels of fluorescence arose from contaminants in the sample, are a result of the rapid absorption of water by the material, or are intrinsic to methamphetamine exposed to DUV. The 785-nm system was able to identify methamphetamine after a 42-s analysis.

Identification of pure materials is a relatively simple task, but pure materials are rarely encountered in the real world. As discussed previously, excipients and fillers are commonly used in pharmaceutical and narcotics manufacture; some of these may be strongly fluorescent or have strong Raman features that obscure the active ingredients. Both of these cases may cause a rapid investigation to fail to identify illicit materials and require time-consuming laboratory analysis. We tested the PRIED hardware and algorithm to begin to understand how much signal is required to positively identify a material, particularly in a complex matrix.

CONCLUSIONS

The ADS results discussed herein (as well as third-party testing) suggest that the PRIED design can successfully identify suspect threat materials from distances of between 1 and 10 m. Accordingly, PRIED is promising equipment that could enhance the operational capabilities of law enforcement, military, first responder, and forensic personnel in the identification and exploitation of clandestine explosives and narcotics laboratories at relatively safe distances.

Results show that common excipients used in combination with street drugs do not have strong fluorescence signals that overpower the DUV Raman spectra of narcotics or legal active pharmaceutical ingredients. Furthermore, if a material of interest is mixed with a highly fluorescent background or material with a complex spectrum, it can be identified within a few seconds from standoff distances. The existing algorithm is able to detect the materials discussed herein at high speed and with a low false alarm rate (FAR). Moreover, it is clear that with additional development, the existing algorithm can be improved to do further mixture identification and possibly composition analysis. Finally, with minimal effort, the on-board PRIED library could incorporate a large suite of narcotics and related materials added for antinarcotics applications and forensic purposes.

Other improvements are also currently on the design table that will continue to refine and improve the user experience for PRIED. Future versions of the instrument will have reduced size, weight, and power consumption, as well as increased durability. And the unique capability of PRIED to provide rapid, standoff detection of narcotics can be expanded to other materials. In short, the ability to detect materials more quickly and/or at longer ranges than many current instruments offers significant advantages for field users for whom time is of the essence and safety is enhanced by distance. ■

ACKNOWLEDGMENTS

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REFERENCES

[1] Fountain III, A. W., S. D. Christesen, R. P. Moon, J. A. Guicheteau, and E. D. Emmons. "Recent Advances and Remaining Challenges for the Spectroscopic Detection of Explosive Threats." *Applied Spectroscopy*, vol. 68, no. 8, p. 795, 2014.

[2] Christesen, S. D., A. W. Fountain III, E. D. Emmons, and J. A. Guicheteau. "Raman Detection of Explosives." *Laser-Based Optical Detection of Explosives*, edited by P. M. Pellegrino, E. L. Holthoff, M. E. Farrell, Boca Raton, FL: CRC Press, 2015.

[3] Tuschel, D. D., A. V. Mikhonin, B. E. Lemoff, and S. A. Asher. "Deep Ultraviolet Resonance Raman Excitation Enables Explosives Detection." *Applied Spectroscopy*, vol. 64, no. 4, p. 425, 2010.

[4] Ostmark, H., M. Nordberg, and T. E. Carlsson. "Stand-Off Detection of Explosive Particles by Multispectral Imaging Raman Spectroscopy." *Applied Optics*, vol. 50, no. 28, p. 5592, 2011.

[5] Mikhonin, A. V., S. V. Bykov, N. S. Myshakina, and S. A. Asher. "Peptide Secondary Structure Folding Reaction Coordinate: Correlation Between UV Raman Amide III Frequency, Psi Ramachandran Angle, and Hydrogen Bonding." *Journal of Physical Chemistry B*, vol. 110, no. 4, p. 1928, 2006.

[6] Nagli, L., M. Gaft, Y. Fleger, and M. Rosenbluh. "Absolute Raman Cross-Sections of Some Explosives: Trend to UV." *Optical Materials*, vol. 20, p. 1747, 2008.

[7] Emmons, E. D., J. A. Guicheteau, A. W. Fountain III, and S. D. Christesen. "Comparison of Visible and Near-Infrared Raman Cross-Sections of Exposives in Solution and in the Solid State." *Applied Spectroscopy*, vol. 66, no. 6, p. 636, 2012.

[8] Hong, Z., and S. A. Asher. "Dependence of Raman and Resonance Raman Intensities on Sample Self-Absorption." *Applied Spectroscopy*, vol. 69, no. 1, p. 75, 2015.

[9] Asher, S. A., and C. R. Johnson. "Raman Spectroscopy of a Coal Liquid Shows That Fluorescence Interference Is Minimized With Ultraviolet Excitation." *Science*, vol. 225, no. 4659, pp. 311–313, 1984.

[10] Pohl, K. R., A. R. Ford, R. D. Waterbury, D. Vunck, and E. L. Dottery. "Optical Hazard Avoidance and Method." U.S. Patent 8724097 B2, 2014.

[11] Nyquist, R., R. Kagel, C. Putzig, and M. Leugers. *Handbook of Infrared and Raman Spectra of Inorganic Compounds and Organic Salts.* San Diego, CA: Academic Press, vol. 2, 1997.

[12] Hong, Z., and S. A. Asher. "Dependence of Raman and Resonance Raman Intensities on Sample Self-Absorption." *Applied. Spectroscopy*, vol. 69, no. 1, p. 75, 2015.

BIOGRAPHY

LUISA PROFETA is a senior scientist at Alakai Defense Systems, focusing on the intersection of the chemistry and explosives parts of chemical, biological, radiological, nuclear, and explosives (CBRNE) with optical spectroscopy and algorithm performance. Prior to joining ADS in 2015, her research and responsibilities included leading 24/7 reachback services for government customers, constructing extensive Fourier transform IR spectroscopy (FTIR) and Raman libraries for hand-portable instrumentation, training government personnel on optical spectroscopy equipment, building quantitative FTIR gas-phase libraries for prescribed-military-base-burns, and developing new methodology for nonlinear design of multivariate optical elements used in multivariate optical computing applications. She holds a Ph.D. in physical chemistry from the University of South Carolina and a B.S. in chemistry from the University of Dallas.

ADAM HOPKINS is a senior scientist at Alakai Defense Systems, specializing in instrument design and performance. His research background is in nonlinear optical vibrational spectroscopy, surface/interfacial chemistry, and high-vacuum technology. He has been with ADS since 2010. He holds a Ph.D. in physical chemistry from the University of Oregon and a B.S. in chemistry from Florida State University.

JUSTIN COOPER is a staff scientist at Alakai Defense Systems, primarily focused on developing and evaluating applications of UV Raman spectroscopy for standoff detection and identification of threat materials. His research experience revolves around analytical spectroscopic methods, specifically fluorescence imaging microscopy, correlation methods, confocal Raman microscopy, and UV-resonance Raman spectroscopy. He holds a Ph.D. in analytical chemistry from the University of Utah and a B.S. in chemistry from the University of Florida.

BUTCH FERGUSON is a retired Army Colonel and the Director of Fort Leonard Wood Operations for Alakai Defense Systems. During his 29-year Army career, he held numerous command and staff positions and served his final assignment as the Director of Combat Developments at the U.S. Army Engineer School. Since that time, he has overseen and managed the development and fielding of numerous systems and technologies that enhance the operational effectiveness, efficiency, survivability, and safety of service personnel, first responders, and others conducting high-risk missions in hazardous environments. He has a B.S. from the United States Military Academy and an M.S. in civil engineering from the University of Colorado, and he is a graduate of the National War College.

DTIC SEARCH TERMS:

Portable Raman Spectroscopy
Threat Detection

RESULTS: 1,890

- Symposia (258)
- Information Science (188)
- Chemical, Biological & Radiological Warfare (151)
- Administration & Management (149)
- Research Management (136)
- Defense Systems (116)
- Abstracts (95)
- Department of Defense (94)
- Materials (93)
- Detection (92)

*See below for explanation ▸

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U.S. Navy Photo

GETTING THE BEST OUT OF LIGHT WITH ADAPTIVE OPTICS

By Justin Mansell

INTRODUCTION

It is hard to imagine a part of the military that does not use some kind of optical system to achieve its mission objectives. Optical systems are used throughout the Services for surveillance, rifle scopes, laser weapons, laser designators, and night vision goggles. And these systems would be used even more if they were lower in cost and offered better performance. Unfortunately, optical manufacturing techniques are expensive because achieving the high precision required for the desired optical performance requires increased manufacturing time. Without significant machine time, optics produced are warped such that their interaction with light causes the system performance to degrade. Accordingly, for the past several decades, industry has been working on developing adaptive optics (AO) technology to combat the performance limitations and enable these aberrations to be fixed.

THE OPTICAL ABERRATION PROBLEM

Optical aberrations have been degrading optical system performance even before mankind invented optics—hence the need for human eyeglasses. In modern optical systems, optical aberrations are caused by manufacturing imperfections, material imperfections, environmental effects on the optics (such as nonuniform heating and cooling), and even the air in and around the optical system. Some of these problems can be addressed with proper optical engineering and manufacturing, but some cannot. Even though AO could be used to improve systems with manufacturing imperfections, the focus herein is on the aberrations that are not able to be addressed by common engineering techniques.

For example, surveillance telescopes used to achieve both space and battlefield awareness look through the atmosphere, which is in a constant state of flux as hot and cold air mix together, especially near the surface of the earth. These pockets of hot and cold air have different refractive indices and therefore bend the light as it passes through them. This effect is what causes stars in the sky and lights in the distance to appear to twinkle at night. It also is the cause of the mirage effect that can be seen on hot days over asphalt roads. The pupil of the human eye is small enough that our visual system and most of our smaller cameras are not significantly impacted by these atmospheric optical aberrations. In most conditions, air turbulence is only a problem if the diameter of the collection optic exceeds about 10 cm, but longer-range imaging and laser delivery systems require these larger optics to achieve high precision at a distance (see Figure 1).

THE AO SOLUTION

AO is an engineering solution to addressing these aberrations. It is essentially the optical equivalent to noise-cancelling headphones, wherein a small microphone measures the sound waves impinging on the headphone and broadcasts a sound wave exactly out of phase with it into the wearer's ear to minimize the noise perceived by the ear. In the most common AO system architecture, a special camera called a wavefront sensor is used to detect the internal or external aberrations induced on a beam of light. Then a device called a deformable mirror (DM) is used to bend the light in the opposite way that the aberrations bent it and cancel out their effect. This technique of optically engineering the light was published by astronomer Horace Babcock in 1953 but required significant component development to mature the concept into functioning systems, which were demonstrated in the 1970s.

Since the first demonstrations of AO, there have been some key advances in technology that make it more appealing for commercial and government applications. In 1971, Roland Shack and Ben Platt published an improvement to the Hartmann sensor that replaced the array of apertures with an array of lenses, thus increasing the optical efficiency, putting the detector in the exact far-field of the incident radiation, and making the sensor practically insensitive to intensity fluctuations in the input plane. This development was important because it made the wavefront detector able to see light from the target at a larger distance. In addition, it made the detector more effective at measuring the wavefront of light after the propagation through the aberrating atmosphere caused the intensity to change due to scintillation.

In the 1970s, Itek Corporation began making versions of the modern DM [1]. These DMs were able to respond faster than the Eidophor proposed by Babcock and were more optically efficient. In the 1990s, Mansell and his colleagues at Stanford University developed silicon-based micro electromechanical system (MEMS) DMs and wavefront sensors based on complementary metal-oxide-semiconductor (CMOS) imagers, enabling both mass fabrication and a significant increase in speed [2].
Of course, throughout this time, microprocessor and field-programmable gate array (FPGA) technology developed considerably, making practical the processing of the massive amount of data received from a wavefront sensor required to control the DM.

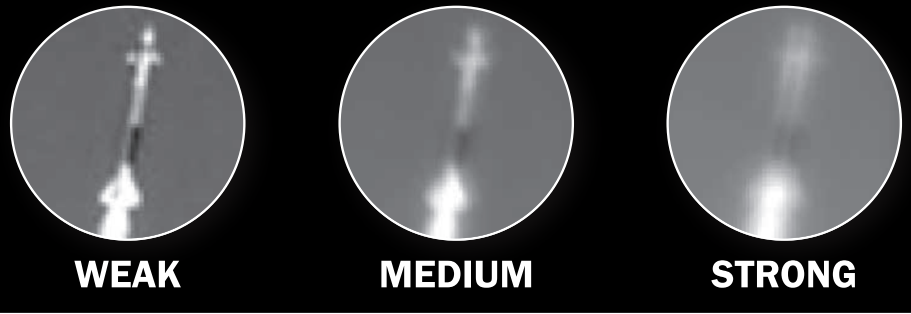

Figure 1: The Effect of Different Strength Turbulence on the Image of a Rocket.

In 2006, MZA Associates Corporation began investigating performance and manufacturability challenges associated with DM technology that were hindering the development of high-power solid-state lasers. DMs were failing under the high power levels due to heating and point defects in the evaporated coatings. Replacement DMs were quoted with estimated 9–12-month production times. However, MZA was able to demonstrate, with prototypes, high-power DMs (as shown in Figure 2) within 6 weeks. Both DMs survived high-power laser testing but had some residual absorption in the surface due to the electron-beam evaporated coatings.

Following the prototype development, the manufacturing process was adapted to enable the use of annealed ion-beam sputtered (IBS) coatings, thereby reducing the absorption in the coating from approximately 20 ppm to 0.4 ppm. This 40× reduction in coating absorption resulted in a DM that could withstand significantly more laser power before heating and damage became a concern.

The first IBS-coated DM was tested in a high-power laser system with 120-kW average power for 5 s and <1 °C heating on the surface when observed by a thermal camera. In the same test, there was no distortion on the surface on an over-resolved (>1 subaperture per DM actuator) Shack-Hartmann wavefront sensor due to this heating. Subsequent testing on a DM coated for reflectivity at 1,064 nm, 1,550 nm, and 532 nm survived an irradiance of >1 MW/cm^2 when illuminated by a 10-kW average power laser for 30 s. This high-irradiance test showed no localized heating on the silicon mirror surface.

These DMs and drive electronics are meeting or exceeding the current requirements of the AO community. Typical MZA DMs have a 3-dB performance bandwidth of 10 kHz, which is well beyond the typical Greenwood frequency requirement of the atmosphere. Further, these DMs have been flattened to a root mean square (RMS) surface figure of less than 2% of an optical wavelength, and the respective drive electronics have a digital latency of less than 10 µs, enabling high-bandwidth wavefront control.

After demonstrating high-power handling capability, MZA proceeded to address several other performance challenges that were plaguing the industry. DMs in AO systems act like a filter, removing all the wavefront distortion at spatial frequencies below the spatial period equal to double the actuator spacing. Unfortunately, some of the older DM designs were inducing a residual wavefront warp at the spatial period equal to the actuator spacing due to heating (mismatch in differential thermal expansion) and internal stresses. This higher-order residual was sometimes leaving the wavefront with a distortion that dramatically limited the efficacy of the AO system. Consequently, a new DM architecture was developed that reduced this higher-order warp significantly, thereby making the AO system much more effective at wavefront compensation.

These new DMs use lead zirconate titanate (PZT) actuators because of their high efficiency, high reliability, and stable performance over a wide temperature range. DMs with up to 18 µm of physical stroke using only 120 V have been successfully demonstrated. Unfortunately, PZT actuators have 12% hysteresis at room temperature, which makes the control of a DM more difficult. However, drive electronics that demonstrated a reduction of hysteresis to 7% were manufactured, thereby enabling faster and more reliable wavefront control.

CONCLUSION

AO technology is currently undergoing a transition from a research curiosity used only in high-end telescopes and military systems to an emerging technology

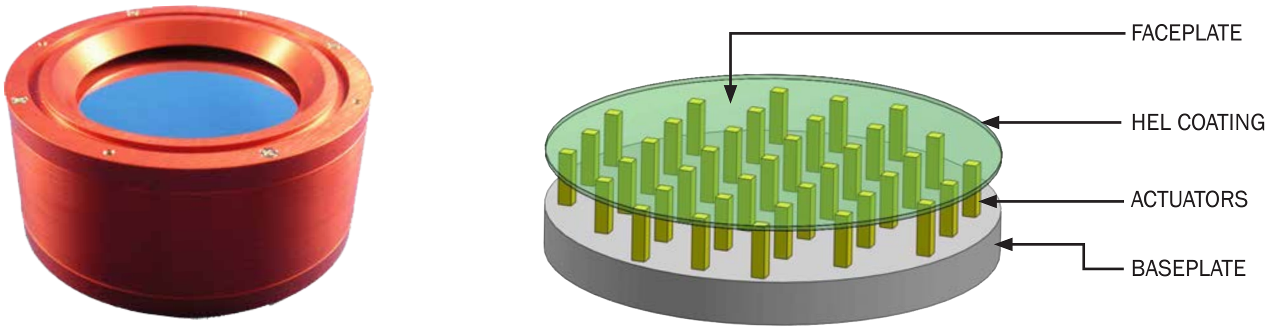

Figure 2: The Basic Architecture of a Surface Normal Plate-Type DM and Prototype.

that is being adopted in a wider range of applications. Commercial industry is now building demonstrator systems using DMs to shape the laser beam intensity profile on target, making more efficient and effective laser machining systems. And both commercial and military imaging systems are being demonstrated with AO to enhance performance in virtually everything from microscopes to surveillance systems. In the future, as DM and AO component performance and system performance continue to be improved and associated costs reduced, these technologies are expected to be increasingly adopted in new optical systems, enabling users to truly get the best out of light with AO. ■

REFERENCES

[1] Hardy, J. W. "Real-Time Wavefront Correction System." U.S. Patent 3,923,400, 1975.

[2] Mansell, J. D., P. B. Catrysse, E. K. Gustafson, and R. L. Byer. "Silicon Deformable Mirrors and CMOS-Based Wavefront Sensors." *SPIE Proceedings*, vol. 4124, 2000.

BIOGRAPHY

JUSTIN MANSELL is the Chief Technology Officer and a Vice President of MZA Associates Corporation, as well as the President of Active Optical Systems, LLC, which is an organization he founded in 2005 to commercialize low-cost AO systems. Holding 11 U.S. patents and authoring more than 30 technical papers and presentations, Dr. Mansell has been developing AO and beam control technology for more than 15 years. He has a Ph.D. in electrical engineering from Stanford University and a B.S. and M.S. from Case Western Reserve University. He is a member of the Optical Society (OSA) and the Directed Energy Professional Society (DEPS) and is a senior member of the Institute of Electrical and Electronics Engineers (IEEE) and SPIE.

DTIC SEARCH TERMS:

Adaptive Optics Laser

RESULTS: 19,100

- Optics (3,659)
- Lasers & Masers (2,103)
- Symposia (1,859)
- Foreign Reports (1,458)
- Lasers (1,449)
- Adaptive Optics (1,321)
- Export Control (1,193)
- Electrical & Electronic Equipment (1,142)
- Information Science (1,048)
- Laser Beams (1,047)

*See page 13 for explanation ▸

NEW RELEASE ANNOUNCEMENT: BRAWLER VERSION 8.2

DSIAC is pleased to announce the release and availability of Brawler Version 8.2 and its respective documentation. Brawler is an air-to-air combat modeling and simulation tool for evaluating aircraft and systems performance. Additional information is provided in the resources section of the DSIAC website. Brawler is provided on two DVDs: an unclassified DVD that contains the Brawler application, and a classified DVD. Both DVDs are subject to export control regulations and distributed in accordance with distribution statement C (U.S. Government agencies and their contractors). Brawler Version 8.2 includes the following enhancements:

- Use of Directed Energy Weapon (DEW) Acquisition/Tracking /Pointing (ATP) for missile support.
  - » Allows DEW ATP tracks to be used for missile command guidance updates and seeker slewing.
  - » Allows pilot to select DEW ATP for use even when there is no intention of using the DEW as the weapon.
- DEW ATP two-dimensional (2D) slewing algorithm.
  - » Provides a complex slewing algorithm, including rates in two axes and acceleration/deceleration times.
- DEW pilot mode vs. missile decision integration.
  - » Fully integrates decision of pilot to fire at a missile into the weapon-target pair decision.
  - » Makes decision-making process consistent with missile-vs.-missile firing decisions.
- SHaRE API integration.
  - » Makes the SHaRE beam propagation model available as C++ libraries and accessible through their application program interface (API).
  - » Allows direct calling of SHaRE by Brawler through this API using a C wrapper.
  - » Removes the overhead associated with the Matlab Compiler Runtime (MCR).
- Multi-antenna active electronically scanned array (AESA) radar control.
  - » Allows control of multiple antennas in the frame-based AESA radar manager.
- National Air and Space Intelligence Center (NASIC) Threat Modeling and Analysis Program (TMAP) updates.
  - » Provides two updated air-to-air missile models.
  - » Renames of interfaces to be generic and unclassified.
- Other Software Change Request (SCR) updates.
  - » Provides nonsymmetric RCS.
  - » Provides noninteractive asimain.
  - » Provides miscellaneous bug fixes.

THE PURSUIT OF PERSISTENT ISR

By Capt. Anthony Ripley

INTRODUCTION

The Naval Research Laboratory (NRL), Pennsylvania State University (PSU), and Naval Postgraduate School (NPS), in conjunction with the Marine Corps Expeditionary Energy Office (E2O), are working to demonstrate the innovative energy-harvesting approach (illustrated in Figure 1) for providing persistent intelligence, surveillance, and reconnaissance (ISR) and communications relay capabilities in the form of an unmanned aerial vehicle (UAV). By integrating the latest technologies in photovoltaics, autonomous soaring, high-energy density storage, maximum power point tracking (MPPT), and cooperative flight, the project team plans to deliver a long-sought-after capability of persistent ISR, which operates purely on solar energy. Initial modeling estimates suggest that a 19- to 20-hr endurance threshold for a single aircraft is within reach. Factoring in the collaborative nature of the system and the remaining trade space for optimization of the aircraft and other systems, the Marine Corps may likely be on its way to having a next-generation persistent ISR capability on a platform that requires no operating fuel.

If all goes as planned, this project could fulfill capability shortfalls specified in various requirements documents for multiple Department of Defense (DoD) Services. This technology is anticipated to have application in a wide range of military unmanned vehicles, dismounted power applications, and installations; and it should be affordable for a wide range of civil and commercial sectors, such as law enforcement agencies, search and rescue organizations, natural resource management agencies, the agriculture community, and possibly even the outdoor recreational and hobbyist communities.

Some may find it surprising that the Marine Corps E2O is interested in funding and endorsing a persistent ISR project; however, energy and power intersect all aspects of the Marine Corps warfighting functions. Therefore, this effort makes a lot of sense when considering the aggregate energy and power needs of deployed troops. In this instance, energy is the driving factor on the persistence side of the equation. When evaluating the Service-level gaps, the overlap between the energy and ISR gaps become even more apparent.

To mitigate development risk, this effort is divided into three phases:

- ***Phase I:*** Develop, integrate, and demonstrate key technologies to enable low-altitude, multi-day UAV missions. The key technologies include:

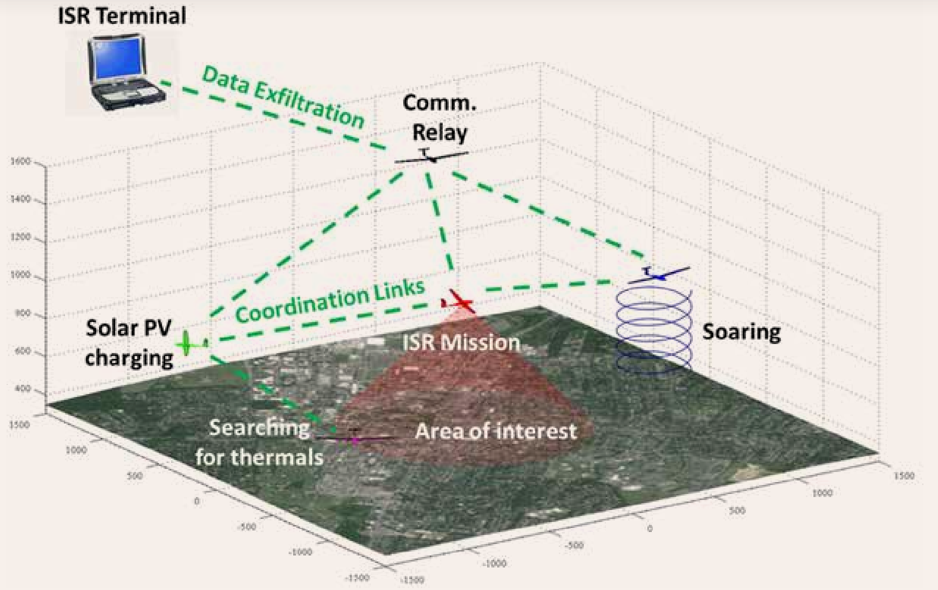

Figure 1: Marine Corps Energy-Harvesting Approach for Persistent ISR.

  - High Efficiency Photovoltaics.
  - Autonomous Soaring Algorithms.
  - Energy-Aware Swarming Algorithms.
  - Power Management.
  - MPPT.
- ***Phase II:*** Design and prototype an optimized airframe that enables greater payloads.
- ***Phase III:*** Develop multi-day, open-ocean, thermal soaring capability and integrate hydrogen fuel cell technology.

While the plan is to execute the project in multiple phases, the focus of this article is on Phase I.

HIGH-EFFICIENCY PHOTOVOLTAICS

The primary goal of Phase I is to validate the concept of a persistent ISR platform that can operate for extended periods of time with no fuel as well as to deliver a proof-of-concept system. In Phase I, NRL is collaborating with industry partners Semprius and SunPower on the photovoltaics. Semprius is developing novel solar cell technologies that consist of stacked multi-junction (MJ) solar cells. This technology hybridizes two individual triple-junction (3J) solar cells by mechanically stacking them with a transfer-printing method commercialized by Semprius. Independent optimization of the two 3J cells allows each to be fully optimized. The transfer printing allows the MJ cells to be integrated into a single device in a cost-effective, efficient, and commercially established process. Figure 2 indicates the anticipated efficiency values in comparison with current world-record values and the status of the NRL/Semprius technology. During Phase I, NRL is performing the modeling and design optimization and will also manufacture the solar cells. Semprius is forming the stacked MJ devices to prove the concept of the high-efficiency stacked solar cell.

Because it may be a few years before the stacked MJ cells technology is available, in the interim, NRL has developed Si-based solar arrays in collaboration with SunPower, a leading terrestrial solar array manufacturer, and GaAs-based arrays with MicroLink. The Si-based solar cells can provide a 24% efficiency at the cell level, and NRL has produced arrays configured for incorporation onto UAV wings with a 22% efficiency. While the Si-based technology offers a lower maximum efficiency when compared with GaAs-based technologies (30% to 40% efficiency), the cost of the Si-based

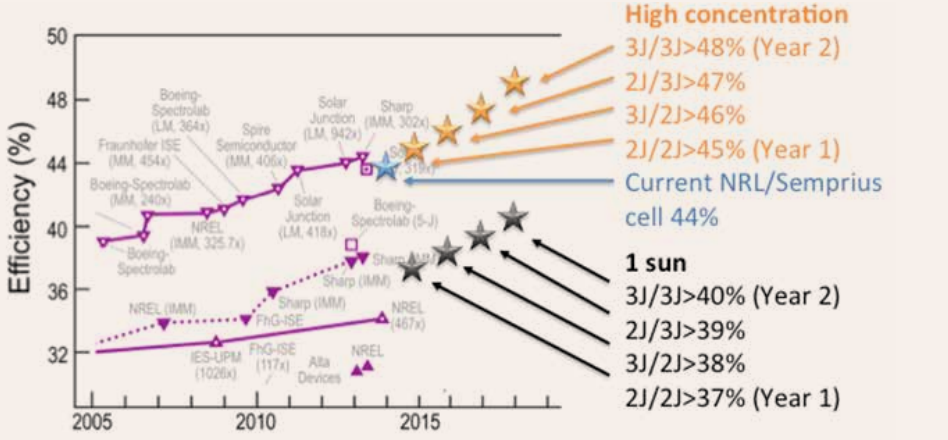

Figure 2: Potential Solar Cell Efficiencies Achievable With the Proposed NRL Technology Compared With Current State-of-the-Art Solar Cells (NRL Graphic).

arrays are approximately an order of magnitude less than the cost of GaAs-based technologies. Figure 3 pictures an example of a commercial-off-the-shelf (COTS) glider with custom high-efficiency photovoltaic arrays ready for integration.

Figure 3. COTS Glider With Monocrystalline Silicon Photovoltaic Cells (NRL Photo).

Within this effort, NRL will build UAV wings with integrated photovoltaics using both the Si-based and GaAs-based solar array wings for a direct comparison of the performance-vs.-cost capabilities of the two technologies.

THERMAL ALGORITHM

NRL is also refining the Autonomous Locator of Thermals (ALOFT) algorithm. ALOFT was developed by NRL's Dan Edwards, who designed the algorithm (partly based on NASA's Cloudswift) to exploit naturally occurring convective thermal updrafts for extending the endurance of UAVs. The ALOFT algorithm essentially uses sensor inputs that detect areas of rising air and then commands an autopilot to orbit within them, resulting in the aircraft gaining altitude [1]. Multiple flights of more than 5 hrs and up to 70 miles have been demonstrated on an unmanned sailplane after a winch launch to just 300 ft of altitude. Figures 4 and 5 show the ALOFT gaining altitude from a thermal updraft and the aircraft used for testing the algorithms.

COOPERATIVE SOARING ALGORITHM

Further, PSU and NPS are refining cooperative soaring algorithms. PSU is refining AutoSOAR, a cooperative autonomous soaring algorithm that enables building an energy map of multiple soaring aircraft measurements. This map is used to provide likely energy sources for trajectory optimization between known hotspots, which increases the probability that an aircraft can balance its energy extraction and mission output. NPS is developing a separate cooperative algorithm that focuses on the guidance using a mapped set of likely updraft locations, and it is providing high-fidelity modeling and simulation in daylight conditions. Ultimately, the outcome of NRL, PSU, and NPS efforts will integrate into one. Figures 6 and 7 show flight testing of the cooperative soaring algorithms.

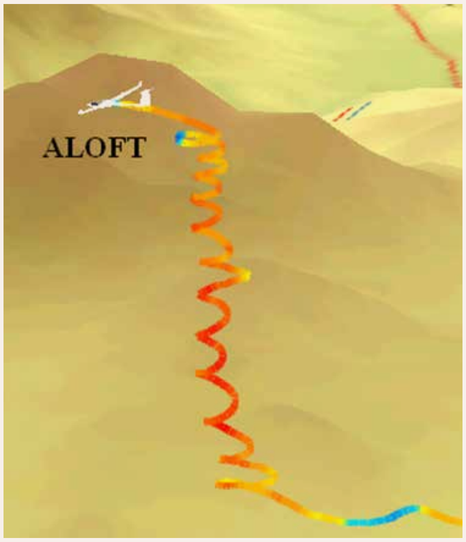

Figure 4 *(top)*: Flight Data Illustrating ALOFT Gaining 1,500 ft of Altitude in a Thermal Updraft. The Warmer Colors Indicate Higher Climb Rates.
Figure 5 *(bottom)*: Hand-Launching a Powered Sailplane UAV to Test the Autonomous Soaring Algorithms (NRL Photo).

POWER MANAGEMENT

Persistent ISR with no fuel is a formidable goal that will require expertise in state-of-the-art power management. Power management in electronics is difficult in itself, but power management in a flight application is exceptionally difficult because of the dynamic nature of flight constantly changes solar exposure to different parts of the photovoltaic arrays, by cloud cover, atmospheric conditions, and soaring maneuvers. Such conditions present challenges for characterizing performance and energy management, and, consequently, software control to trigger the appropriate sleep or hibernation states for energy-consuming components.

Figure 6 *(top)*: Both NRL and PSU Aircraft Climb in the Same Updraft During Cooperative Autonomous Soaring Testing in 2015 (NRL Photo).
Figure 7 *(bottom)*: NRL and the Air Vehicle Intelligence and Autonomy (AVIA) Lab at PSU Demonstrate Autonomous Soaring Algorithms (PSU Photo).

Fortunately, Packet Digital, another industry partner, is established in dynamic power management. According to NRL, Packet Digital's approach will address limitations of software-based power management and will provide high-efficiency power distribution with internal load management, resulting in "just in time/just enough" system-wide power management [2]. The Packet Digital Power Manager is pictured in Figure 8.

Past Marine Corps efforts with Packet Digital have proven beneficial. For example, a Small Business Innovation Research (SBIR) effort demonstrated that Packet Digital's unique technology reduced power consumption in commercial radios by more than 40%. Similar technology and expertise will be leveraged to provide a key element of the persistent ISR UAV effort.

MPPT

As mentioned previously, power tracking via an MPPT is vital piece of the persistent ISR equation. As an aircraft maneuvers, an entire array of photocells can be rendered useless if obscured by a shadow. In addition to this problem, photovoltaic cells have a unique current-voltage operating point that produces maximum power. Solar cells generally do not operate at their maximum power point when under a load. This fact is generally true for modules and arrays as well. Thus, the MPPT enables photovoltaic devices to operate at their MPP by decoupling the photovoltaic from the load and computing an algorithm to track the MPP [3]. To address these problems, Packet Digital is leveraging its novel methods for achieving MPPT of a solar array, and it is investigating a new approach to MPPT algorithms that will be more efficient when solar intensities vary across photovoltaic cells. Figure 9 pictures the Packet Digital MPPT assembly.

Figure 8: Power Manager (Packet Digital Photo).

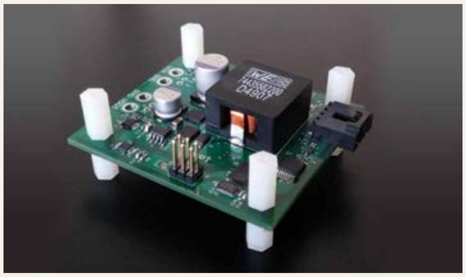

Figure 9: MPPT Device (Packet Digital Photo).

CONCLUSION

Many researchers tend to charge toward the pursuit of pushing theoretical boundaries for single technologies that improve current capabilities when relatively simple integration of disparate technologies may offer a better approach for capabilities improvement. While some of the technologies described herein are pushing current technological limits, this effort could still produce a capability that advances current capabilities by simply integrating several COTS solutions. This UAV effort has the potential to provide persistent ISR and communications relay capabilities, which closes many of the technology and capability gaps for the military Services. And if all goes according to plan, we expect this phase of the effort to wrap up in late 2016. ■

REFERENCES

[1] Edwards, D. "Autonomous Locator of Thermals (ALOFT) Autonomous Soaring Algorithm." Naval Research Laboratory, NRL/FR/5712-15-10,272, 3 April 2015.

[2] Walters, R. Personal Communication. Naval Research Laboratory, 22 July 2014.

[3] O'Connor, Maj. Joseph E. "Harvesting Maximum Power From Photovoltaic Solar Cells." Doctoral Research Proposal, April 2015.

BIOGRAPHY

CAPT. ANTHONY RIPLEY is currently serving as the Science and Technology Lead for the Marine Corps Expeditionary Energy Office. His more than 20 years of military service includes serving as an Aviation Warfare Systems Operator and Search and Rescue Swimmer in the U.S. Navy, as well as serving as a Maintenance Materiel Control Officer, Assistant Aircraft Maintenance Officer, Airframes and Aviation Life Support Systems Division Officer, and HAZMAT Officer in the U.S. Marine Corps. His service has also included multiple deployments to the Persian Gulf, Iraq, and Afghanistan. Capt. Ripley holds B.S. degrees in criminal justice and sociology from the University of Idaho, as well as an M.S. in management and certifications in energy and defense systems analysis from the Naval Postgraduate School.

DTIC SEARCH TERMS:

Autonomous Persistent Solar UAV

RESULTS: 1,010

- Military Operations, Strategy & Tactics (146)
- Military Forces & Organizations (116)
- Defense Systems (115)
- Symposia (94)
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BETTER BUYING POWER 3.0 INTEGRAL TO DOD'S FY17 SCIENCE & TECHNOLOGY PLAN

By Bruce Simon


Committee on Armed Services Photo

On 24 February 2016, DSIAC attended a hearing of the U.S. House Armed Services Emerging Threats and Capabilities Subcommittee. The subcommittee discussed some of the complex science and technology (S&T) challenges facing the Department of Defense (DoD), the growing concern about the shrinking gap between the United States' technological edge and the advances of our adversaries, and some of the ongoing and future DoD efforts to address these issues.

In opening the hearing, which was titled "DoD FY17 S&T Programs: Defense Innovation to Create the Future Military Force," Chairman Joe Wilson (R-SC), stated, "We can only deter these competitors and adversaries when DoD harnesses innovation and creates new capabilities for the military that will maintain and expand our tech-superiority now and into the future." Chairman Wilson also welcomed the following witnesses to address the House members and discuss the issues with them:

- Dr. Stephen Welby, Assistant Secretary of Defense for Research and Engineering.
- Ms. Mary Miller, Deputy Assistant Secretary of the Army for Research and Technology.
- Rear Adm. Matthias Winter, U.S. Navy Chief of Naval Research.
- Dr. David Walker, Deputy Assistant Secretary of the Air Force for Science, Technology and Engineering.
- Dr. Arita Prabhakar, Director, Defense Advanced Research Projects Agency (DARPA).

Dr. Welby discussed investing in young engineers and talented personnel, enhancing our asymmetric capabilities, and working with the private sector and academia. He also noted that the President's FY17 budget submission demonstrates support for strong DoD S&T investments, and he described the initiative continued by the current Under Secretary of Defense for Acquisition, Technology, and Logistics (USD[AT&L]). This initiative, called the Better Buying Power 3.0 initiative, is principally focused on the "criticality of the research and engineering components of the acquisition community in sustaining U.S. technological superiority." Dr. Welby also emphasized the areas using prototyping to accelerate operations assessments and adopt key technologies, as well as to support robust DoD science, technology, engineering, and math (STEM) engagement.

In addition, Ms. Miller addressed the S&T race the United States is currently in with our adversaries and stated that we must be agile, adaptive, and innovative to remain dominant. Furthermore, we must identify risk early on in programs and eliminate vulnerabilities. Adm. Winter and Dr. Walker highlighted the President's most recent budget request and identified key technological priorities, such as directed energy, autonomous vehicles, lab integration, information access, and cyber attack protection. Finally, Dr. Prabhakar discussed DARPA's efforts in working with the S&T community, the pivotal role of making early investments in the right technology, and keys technology areas such as artificial intelligence and electronic warfare.

From the congressional side of the table, members of the subcommittee emphasized the need for Congress to be involved and visit labs and facilities. Members also expressed concern over online protection against cyber attacks from ISIS and adversary nation states, as well as the importance of avoiding redundancy and of having speedy access to information.

DSIAC is currently involved in addressing many of the issues raised by the Emerging Threats and Capabilities Subcommittee. Congress plans to continue to study the issues raised at the hearing, including examining the budget and looking at the Better Buying Power 3.0 initiative in relation to the programs discussed. Likewise, DSIAC will continue to serve as a crucial data repository for the DoD, working to gather data from across the DoD and the Services, as well as to address the information redundancy, speedy access, and coordination issues identified.

See page 3 for Bruce Simon's biography.

CONFERENCES AND SYMPOSIA

APRIL 2016

17th Annual Science & Engineering Technology Conference
12–14 April 2016
Hilton Tampa Downtown Hotel
Tampa, FL
http://www.ndia.org/meetings/6720 ▸

2016 Joint Aircraft Survivability Program (JASP) Model Users Meeting (JMUM)
19–21 April 2016
The Advance Technical Intelligence Center for Human Capital Development (ATIC)
Beavercreek, OH

Science of Cook Off
25–29 April 2016
AMA Atlanta Executive Conference Center
Atlanta, GA
https://www.msiac.nato.int/workshop/science-of-cook-off ▸

2016 DT&E Ground Vehicle Survivability and Force Protection Short Course
26–28 April 2016
Quantico Corporate Center
Stafford, VA
https://www.dsiac.org/resources/events/ground-vehicle-survivability-short-course ▸

2016 Threat Weapons and Effects
26–28 April 2016
Hurlburt Field
Hurlburt Field, FL
https://www.dsiac.org/resources/events/2016-threat-weapon-and-effects-training ▸

2016 Army Aviation Mission Solutions Summit
28–30 April 2016
Georgia World Conference Center
Atlanta, GA
http://www.quad-a.org/2016Summit ▸

MAY 2016

XPONENTIAL 2016
2–5 May 2016
Marine Corps Base
Camp Pendleton, CA
http://www.marinemilitaryexpos.com/marine-west.shtml ▸

59th Annual Fuze Conference
3–5 May 2016
Charleston Marriott
Charleston, SC
http://www.ndia.org/meetings/6560 ▸

2016 Tactical Wheeled Vehicles Conference
9–11 May 2016
Hyatt Regency Reston
Reston, VA
http://www.ndia.org/meetings/6530 ▸

8th Annual EW Capability Gaps and Enabling Technologies Operational and Technical Information Exchange
10–12 May 2016
Crane Club Lakeview Event Center
Crane, IN
http://www.crows.org/event/192-aoc-conferences/2016/08/10/54-8th-annual-ew-capability-gaps-and-enabling-technologies-operational-technical-information-exchange.html ▸

Sea-Air-Space
16–18 May 2016
Gaylord National Convention Center
National Harbor, MD
http://www.seaairspace.org ▸

Special Operations Forces Industry Conference (SOFIC)
23–26 May 2016
Tampa Convention Center
Tampa, FL
http://www.sofic.org/Pages/Default.aspx ▸

JUNE 2016

SAE 2016 Additive Manufacturing Symposium
14–15 June 2016
Knoxville Marriot,
Knoxville, TN
http://www.sae.org/events/ams ▸

National Space & Missile Materials Symposium
20–23 June 2016
Westin Westminster Hotel
Westminster, CO
http://www.usasymposium.com/nsmms ▸

International Applied Reliability Symposium North America
21–23 June 2016
Coronado Island Marriott Resort and Spa
San Diego, CA
http://www.arsymposium.org/northamerica ▸

Advanced High-Power Lasers and Beam Control Conference
27–30 June 2016
The Antlers Hotel
Colorado Springs, CO
http://deps.org/DEPSpages/AHPL16.html ▸

For more events, visit:
dsiac.org/resourses/events ▸

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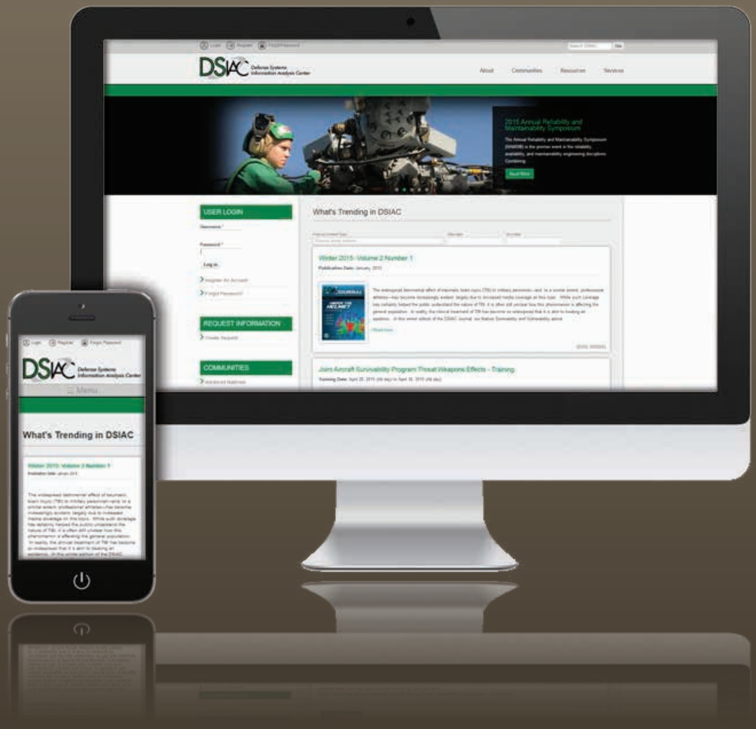
- Collecting, electronically cataloging, preserving, and disseminating Defense Systems scientific and technical information (STI) to qualified users.
- Developing and deploying products, tools, and training based on the needs of the Defense Systems community.
- Fostering and supporting the DSIAC technical Communities of Practice.
- Participating in key DoD conferences and forums to engage and network with the S&T community.
- Performing customer-funded Core Analysis Tasks (CATs) under pre-competed IDIQ Delivery Orders.



DSIAC SCOPE AREAS INCLUDE:

- Advanced Materials
- Autonomous Systems
- Directed Energy
- Energetics
- Military Sensing
- Non-Lethal Weapons
- Reliability, Maintainability, Quality, Supportability, and Interoperability (RMQSI)
- Survivability and Vulnerability
- Weapon Systems