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In Aviation & Other Military Applications

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Department of Defense Information Analysis Centers

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Message from the Director: Better Buying Power 3.0

Stuart Stough
HDIAC Director

The Department of Defense (DoD) is always looking to strengthen innovation capacity and technical excellence while improving efficiency and productivity. The Core Analysis Task (CAT) is one way the Homeland Defense and Security Information Analysis Center (HDIAC) meets this DoD goal. HDIAC is currently executing a CAT for the United States Special Operations Command (USSOCOM), which exemplifies how the Information Analysis Center (IAC) program supports the Better Buying Power (BBP) 3.0 concept.

The CAT with USSOCOM addresses improving the response to medical issues involving military canines. Canines have unique detection and protection capabilities and are deployed for security patrols and bomb detection, among other duties. As canine deployment continues to rise, the military recognizes a need for improved training efforts for canine utilization.

HDIAC completed a gap analysis showing that veterinarian trainers and students would benefit from a more realistic, advanced canine medical simulator to ensure better outcomes and increased survivability for injured military canines.

BBP 3.0 guidance includes increasing the use of prototyping and experimentation to more rapidly field technology. The medical canine prototype for USSOCOM will meet this need and allow veterinarians and other users to determine its operational potential prior to a more substantial manufacturing commitment.

Utilizing the IAC CAT program meets the BBP 3.0 initiative in several ways. HDIAC connected USSOCOM with a technical industry leader in medical simulators to ensure production of the best canine simulator. Through this process, USSOCOM was directly engaged with industry from the earliest stages of concept and design requirements to ensure creativity and innovation.

HDIAC continues to stay at the forefront of technology and develop key relationships with industry and academia throughout our eight focus areas. This allows our center to be readily available to compete for tasks, such as the USSOCOM project.

While HDIAC works to meet USSOCOM's needs, we also recognize that these needs may cross other commands and military departments. During discussions with USSOCOM, HDIAC learned of additional needs for canines in the field, including improved ballistic body armor design and standardized nutritional requirements.

HDIAC is able to utilize knowledge and research stemming from the USSOCOM canine medical training apparatus project to develop technical solutions for other canine requirements, which ensures HDIAC is addressing needs without providing additional costs to the government.

Throughout the process, the CAT contract vehicle and the BBP 3.0 initiative will have provided USSOCOM with an innovative canine medical simulator, which will improve canine survival, outcomes and quality of life. ■

Better Buying Power Focus Areas

1. **Achieve Affordable Programs**
2. **Control Costs Throughout the Product Lifecycle**
3. Incentivize Productivity and Innovation in Industry and Government
4. **Eliminate Unproductive Processes and Bureaucracy**
5. **Promote Effective Competition**
6. **Improve Tradecraft in Acquisition of Services**
7. **Improve the Professionalism of the Total Acquisition Workforce**

Wearable Thermoelectric Generat Powered by Body H

By: Jie Liu, Ph.D.
Melissa Hyland
Haywood Hunter
Michael J. Hall
Elena Veety, Ph.D.
&
Daryoosh Vashaee, Ph.D.

Wearable thermoelectric module manufacturing is an emerging field with applications including self-powered wearable electronics, self-powered health and performance monitoring devices, and self-powered sensors and communications equipment.

Overview

Thermoelectric generator (TEG) devices have emerged as viable alternatives for certain power generating applications. Because TEG technology is able to produce power from low-grade or waste heat, such as that obtained through body heat harvesting, it is of growing interest to the military and individual users. This technology has garnered attention for its ability to power wearable sensors and electronics, eliminating the need for and subsequent use of batteries.

TEG devices enhance operational reliability of energy-dependent devices, providing constant, uninterrupted energy from body heat. The average warfighter carries at least 60 pounds of equipment, with specialized warfighters carrying more than 132 pounds. [1,2] A significant portion of this load can be attributed to battery-reliant systems and equipment including radios, night vision, flashlights, GPS, scopes, binoculars, sensors, lasers and precision targeting devices. [1,2,3] For a 72-hour mission during Operation Enduring Freedom, a U.S. Airborne soldier carried 70 batteries totaling 16 pounds. [1]

Wearable TEG devices could be implemented as reliable power generators for Department of Defense (DoD) applications. The U.S. Army's Program Executive Office Soldier has developed and is continuing to research power solutions to help offset the aforementioned battery load. [1,2] The Soldier Power portfolio includes the Squad Power Manager, the Modular Universal Battery Charger, the Soldier Worn Integrated Power Equipment Systems and the Conformal Battery. [4]

Additionally, the U.S. Army is researching sensors to aid in the monitoring of physiological parameters in order to enhance battlefield performance. [5] Environmental sensors could also be utilized to detect exposure to chemical weapons or extreme environments [5] and record critical ambient conditions and various biochemicals such as carbon dioxide, carbon monoxide, noise, temperature, humidity, ozone, luminosity, air quality, etc. [6] In addition to powering warfighter electronics, TEGs can power these health monitoring and environmental sensors. Such batteryless sensors can consistently monitor warfighter health and safety conditions.

The National Science Foundation (NSF) Nanosystems Engineering Research Center for Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST) at North Carolina State University developed these TEGs that use body heat energy to power wearable sensors for health and environmental monitoring. Relying on body heat energy, batteryless wearables can run without interruption.

Wearable TEG Devices for Body Heat Harvesting

A TEG uses the temperature difference between the body and the ambient environment to produce electric power. However, several conditions must be maintained to ensure wearable TEG efficiency. Namely, heat from the body must be directed into the generator with minimal loss; the generator must be designed for maintaining a high temperature differential across the thermoelectric material; and the generator

must have a small weight and form factor for comfort on the body.

The development of flexible TEGs for wearable applications was a major innovation in body heating harvesting, and several prior studies have demonstrated this concept. [7,8,9,10,11,12,13,14] A flexible TEG provides better contact between the generator and the skin, resulting in smaller thermal interface resistance and, consequently, a larger temperature difference across the TEG. Although the form factor of the flexible device was suitable for wearable applications, the overall power densities were in the range of sub-microwatt per square centimeter, which was too small to power up sensors or electronic circuits. Several fundamental problems in their construction at the material, device or system levels resulted in low performance. [15]

For example, methods such as printing, spraying and molding cannot be used to construct TEGs, as they often result in low quality thermoelectric materials, impacting the TEGs operational effectiveness.

At the device level, a wearable TEG generally suffers from a small temperature difference between the skin and the ambient environment. In order to maximize the temperature differential across the TEG, a small fill factor and large TEG thickness are preferred. [14] A very thin TEG cannot maintain a large temperature differential, resulting in poor performance.

Moreover, it is important to minimize the parasitic heat conduction paths so heat from the body goes into the thermoelectric material and is not wasted by going through other unwanted paths. In order to accomplish this, it is imperative to leave empty space (air or vacuum) between the pellets. Any filler material that has higher thermal conductivity than air can introduce a parasitic heat transfer path and impact the TEG performance. Therefore, flexible TEGs implementing polymeric fillers, such as polydimethylsiloxane, significantly suffer from such non-ideal effects.

At the system level, overall efficiency must be considered — not just that of the TEG. Since the TEG voltage is often small (in the millivolts range), it has to be amplified before it can be used. DC/DC boost converters are often used to amplify the voltage. However, their efficiency is a function of the input voltage. In particular, a higher

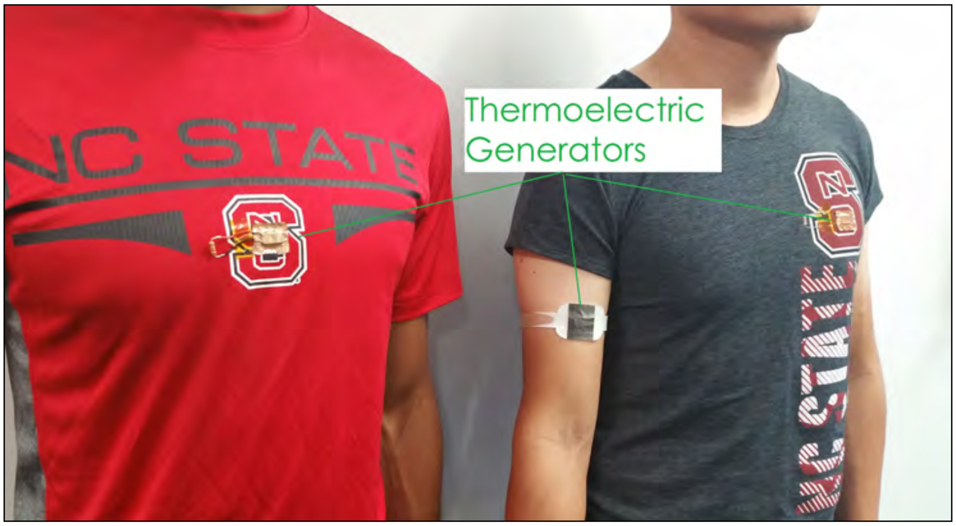

Figure 1: Demonstration of how TEGs are worn. (Released)

Table 1: Military Battery

Battery-reliant equipment carried by the warfighter during **Operat**

Equipment						
Equipment Name	AN/PVS-14 (Monocular Night Vision Device) [4]	Mark VII (Laser Target Locator) [4]	AN/PRC-148 Multiband Inter/ Intra Team Radio (Radio) [17]	Sure Fire Light [17]	Mag Lite [17]	Defense Advanced GPS Receiver (GPS) [17]
Total Battery Weight (lbs)	0.106	0.256	6.4	0.222	0.106	1.3

TEG voltage results in higher system efficiency. For this reason, the TEG must be made of many thin, long pellets oriented in series. Flexible TEGs often have a low density of pellets, and due to their construction, suffer from non-optimum pellet geometry.

Integrating a TEG into clothing or wearable technology poses additional challenges related to various factors, such as the wearable size and weight, effective capturing of the body heat, providing air flow with respect to the TEG, basic human anatomy and respective type of clothing for a man or woman, and the appropriate placement of the TEG on the body considering both the comfort and efficiency.

Addressing these challenges, researchers at the NSF Nanosystems Engineering Research Center for ASSIST have developed a new wearable TEG that enables integration of highly efficient thermoelectric materials with optimum geometries and combined them with thin and light heat spreaders as shown in Figure 2. In this design, heat spreaders were mounted at the top and bottom of the TEG.

The top heat spreader provides better heat dissipation and cooling, and the bottom heat spreader conducts body heat into the thermoelectric material. These functions enhance overall TEG performance, including durability for wearable applications and integration within clothing. TEGs were integrated into wearable bands and a T-shirt, and the devices were measured at different body conditions.

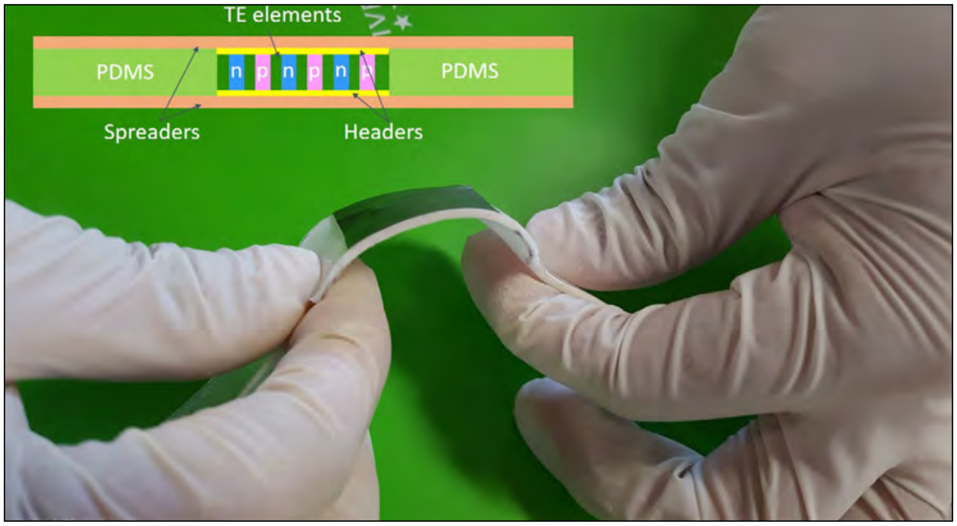

Figure 2: A TEG integrated in between flexible heat spreaders. (Released)

The generated power reached approximately 20 microwatts per square centimeter (µW/cm^2) at normal walking speed (~1.4 meters per second), which is sufficient to turn on low-power wearable sensors such as accelerometers, electrocardiogram sensors and ozone sensors. The power consumption of those devices are 10, 50 and 150 µW, respectively, which can be provided by a TEG with an area of 0.5, 2.5 and 7.5 cm2, respectively. The small footprint of this TEG allows for integration into a variety of wearable devices.

TEGs were further tested on various parts of the body including the upper arm, wrist and chest. [16] Results show the upper arm area generates more power compared to other tested parts of the body. Less significant power generated at the wrist area can be attributed to wrist contours that prohibit complete TEG-to-skin contact. The chest sensor lacked air flow, which resulted in a smaller temperature difference across the TEG, generating less power output. Although it produced the lowest level of power, the TEG integrated into a T-shirt was the most convenient and comfortable design, still producing useful power in the range of 2-8 µW/cm^2 — depending on walking speed.

-Reliant Equipment
tion Enduring Freedom - Afghanistan 72-hour mission. [4,17]

						Total Weight: 15.49 lbs
Head Set [17]	AN/PEQ-2A (Infrared Target-Pointer/Illuminator/Aiming Laser) [17]	HTWS (Night Rifle Scope) [17]	M68 Close Combat Optic (Day Rifle Scope) [4]	LMR (Radio) [17]	P-Beacon [17]	
0.106	0.106	.384	.007	6.4	0.1	

Summary

Although batteries are the most familiar, widely-used power sources, there are ongoing efforts to replace them with permanent sources of energy, including research conducted by U.S. Army Program Executive Office Soldier. TEGs generate energy by harnessing body heat, producing consistent, reliable electric power from the temperature difference between the body and the ambient environment. The aforementioned TEGs are small and lightweight, enabling integration into clothing and wearable sensors.

TEGs are now capable of powering low-power wearable electronic devices. In the future, TEGs could be implemented as part of the U.S. Army Soldier Power portfolio, [4] reducing warfighter weight load while simultaneously enhancing device reliability. TEGs also enable development of self-powered wearable health and environmental monitoring sensors, which could provide uninterrupted monitoring of warfighter health and safety conditions. ■

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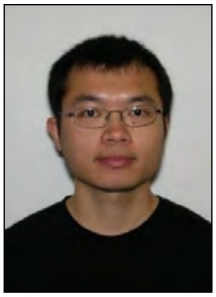

Jie Liu received his Ph.D. from Pennsylvania State University in 2013. His doctoral work focused on the development of monolithically integrated semiconductor devices by integrating gallium nitride light-emitting diodes (LED) and Schottky barrier diodes on commercially available LED wafers. He also worked on the investigation of colloidal quantum dot phosphors and LEDs. Liu obtained both his B.S. in electronics engineering and M.S. in optical engineering from Tsinghua University, Beijing, China. He joined North Carolina State University (NCSU) as a postdoctoral researcher in 2015. Liu is working on the development of thin film and flexible thermoelectric generators.

Melissa Hyland graduated Cum Laude with a B.S. in Earth science from the University of North Carolina at Charlotte. She is currently pursuing a degree in civil engineering at NCSU.

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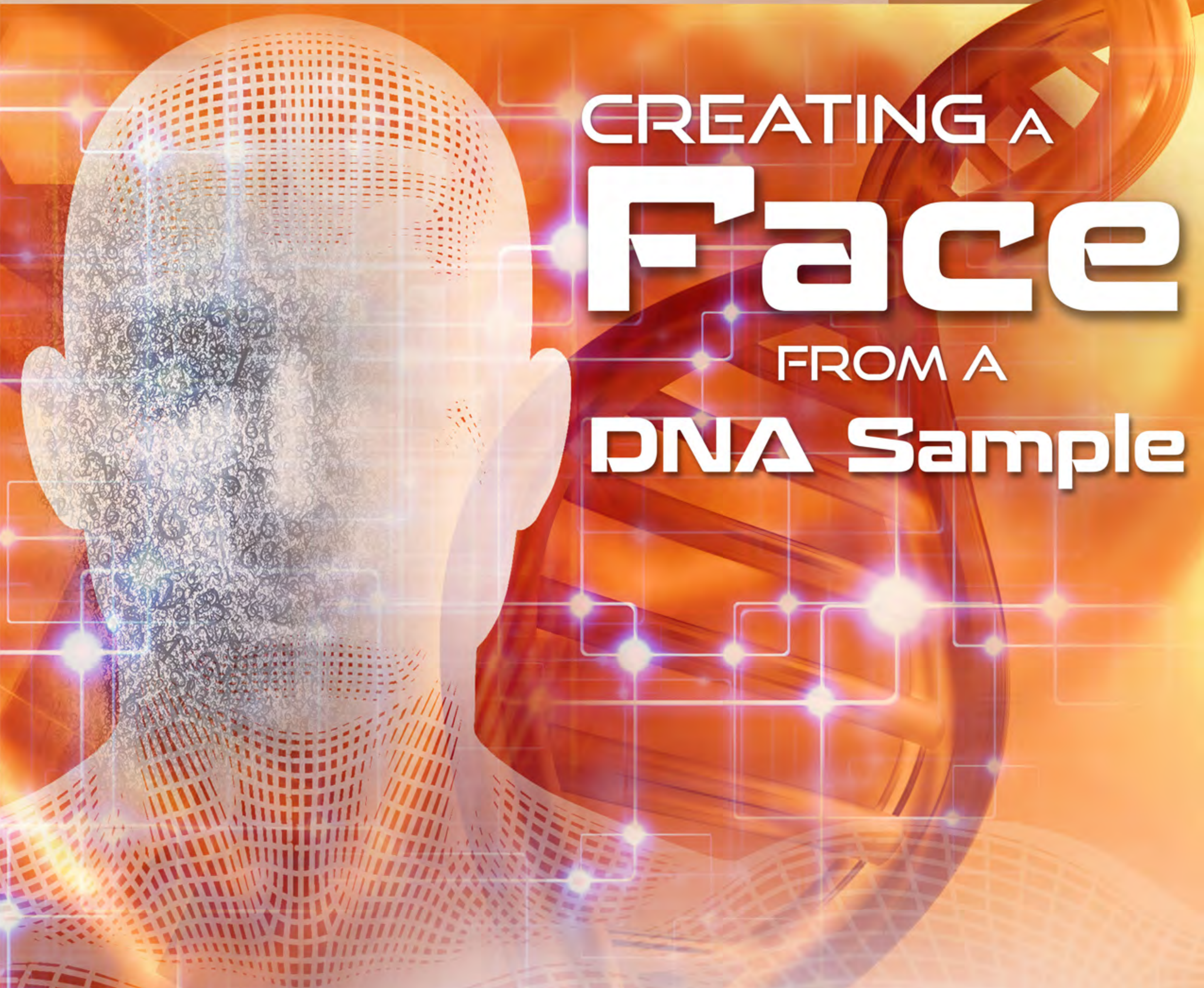
Elena Veety received her Ph.D. in electrical engineering from NCSU in 2011. Since then, she has been a teaching assistant professor of electrical and computer engineering at NCSU. Her research focuses on liquid crystal polarization gratings for tunable optical filters and telecommunications applications. Veety also serves as the education director for the NSF Nanosystems Engineering Research Center for Advanced Self-Powered Systems of Integrated Sensors and Technologies.

Daryoosh Vashaee received his Ph.D. from the University of California, Santa Cruz, in 2004. He worked at the Massachusetts Institute of Technology as a postdoctoral scholar, at Oklahoma State University as an assistant professor and joined the NCSU Department of Electrical and Computer Engineering as an associate professor in 2014. He is an expert in superlattices and nanostructured materials for energy conversion and sensing applications. In the past, he has contributed to the development of several key thermoelectric structures including heterostructure thermionic devices and bulk nanocomposite thermoelectric materials. Vashaee received a 2015 National Science Foundation Faculty Early Career Development award and the 2004 International Thermoelectric Society Goldsmid Award for Excellence in Research in Thermoelectrics by a Graduate Student.



CREATING A Face FROM A DNA Sample

By: Ryan Tokola & Michael Leuze, Ph.D.

Introduction

The Department of Defense (DoD) continually seeks new and emerging methods to improve biometrics for enhanced security and identification. Biometric facial recognition technology analyzes collected information and establishes unique facial characteristics to compare against watch lists of suspected or known terrorists for identification purposes.

Some existing technologies use DNA to identify demographic characteristics, such as gender and ethnic background, and create a face prediction consistent with these general attributes. This approach is of limited use for identification as the predicted faces do not account for the individual's specific genetic information.

In contrast, the ongoing research at the Department of Energy's Oak Ridge National Laboratory (ORNL) focuses on interpreting portions of DNA that govern the unique facial structure of each person.

Traditional facial recognition biometrics techniques use cameras or sensors to capture an image before comparing it to a previously established database of known suspects in order to identify unknown persons. [1] Likewise, DNA samples are typically useful in biometrics only when referenced back to a pre-existing database of identified DNA.

Researchers at ORNL are moving the idea of creating a face from a DNA sample closer to reality with a novel method that assesses facial scans and compares them to genetic markers.

The ability to create a facial image based solely on small amounts of genetic material, without the need for pre-existing images of the individual or extra equipment, provides a huge advancement in current biometric capabilities.

ORNL's DNA2Face project demonstrates that predicting a person's facial structure from their genetic data, such as a small blood or tissue sample, is possible. The advanced identification possibilities brought forth by this technology will benefit the DoD community as well as law enforcement, national security and the intelligence community.

DNA2Face Project

The goal of the initial DNA2Face project was to determine whether a significant association exists between DNA and unique facial features. In order to demonstrate the association, ORNL researchers created a statistical method to represent the 3D shape of faces.

The researchers' novel biometric approach first defined a reference, average face, mapped with tens of thousands of 3D points. The reference face was then aligned with a similarly mapped facial scan. Comparing the two created correspondence vectors (CV) — essentially a measure of the differences between the reference face and the scanned face.

Once the CVs were established, the researchers applied the statistical technique, principal component analysis (PCA), which transformed each CV into a relatively small set of numbers, providing a very compact representation of the face.

The researchers then performed a genome-wide association study (GWAS) using DNA samples obtained from the subjects of facial scans. A GWAS is a statistical approach to finding genomic variations that are associated with a particular trait. The results of the GWAS showed several strong connections between DNA and facial features by comparing PCA scores to DNA markers. [2]

The researchers found 30 mutation locations with genome-wide significance and more than 5,000 locations with suggestive significance. In comparison, an earlier study without ORNL's statistical method found only five regions with genome-wide significance. [3]

"These days if you get a genetic sample from a crime scene, basically all you can do is apply it to some databank of samples, and we don't have a lot of those. But if you can take that genetic material and make a face prediction then you can run it against a database of faces, which we have a lot more of," notes Principal Investigator Ryan Tokola of ORNL's Imaging, Signals and Machine Learning Group.

Recognition and Prediction

Using facial recognition technologies is not a new concept for the DoD. From 1993 to 1997, the DoD's Face Recognition Technology (FERET) program's primary mission was to develop automatic face recognition capabilities able to assist security, intelligence and law enforcement personnel in performing their duties. [4]

The ability to identify an individual from genetic material would enable the DoD to identify extremists from remaining touch DNA or any genetic material left behind. Furthermore, the ability to create a facial image without a database of known persons could allow the military to track and identify extremists operating near deployed forces.

With the rise of lone-wolf terrorism, it is impossible to keep a comprehensive record of individuals who may commit acts of terrorism. The ability to identify suspects with only genetic material available will assist officials in tracking and apprehending persons of interest.

The DNA2Face method could also be deployed to identify unknown remains of service members killed in action. Additionally, during special operation missions, the DNA2Face technology could provide target confirmation after military operations.

The Details

As technology reduces the time and cost required to sequence DNA and identify genotypes, researchers are better able to produce massive databases containing human genomics information. This allows portions of genetic code to be correlated to specific physical traits, or phenotypes.

Utilizing vectors to define facial characteristics allows efficient comparison of genetic variations from different individuals with a variety of traits. Employing a GWAS allows for the rapid scanning of the genome to pinpoint markers and genetic variations for the same feature, such as facial shape. The GWAS array used in the study consisted of more than 700,000 single-nucleotide polymorphisms, or small variations in the genome. [5]

In order to minimize cost and to analyze many faces to identify correlations between phenotype and genotype, researchers used pre-existing data sets via the FaceBase Consortium. [6] Phenotype datasets provided 3D face meshes in a Wavefront format. Each of the faces were oriented facing the –y direction with the origin of the coordinate system located either behind or in front of the facial plane.

"Because the coordinate points are very close together, and there are tens of thousands of them, it results in a very dense representation of the face," Tokola explained.

Demographic characteristics such as ethnicity, gender and age were taken into account for the subjects included in the research. The most significant cluster of variations was found on chromosome 3 on the RAF1 gene, which is known to affect craniofacial shape. Researchers suggest analyzing select portions of the face could result in the discovery of more genes that directly influence facial shape.

Conclusion

Researchers at ORNL have demonstrated a strong association between genetic data and facial morphology. Going forward, a much larger dataset will be required to account for genetic variations in order to accurately predict facial shape and other finer features.

This predictive capability would be a significant step forward in the application of biometrics to several security and intelligence-related problems. With additional research and technological advances such as high-powered computing, the ability to map a complete face with genetic material is possible.

The ability to recreate faces based on DNA sequences would revolutionize the way unknown individuals are tracked and monitored. This technology could also benefit border and airport security. Additionally, this technology could be used by the DoD to confirm and identify extremists and positively identify service members killed in action. ■

Morphometric and genomic data from faces were obtained from FaceBase (www.facebase.org), and were generated by project U01DE020054. The FaceBase Data Management Hub (U01DE020057) and the FaceBase Consortium are funded by the National Institute of Dental and Craniofacial Research.

Biometrics Timeline

1858: First systematic capture of hand images for identification purposes is recorded. Sir William Herschel records a handprint on the back of a contract for each worker to distinguish employees from others who might claim to be employees when payday arrived. [1]

1904: NY State Prisons begin using fingerprints. All Bertillon Units in the state's prison system begin collecting fingerprints in addition to Bertillon measurements. [2]

1960s: Facial recognition becomes semi-automated. Woodrow W. Bledsoe develops first semi-automatic face recognition system. The system required the administrator to manually locate features such as eyes and ears on photographs. [3]

1970s: Facial recognition moves forward. Goldstein, Harmon and Lesk used 21 specific subjective markers such as hair color and lip thickness to further automate face recognition. Measurements were still manually located. [3]

1988: Law enforcement runs composite drawing against mugshot database. A division of the Los Angeles County Sheriff's Department began using composite drawings or video images of a suspect to conduct a database search of digitized mugshots. [3]

1993 to 1997: DoD's FERET Program. Working with the Defense Advanced Research Projects Agency, FERET's mission was to develop automatic face recognition capabilities that could be employed to assist security, intelligence and law enforcement personnel in the performance of their duties. [4]

2000: Face Recognition Vendor Test (FRVT) developed. The goal of FRVT was to compare competing techniques for performing facial recognition. [5]

2014: FBI launches Interstate Photo System (IPS). Using facial recognition, the IPS provides a way to search millions of criminals' photos and generates a list of ranked candidates as potential investigative leads for authorized agencies. [6]

Ongoing: Researchers at ORNL develop DNA2Face project. The DNA2Face project uses DNA sequences from blood or tissue samples in order to create a rendering of a face.

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Improving Cognitive Performance in Aviation & Other Military Applications

By: Stefanie Lattner, MSBE, MBA
& Ed Hall, J.D.

Background

Optimal cognitive performance is critical to warfighter success. Methods to improve cognitive performance could enhance decision making, improve perception and even decrease deadly aviation accidents. [1,2] The Army, Air Force and Naval Research Laboratories are all actively researching new methods to improve warfighter cognitive performance. [3,4,5]

Sustained attention, in particular, is difficult for even the healthiest of individuals due to natural occurrences including circadian rhythms, fatigue, nutritional imbalances, etc. Shift work further deteriorates vigilance. This chronic disruption of circadian rhythms results in lower cognitive functioning in terms of processing speed, selective attention and memory. [6] Reaction time and errors of commission also worsen with shift work and long work hours. [7]

Even under optimal conditions, individuals absorb visual and auditory information with varying proficiencies. Processing both visual and auditory data simultaneously can be challenging even over short durations, particularly if rapid decision-making is required. This can significantly stress/impair performance, which typically declines over time. Distractibility often occurs as vigilance declines. It occurs when one becomes hypersensitive to immediate environmental disturbances. Whether brain resources are reallocated to block distractions or whether integration of sensory input is skewed is not known, but cognitive performance will decline.

Understanding the neurobiology behind cognitive performance and potential methods to improve sustained attention could noticeably impact decision-making and ultimately save lives.

Neuroanatomy of Attention

It is generally accepted that alertness, focus, distractibility and impulse control are directly affected by sleep/wake cycles and circadian rhythms and are diffusely controlled by multiple areas of the brain. Prolonged wakefulness or short-term sleep deprivation deteriorates focus and produces widespread decreases in brain activity, particularly in the cortico-thalamic network that mediates attention and executive functioning. [6] Precisely how they are integrated neurologically is an active area of research. Numerous investigators have converged on initial theories of the neural pathways that control these functions by studying Parkinson's disease, Attention Deficit Hyperactivity Disorder (ADHD) or brain injuries that produce similar symptoms. A. De La Fuente provides an overview of the relevant literature. [8] Most attentional and executive functions are believed to involve the dorsolateral and ventrolateral prefrontal cortex, dorsal anterior cingulate cortex, the caudate, cerebellum and the parietal cortex. [9]

Neuroanatomists have also been investigating the role of the basal ganglia with regard to attention and executive function. [10,11,12] The basal ganglia comprise an intricate neural network beneath the cortex. These nuclei accept inputs from multiple cortical areas and, through excitatory and inhibitory control loops, determine the appropriate response by adaptively controlling behavior through interactions with sensorimotor, motivational and cognitive areas. [13]

Figure 1 shows a simplified version of the control loop. [14] Green arrows represent excitatory projections (glutamate) and red arrows represent inhibitory pathways (gamma-Aminobutyric acid (GABA)). The function of the basal ganglia is often described in terms of a "brake" theory or inhibition/disinhibition. To sit still, the brain must inhibit/brake all movements except those that maintain posture. To move, the brain releases the brake (disinhibits), allowing voluntary movement. A key modulator of this circuit is dopamine, which is produced in the substantia nigra, represented by the blue arrow. Decreased production of dopamine, as seen in Parkinson's disease and suggested in ADHD, causes perturbation of the excitatory/direct pathway resulting in motor movements as the circuit is no longer properly inhibited. Supporting this theory, volumetric differences in the striatum of children with ADHD have been reported, which may reduce its ability to inhibit the circuit properly. [15]

Current Methods to Improve Cognitive Performance

Numerous methods are used to reduce fatigue and enhance cognitive performance, including medications typically prescribed for ADHD. Common medications for ADHD are psychostimulants, such as methylphenidate. These stimulants interfere with a dopamine-reuptake mechanism, leaving more dopamine in the synapse to bind to the receiving cell. This compensates for a proposed deficiency of dopamine production in those with ADHD, resulting in a reduction of motor movements (fidgeting), increased concentration and less anxiety. However, when no dopamine deficiency is present, these medications can produce the opposite effect, leading to excitability, stress, distractibility and lack of focus. Additionally, these medications must be metabolized, which places stress on the liver. These controlled substances also pose a high risk for abuse, which can lead to dependence, cardiac risks and other health hazards. [16]

Caffeine, a central nervous system stimulant, is another method used to improve cognitive performance. During prolonged wakefulness, adenosine naturally accumulates in the brain, promotes drowsiness and lowers blood pressure as it binds to A_2a receptors in the basal ganglia. Caffeine prevents drowsiness by non-selectively blocking adenosine from binding to these receptors. [17] The A_2a receptor and dopamine D_2 receptor have reciprocal antagonistic interactions in GABAergic neurons that drive the above-described indirect pathway. This is consistent with animal data that showed that A_2a knockout mice had higher anxiety, aggression and blood pressure. [18] Continued use/overuse of caffeine has serious negative effects including aggression, [19] sleep disturbances, withdrawal headaches, cyclical alert/sleepy behavior, heart rate variability and increased blood pressure. [20]

As ingestible methods are known to cause the negative systemic effects discussed above, non-ingestible solutions are being investigated. Exercise is being more formally studied to identify its neurobiological effect on cognition. Animal models of rats with ADHD show hyperactivity, spatial learning memory deficit, reduction of tyrosine hydrox-

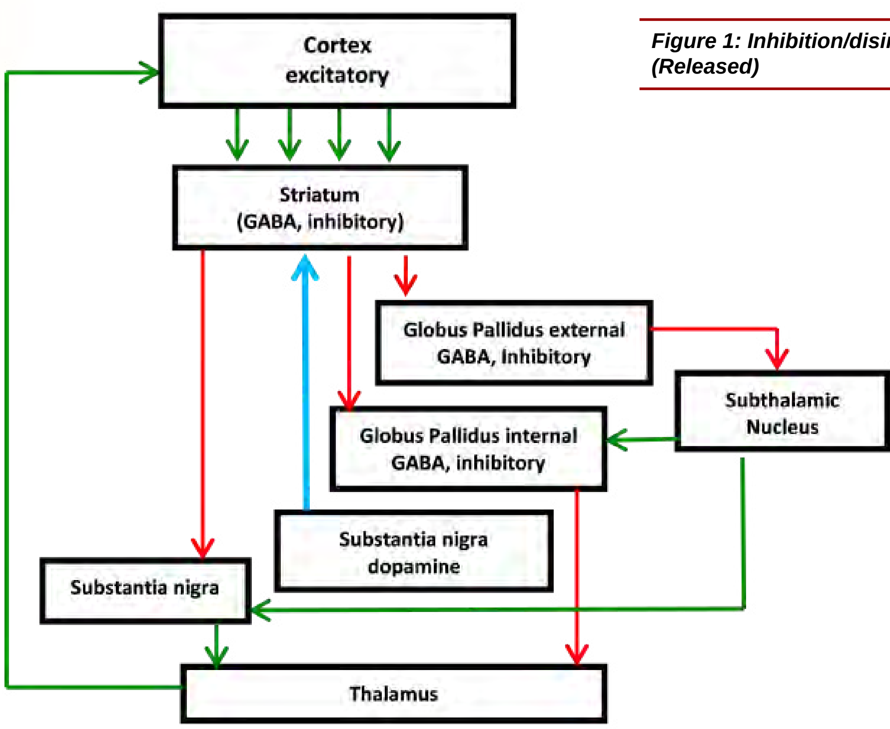

Figure 1: Inhibition/disinhibition. (Released)

ylase (TH) in the striatum and substantia nigra pars compacta and brain-derived neurotrophic factor (BDNF) in the hippocampus. Both treadmill exercise and methylphenidate alleviated the ADHD-induced hyperactivity and spatial learning memory impairment, increasing both TH and BDNF. [21] Exercise in rats also increased dopamine, serotonin and norepinephrine if fatigue was not reached. [22] In human studies, acute exercise significantly improved continuous-performance scores including response time, impulsivity and vigilance measures. [23]

More recently, two types of neurostimulation have been investigated to identify the effects on cognitive performance. The first is transcranial stimulation, which delivers either electrical or magnetic energy to the scalp. Based on questionnaires, mild improvement of attention scores was reported with no effect on anxiety or hyperactivity. [24] Extracellular dopamine release with repeated magnetic stimulation over the left prefrontal cortex has also been indicated. [25] This technology may prove to be very important in identifying specific neural pathways. However, the therapeutic benefit, practicality and safety have yet to be determined. [26]

The second type of neurostimulation, presented below, is a novel method of providing a safer form of stimulation through a wearable device without delivering electrical or magnetic stimulation. This is accomplished through frequency-specific vibratory bone conduction.

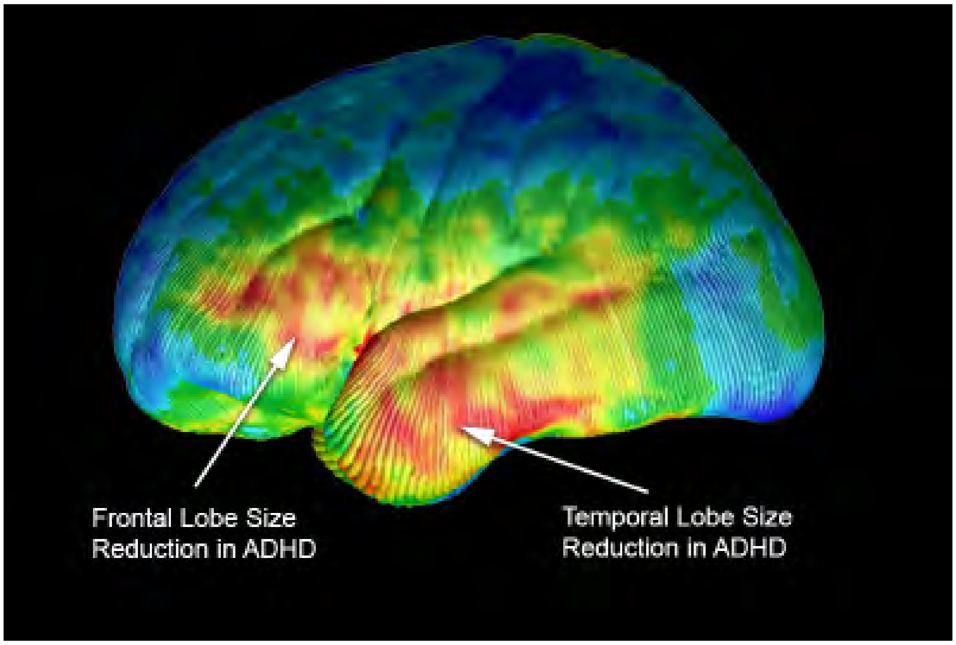

Figure 2: Volumetric differences. (Courtesy of Arthur W. Toga, Ph.D., University of Southern California Laboratory of Neuro Imaging, USC Mark and Mary Stevens Neuroimaging and Informatics Institute - www.loni.usc.edu/Released)

Feasibility of Novel Vibratory Technology

Several disparate bodies of work suggest that the vestibulocochlear nerve may play a key role in cognitive performance. Volumetric deficiencies and hypoperfusion in the prefrontal cortex and temporal lobe have been reported in children with ADHD. [27,28] Poor perfusion in these regions was also reported in drowsy versus non-drowsy individuals. [29] Both children and adults with attention deficit sleep disorders, autism and anxiety will self-soothe by body rocking, head shaking, bouncing or spinning — all of which naturally stimulate the vestibulocochlear nerve. Exercise stimulates this nerve and has been shown in animals and humans to increase perfusion, slow deterioration of volumetric reductions, [30] increase volume in the prefrontal cortex and temporal lobe and improve synaptic plasticity. [31] Given that this nerve originates in the pons, is tightly connected to the cerebellum and is easily accessible (shown below), we sought to artificially stimulate this region to identify its effect on attention, cerebral blood flow and cognitive performance.

Our first subject was a 29-year-old female with ADHD who was studied using quantitative electroencephalography (qEEG) at a licensed neurofeedback facility. The qEEG is conducted by instrumenting the subject with a standard 10-20 EEG electrode cap. Baseline data were collected at rest and after mechanically stimulating over the right mastoid unilaterally. The qEEG system automatically collects data and compares it to a normative database of age and gender matched controls. Data are then automatically scored as being consistent with either the ADHD or "normal" population. A representative image of the study is shown in Figure 3. The top panel shows a characteristically familiar profile of an individual with ADHD. Broad-spread hypoperfusion is noticeable in several areas of the cortex. The bottom panel illustrates that after five minutes of use, many of these areas scored similarly to individuals without ADHD. These data show promise, as they are very similar to other published effects of medication, but

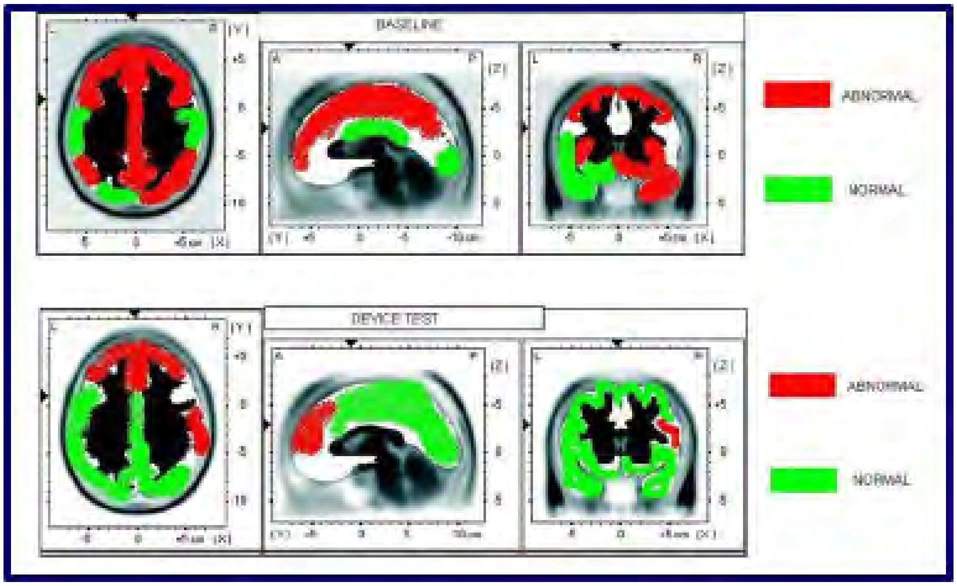

Figure 3: Cerebral perfusion. (Released)

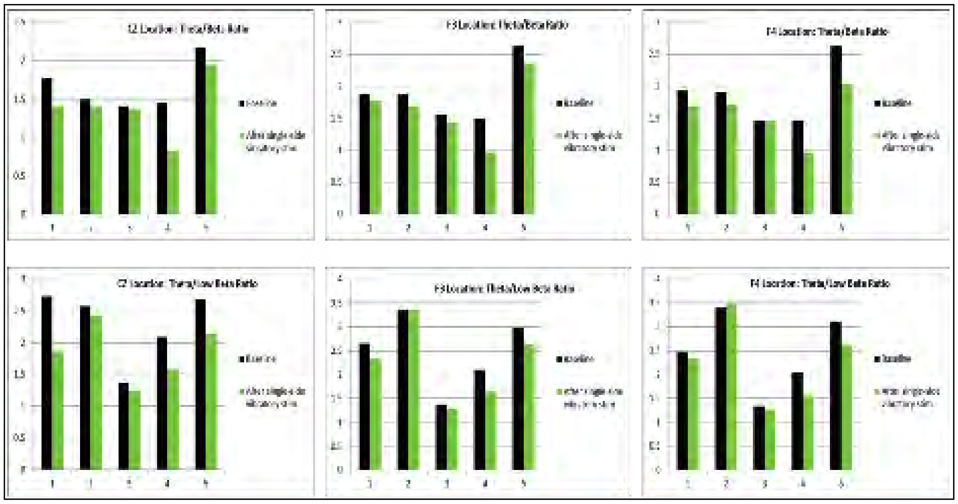

Figure 4: Summary of qEEG data. (Released)

do not negatively impact the heart or liver. While the duration of this effect is not yet known, we believe it is worth studying both the effect of wearing the device longer and the overall long-lasting effect.

Next, five healthy college students were studied using qEEG. Individuals were instrumented as above. Resting EEG data were collected for one minute before and after using the stimulation for five minutes on either the right or left mastoid. qEEG data were separated into frequency bands for each lead. The theta/beta ratios for the CZ location, as well as F3 and F4 locations, have been reported as viable objective indicators of attention. [32,33] A decreased ratio indicates better focus. A meta-analysis of qEEG data supports that the theta/beta ratio increases with attention deficit. [34] The summary data is presented in Figure 4, which shows that the stimulation decreased the theta/beta ratio in almost every case, suggesting an increase in focus/alertness. The consistency across leads and across subjects supported further research into identifying cognitive benefits of vestibulocochlear stimulation.

To ascertain if vestibulocochlear stimulation has any effect on cognitive performance, a wearable device was designed that delivers vibratory stimulation bilaterally in a specified pattern. Ten volunteers with self-reported distractibility or attention deficit participated. The Test of Variables of Attention (TOVA) was used to provide objective measures, including errors of commission, errors of omission and response time variability. Each test took approximately 20 minutes and required the user to click a button when they either saw or heard a designated target. Each volunteer was tested before and after wearing the device for 30 minutes. The software presents the targets in random order to minimize any potential learning effect. All data were collected automatically and independently scored by the TOVA Company, which compared each subject's data to a database of age and gender matched controls. The results indicate whether each subject's scores align with either an ADHD or normal population. The test is comprised of two 10-minute segments. The first half tests one's ability to stay focused when the target is presented infrequently. (Does the subject daydream or overcompensate?) The second half tests performance when the target is presented frequently. (Does the subject get anxious or anticipate responses?) In total, 20 segments were collected as shown in Figure 5 (10 subjects; slower segment and faster segment). Green indicates the test result aligned with the normal data for that subject's age and gender. Red indicates the test result aligned with the ADHD data.

Observations

Across the data set, the total number of errors of commission (impulsivity), omission (inattentiveness) and response time variability (consistency) improved after wearing the device. This particular population of 10 volunteers had more difficulty with errors of commission (impulsivity) and inconsistent reaction time. Errors of omission were particularly noticeable in the more rapid environment. Errors of omission and reaction time variability occurred slightly more frequently during the auditory test than the visual test, and the subjects responded well

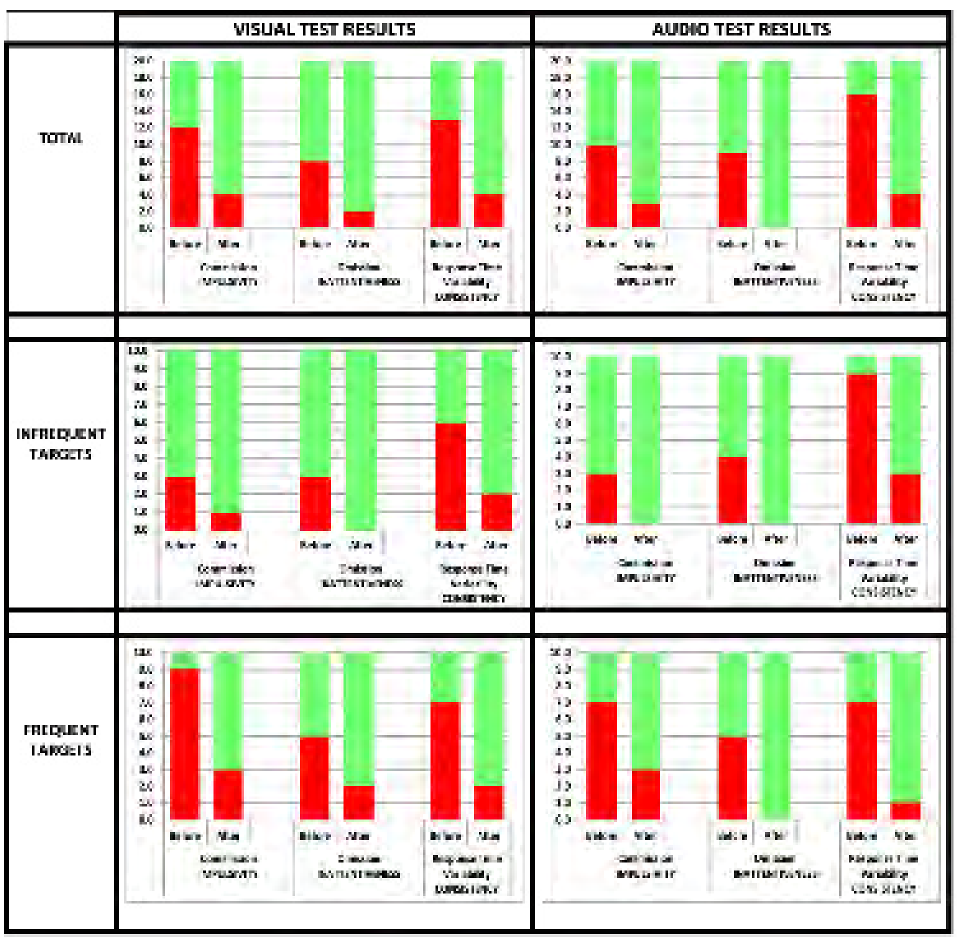

Figure 5: Continuous Performance Test data summary. (Released)

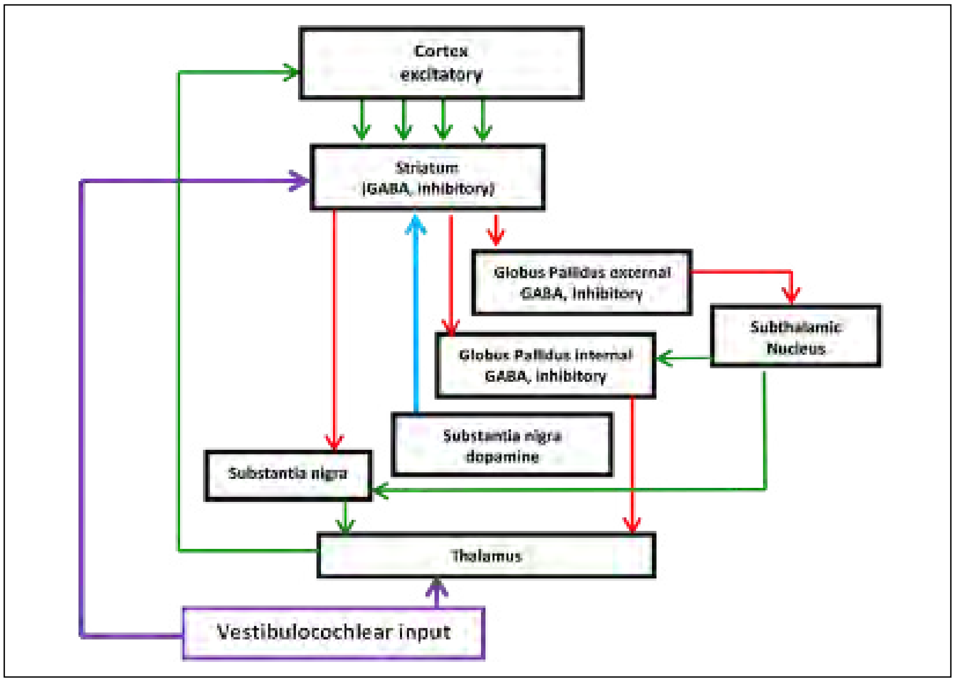

Figure 6: Proposed feedback loop. (Released)

to the stimulation. Equally important, none of the volunteers became drowsy, nauseated or anxious.

While each of the tests within the third study has shown promising results, due to the small population size, no definitive conclusions can be drawn. The TOVA test also had several limitations. Firstly, the comparison database for the auditory database is not segmented adults. Secondly, the testing environment separates the visual test and the auditory test. This helps isolate potential issues but does not challenge the subject with both auditory and visual information simultaneously. Finally, if the data falls into the "normal" range, the data cannot be segmented further to see if there is improvement after using a particular intervention.

Discussion

While the exact mechanism of action is not yet known, there are clues to the anatomy involved. E. D'Angelo and S. Casali propose that the cerebellum acts as a co-processor that integrates sensory inputs, memory, emotion and timing information through various feedback loops, and then affects cognition and motor control. [35] This notion is supported by the multiple vestibulocochlear neuropathways developed for different functions. It is known that the cerebellum tightly controls the oculomotor activity and is directly connected to the vestibulo-ocular reflex and that vestibular inputs to the thalamus communicate with the motor cortex for motor control. More recently, M. Hitier, S. Besnard and P. F. Smith describe five currently known and proposed neuropathways between the cerebellum and the cortex. [36] Of particular interest are the proposed direct connections to the cerebellum and to the striatum. Referring to the previous discussion of the basal ganglia, the circuit is presented again in Figure 6 with these connections added. If these pathways exist, it may describe a direct role in modulating the circuit. Instead of effecting dopamine, it most likely would have an inhibitory influence (purple arrow to the striatum). This might explain the reduction of errors of commission (excitability) and more consistent reaction time seen in our feasibility studies. It is not yet known how this stimulation affects the elegant control experienced by the brain, but at a conceptual level, it could be that keeping this circuit active at an optimal frequency, ideally below a level that would cause gross motor movement, keeps the cerebellum, visual system, auditory system and executive function engaged and properly inhibits the thalamus.

Current and Future Studies

Due to the limitations of the test environment previously used, a more robust test that intermixes audio and visual targets simultaneously has been chosen for the current study. This tests one's ability to rapidly switch focus and make a decision. It also allows differentiation for individuals that are higher functioning in the "normal" range. Future studies of interest include testing individuals on a longitudinal basis; testing individuals with Post-Traumatic Stress Disorder (PTSD); and, due to the perfusion data, testing the healing time of head injuries, such as concussion or stroke.

Potential DoD Applications

Further study could utilize this EEG technique to evaluate individuals with PTSD, concussion or stroke. This research could prove beneficial to the DoD as these injuries are common among service members across all military branches. Study results could lead to recommendations that could help mitigate and prevent these warfighter injuries.

Based on the performance data, the most likely follow-on studies to the second study could be centered on decision-making and focus in a rapid manner without getting overwhelmed. Drone pilots would be a fitting group for a follow-on study, as their responsibilities require quick decisions and intense focus. ■

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By: Gregory Nichols, MPH, CPH

Background

The 100th anniversary of the day the United States entered into World War I is a good time to evaluate how the scientific enterprise is often used to develop technologies that find their way into combat and how those technologies change the face of warfare itself. World War I saw the introduction of the flamethrower, the tank, the airplane and radio into war as well as the first large-scale use of chemical weapons. [1]

Each of these technologies were developed many years before the outbreak of the war in 1914, but World War I was the first venue in which they could be adapted to combat. Likewise, radiation was first discovered in the late 1890s, but it was not until World War II that it was weaponized. Unfortunately, these examples illustrate that many technologies, even if originally developed for beneficial purposes, are often weaponized in some way.

The advent of a new technology, nanotechnology, promises improved economies but also presents challenges to the security environment by creating a new arms race sparked by scientific research.

Nanotechnology as a Weapon of War

In general, nanotechnology is the manipulation of matter using specialized tools to create new structures and materials with at least one dimension measuring between 1 and 100 nanometers. At this scale, materials have unique physiochemical properties, and it is this aspect of nanotechnology that can either create wonderful benefits for humanity or potential weapons of war. Military spending on nanotechnology has been reported by several countries, including China, France, India, Iran, Israel, Malaysia, the Netherlands, Russia, Sweden, the United Kingdom and the United States. [2] Breakthroughs in nanotechnology have already led to new developments in camouflage, stealth and armor, [3] and this development will continue. However, there is also continued concern for the misuse of nanotechnology.

Civilian and military research on emerging technologies has been overlapping, which has caused some to fear a reduction in transparency and that nanotechnology could be misused to make weapons of

HNOLOGY & the New Arms Race

mass destruction. [4] Weapons made with nanotechnology (nanoweapons) could potentially be found in five different forms:

1. **Augmented** varieties of existing weapons types
2. **Tiny machines**, such as robots, that could create new types of destruction
3. **Hyper-reactive explosives** due to extremely small particle sizes and unique physicochemical properties
4. **Pathogens and chemicals** linked to nanomaterials creating new types of hybrid chem-bioweapons with more efficient delivery systems
5. **Materials** with superior electromagnetic properties that could cause disruption to the electrical grid and communications infrastructure

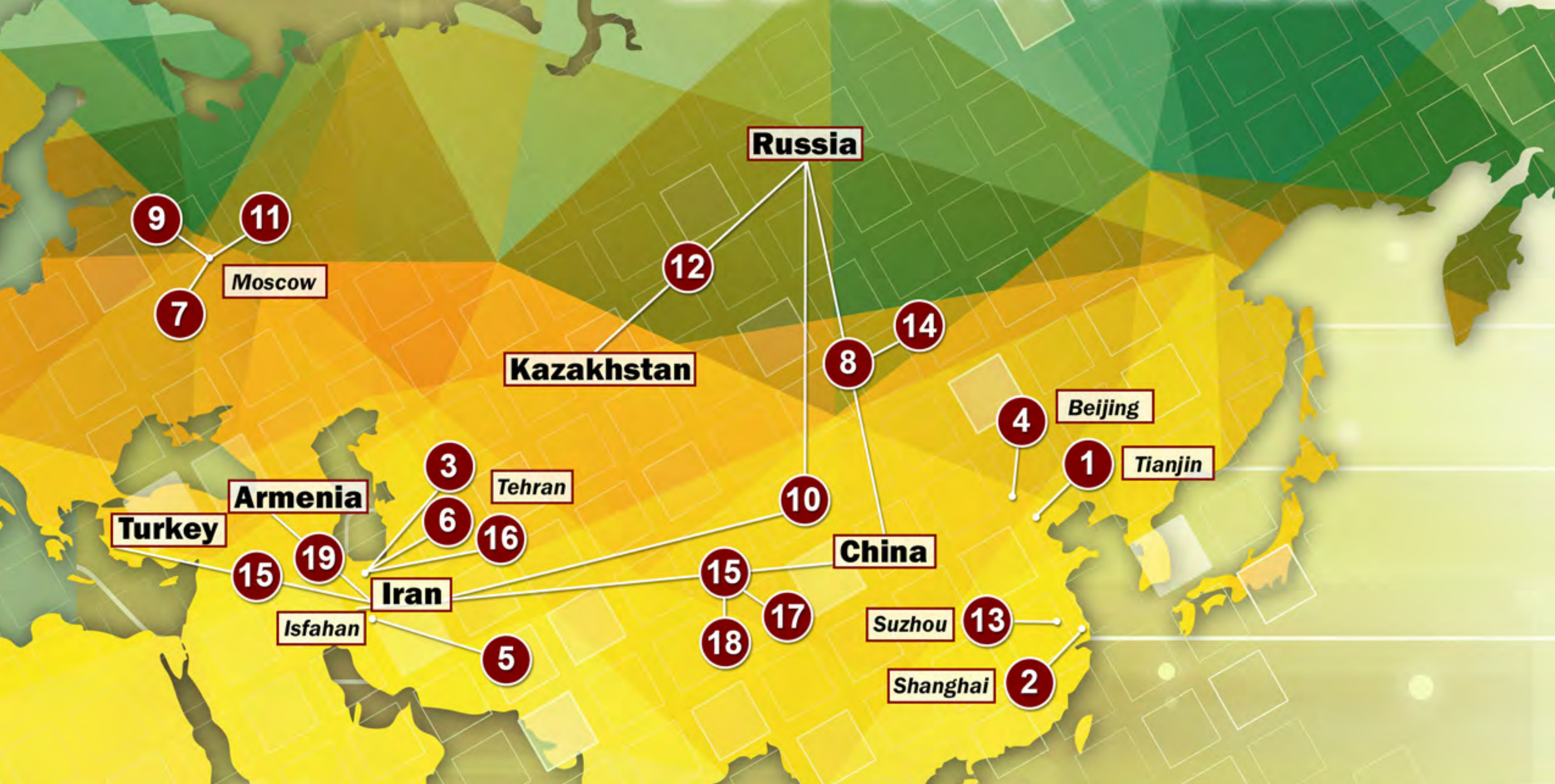
In 2008, at the Global Catastrophic Risk Conference in Oxford, participants were given a survey regarding their opinions on different types of disasters that could happen by 2100. One quarter of participants answered that molecular nanoweapons would be responsible for the death of at least 1 million people, and 10 percent of participants believed at least 1 billion people could die from the same fate. [5] It has even been argued that nanotechnology could be used to create the next generation of nuclear weapons. [6] More recently, there has been concern regarding the convergence of nanotechnology with other emerging technologies, such as biotechnology and synthetic biology, to create a new type of biological weapon. [7] Nanotechnology seems to be a key target for many nations in terms of changing the landscape of politics and war.

United States

The United States has taken the lead in nanotechnology research, particularly for defense applications. So far, most of these developments have used nanotechnology to enhance existing weapons types. For example, a patent was filed in 2009 for an advanced armor-piercing projectile partially constructed of a material known as NanoSteel, [8] which is composed of nanoscale particles of austenitic and ferritic stainless steels. [9]

The U.S. military accounts for 90 percent of global military nanotechnology research and development spending, [2] establishing the Department of Defense (DoD) as the largest military spender on nanotechnology research in the world. In 1995, former Vice Chairman of the Joint Chiefs of Staff Adm. David Jeremiah stat-

THE RACE BETWEEN COUNTRIES



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ed that military applications of molecular manufacturing have greater potential to change the balance of power than even nuclear weapons. [10] The DoD has spent approximately $5 billion on nanotechnology research since 1999, [11] and most of the funding has been directed to eight organizations: the U.S. Army Research Laboratory, Air Force Office of Scientific Research, Office of Naval Research, Defense Advanced Research Projects Agency (DARPA), Defense Threat Reduction Agency, U.S. Army Engineer Research and Development Center and Assistant Secretary of Defense for Research and Engineering.

The DoD has established two institutes solely dedicated to defense-related nanotechnology research. The Institute for Nanoscience was established at the Naval Research Laboratory in 2001 to conduct multidisciplinary research at the nanoscale, and the U.S. Army established the Institute for Soldier Nanotechnologies in 2002 at the Massachusetts Institute of Technology (MIT) to conduct basic and applied research to create new materials, devices, processes and systems and to transition promising results toward practical products useful to the warfighter. [12] In 2016, the DoD announced a $75 million investment in the Revolutionary Fibers and Textiles Manufacturing Innovation Institute at MIT, where nanomaterials will play a significant role. [13]

China, Russia and Iran

The worldwide growth of nanotechnology has been unprecedented compared with other technologies. China, Russia and Iran have demonstrated extremely strong growth as evidenced by increased collaboration in science, education and business ventures centered on nanotechnology.

In late 2016, Deputy Defense Secretary Bob Work commented that Russia and China were competitors because they are developing advanced capabilities that worry the United States. [14] In particular, a new type of race regarding nanotechnology has been brewing between the two powers for more than 15 years, with each exploring the use of the technology for military applications. [15]

China has been interested in military applications of nanotechnology for nearly as long as the United States. In 1996, Maj. Gen. Sun Bailin of the Chinese Academy of Military Science wrote an article, “Nanotechnology Weapons on Future Battlefields,” in which he described potential applications of nanotechnology in warfare. [16]

In 2002, a major nanotechnology conference supported by the People’s Liberation Army General Equipment Detachment and the National Defense Science and Engineering Committee was held in Beijing. [17] China has several programs aimed at developing new technologies for a variety of uses. Most notably are the 863 Program (National High Technology Research and Development Program), which stimulates the development of advanced technologies in a wide range of fields, singling out nanotechnology as a priority, and the 973 Program (National Basic Research Program), which “seeks to improve capacity for innovation” and also has projects involving nanotechnology. [18]

Additionally, Russia has focused efforts on nanotechnology in two major areas. First, through its Rusnano Corporation, Russia aims to commercialize major achievements in nanotechnology and turn them into viable businesses.

Rusnano was formed in 2011 following the reorganization of the Russian Nanotechnologies Corporation, which was a state-owned entity established in 2007. The platform for Rusnano uses the capacities of Russian science and the transfer of advanced foreign technologies. [19] Second, in 2012, Russia established the Russian Foundation for Advanced Research Projects, which focuses on high-risk research and is modeled

Article continued on page 22

through reorganization of the state-owned Russian **Nanotechnologies Corporation:** Rusnano. (n.d.). Rusnano Corporation. Retrieved from http://en.rusnano.com/about (accessed April 12, 2017).

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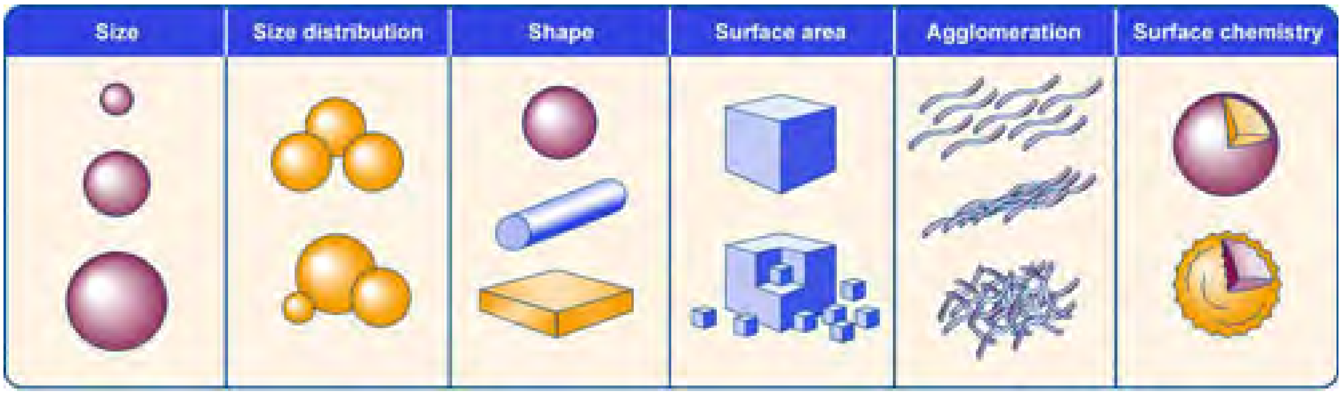

Figure 1: Some nanomaterial characteristics that could affect risk. (Courtesy of the U.S. Government Accountability Office/Released)

after DoD's DARPA, to develop weaponry and defense systems that could be used by 2025/2030. [20] One project, the Integrated Protective Soldier Systems, will combine nanotechnology with advances in body armor and exoskeleton technology to create a force-multiplier for Russian troops.

In 2007, Russia announced the development of a bomb nicknamed the Dad of All Bombs. It is four times more powerful than the previously most powerful bomb, the U.S. Massive Ordinance Air Blast (MOAB) nicknamed the Mother of All Bombs. [21] This weapon is the largest non-nuclear bomb, containing less explosives than the MOAB with the ability to create a blast radius twice as large as that of the MOAB. What sets this bomb apart is that the explosives were designed with the use of nanotechnology.

The working theory is that the smaller particles are more reactive and thus a smaller volume is needed to produce an equally large, if not larger, explosion than the same or larger volume of explosives with larger particles. Weapons technology such as this could revolutionize how ordinance is manufactured.

Iran has been actively engaged in nanotechnology research since 2002 when the Nanotechnology Initiative Council was founded. [22] In 2004, a center for nanotechnology research was established in Isfahan, which is a defense and research focal point of Iran where the Iranian nuclear program is based. [18] The steady growth of nanotechnology development in Iran, even in the face of economic sanctions, has moved Iran into the top ranks of nanoscience placing it among the likes of the United States and China. [23]

Stopping an Attack

Nanotechnology is often referred to as a "dual-use" technology in that most of the legitimate uses of the technology could also be misappropriated. Not all of the interest in nanotechnology gravitates toward weapons development. Quite a bit of the nanotechnology research worldwide seeks to understand applications of nanotechnology for non-military use as well as countermeasures, particularly for CBRN defense. As with any technology, there is the chance that individuals or groups could use nanotechnology for nefarious purposes – if they have not done so already. The challenge is twofold: how to deter the weaponization of nanotechnology without stifling beneficial research; and, if nano-enabled weapons are developed and/or used, how to detect and counter them.

Most experts agree that existing treaties and policies regarding humanitarian protections and those that ban the development and use of chemical and biological weapons are mostly sufficient to cover the use of nanotechnology for weapons developments. However, holes still remain as the concept of nanotechnology could possibly evade parts of some of these conventions. [24,25,26] Still, until the legal/regulatory debate is ironed out, the possibility of nanoweapons lingers. Several recommendations from the Partnership for Peace Consortium's Security Challenges Working Group provide a good starting point for being prepared for the use of nanotechnology in weaponry:

- Raise awareness of developments that could threaten the security of a state, society and individual
- Increase awareness of the dual role of emerging technologies and their unintended consequences
- Promote partnerships with [nongovernmental organizations], think tanks, academia and industry to increase analytical capacities available to policy institutions
- Identify and address [emerging security challenges, (ESC)] issues now, even if the threat seems to be remote
- Build ESC into national curricula and have it addressed within national institutions [27]

A key way to minimize the likelihood that nanotechnology will be misused is to create a culture of responsible research and innovation, which is "an approach that anticipates potential implications and societal expectations with regard to research and innovation" and aims "to foster the design of inclusive and sustainable research and innovation." [28] Responsible research and innovation involves researchers, citizens, policy makers and organizations working together to improve research and innovation outcomes aligning with societal values and expectations. Creating communities of practice centered around what it means to innovate responsibly ensures that researchers and innovators are held accountable for their actions, keeping them in check against the needs of the communities they serve.

Conclusion

Existing military applications of nanotechnology primarily include defensive gear, countermeasures, armor, medications, new high-yield explosives and enhancements to existing classes of weapons. It does not appear that fundamentally new types of weapons have been developed with nanotechnology. However, with global military interest and high levels of defense spending on nanotechnology, particularly with nations such as China, Russia, Iran and the United States, a true nanoweapon is bound to be developed and possibly even used at some point in the near future.

The first step to ensuring that more advanced weapons development does not occur is to promote awareness of the potential for nanotechnology to be used as a weapon and to create a culture centered on responsible research and innovation with the hope that nothing further would be needed. The second step is to begin preparing for attacks involving advanced nanoweapons in case the first step fails. ■

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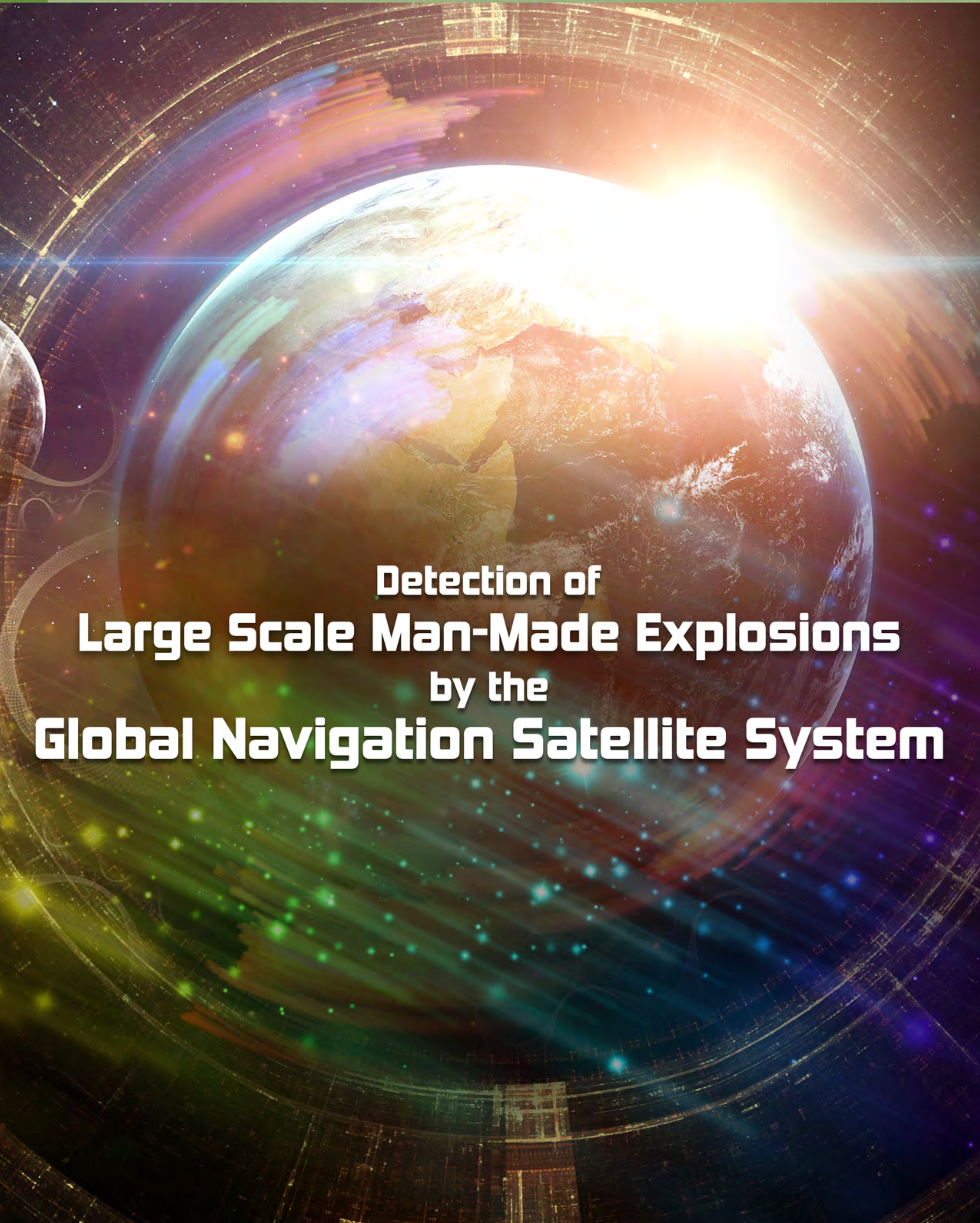

Detection of Large Scale Man-Made Explosions by the Global Navigation Satellite System

By: Jihye Park, Ph.D. & Joseph Helmboldt, Ph.D.

As the U.S. military stands prepared to respond to emerging threats and remains deployed throughout the world, our adversaries are employing sophisticated capabilities, including testing nuclear weapons, utilizing chemical weapons and deploying stronger and more advanced explosives. The U.S. government, including the departments of Defense and Energy, employ space-based detection capabilities to support identification, location and strength of explosive events. Detection via ionospheric disruption through Global Navigation Satellite System (GNSS) stations could potentially augment the Department of Defense's (DoD) current capabilities for technical intelligence and battlespace awareness.

The ionosphere is a layer of Earth's upper atmosphere in which electron density varies based on the sun's diurnal cycle. This atmospheric layer affects radio signals utilized on Earth for communication and navigation, such as those used by GPS. Acoustic, gravity and acoustic-gravity waves are generated by natural Earth activities, such as geomagnetic storms, earthquakes, tsunamis and volcanic eruptions, as well as artificially conducted events like large-scale explosions. [1,2,3,4,5] These waves take on variable shapes and properties based on the nature of their source. The waveforms then propagate to upper atmospheric regions where they change the distribution of electron density in the ionosphere, driving irregularities referred to as traveling ionospheric disturbances (TID), typically at mid latitudes. TIDs can be extracted by observing the spatio-temporal variation of the electron density in the ionosphere.

The DoD could potentially utilize the GNSS alongside existing platforms to improve precision monitoring of anthropogenic events by measuring total electron contents (TEC) along ray paths using the refractive property of signals in the ionosphere. [4,6,7] From the observed TEC on GNSS signals, the abnormal fluctuation due to the geophysical activities can be extracted. TIDs can be isolated after removing major TEC trends such as the sun's diurnal cycle and changing satellite geometry. Numerous studies have applied the GNSS technique to observe natural or artificial events by monitoring the ionospheric state [4,5,8,9,10], and this technique has become a staple of ionospheric research. In practice, relating a TID wave to a specific event is not straightforward because numerous events can generate disturbances in the ionosphere, and the background noise of the ionosphere increases the level of difficulty. Hence, the below research provides the DoD the process to detect TID wave properties individually but also its propagation pattern using multiple adjacent GNSS network stations to identify these explosive events.

This article presents experiments of mapping and analyzing TIDs generated by acoustic-gravity waves from anthropogenic events, including underground nuclear explosions (UNE), mine collapses, mine blasts and large chemical explosions (LCE), and how this technology could augment current capabilities and support future military/DoD deployments.

TID Detection

With the refractive property of GNSS signals through the ionosphere, the TEC along the GNSS ray path can be precisely measured by taking the geometry-free (GF) linear combination in Equation 1 using two or more different frequency signals. The GF observation between a station (i) and a satellite (k) is described by Equation 1 on the following page.

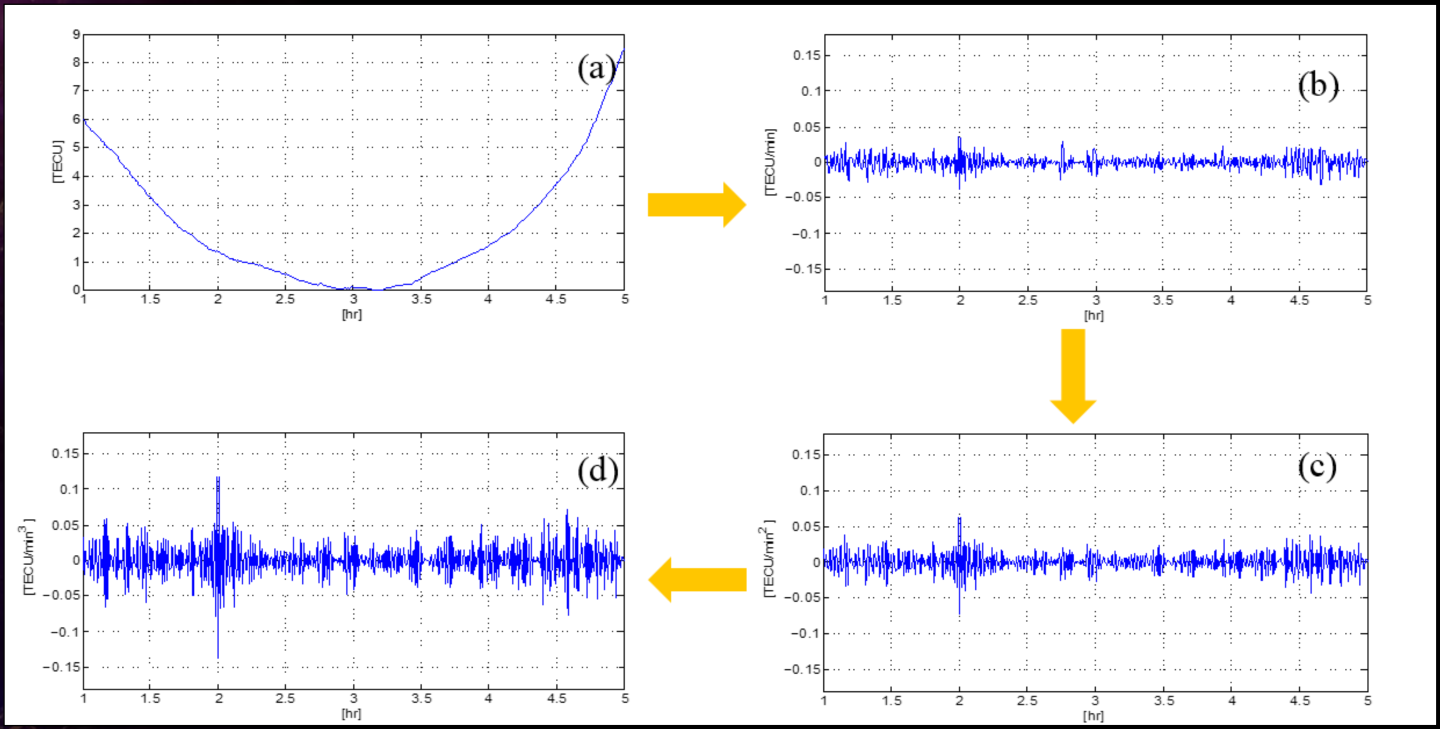

Figure 1: Numerical derivatives of STEC data span; (a) STEC, (b) the first order derivatives of STEC, (c) the second order derivatives of STEC, (d) the third order derivatives of STEC. (Released)

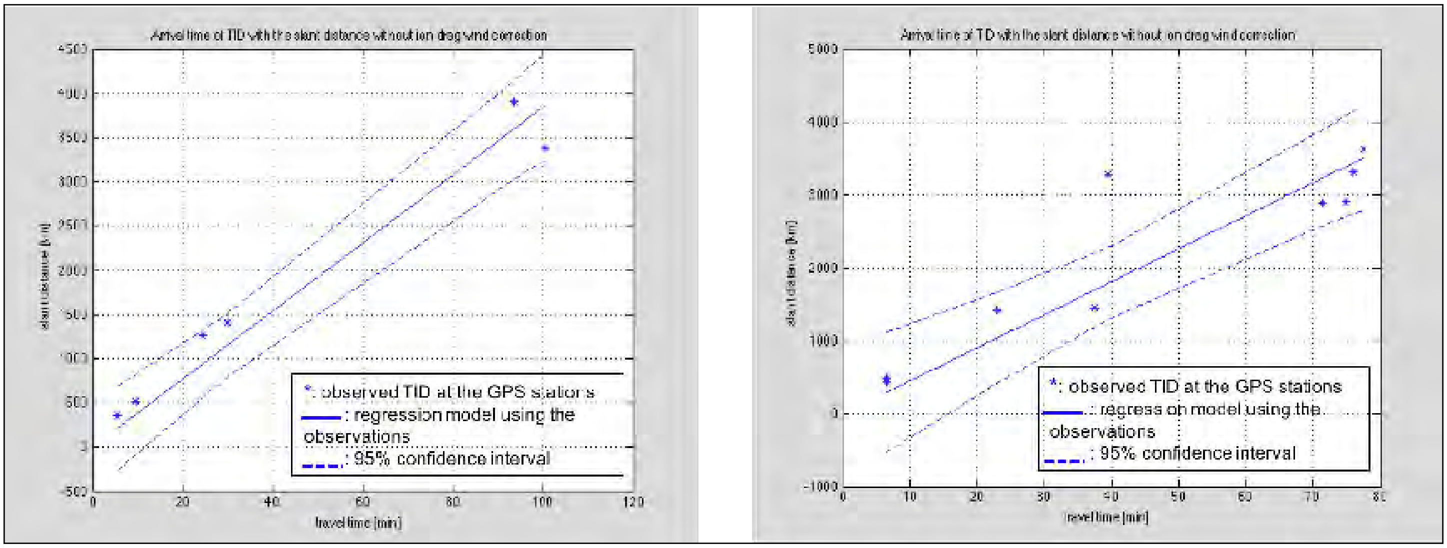

Figure 2: Linear model of TID travel time and distance plots of U.S. UNEs in 1992; Hunters Trophy (left) and Divider (right). (Regenerated from Figures 1 and 2 in [12]/Released)

Equation 1

$$\Phi^{k}_{i,GF} = \left(\frac{f_1^2}{f_2^2}-1\right) I^{k}_{i,1} + \beta + \varepsilon$$

where Φ_(i,GF)^k is the GF observation at a station (i) observing a satellite (k) from dual frequency GPS signals L1 and L2 with respective frequencies (f1 and f2), I_(i,1)^kis the ionospheric delay on the L1- signal; β is a constant bias over a continuous data span, and ε is the observational noise. [10]

The ionospheric delay, I_(i,1)^k in Equation 1, can be converted to slant TEC (STEC), [11]

Equation 2

$$\Phi^{k}_{i,GF} = \left(\frac{f_1^2}{f_2^2}-1\right)\cdot\left(\frac{40.3}{f_1^2}\right) STEC^{k}_{i} + \beta + \varepsilon$$
$$= 40.3\left(\frac{f_1^2-f_2^2}{f_1^2 f_2^2}\right) STEC^{k}_{i} + \beta + \varepsilon$$

where STEC_i^k is the STEC along the ray path between GNSS receiver (i) and GNSS satellite (k). [10]

Under normal conditions, the STEC observation is expected to smoothly change with the sun's diurnal motion and the satellite-to-receiver geometry. The STEC observation also includes tropospheric error, clock jitter, multipath error, constant bias term and other errors. To minimize these effects and better isolate possible TIDs, the numerical derivative method [5] is applied. The numerical derivative method is computed using three consecutive data points and acts as a kind of high-pass filter. Specifically, by taking the third order numerical derivatives of the continuous ray path data span, possible short-period (on the order of a few minutes) TID candidates can be identified, and they are confirmed by visual inspection and cross-covariance analysis. [5,10,12]

Figure 1 shows the gradual filtering process of original STEC in (a) to isolate TID candidates as shown in (d) by increasing the order of numerical derivatives.

In (a), a dominant trend is found in the STEC data span that is mainly due to both the geometry change of a satellite and the sun's diurnal motion. The main trend is sufficiently removed by taking the numerical derivatives using a sliding window, while the other effects from various error sources within the GNSS signal exist in (b). When the higher order filters were applied, some distinguishable peaks remained in (d) that are the candidate TID waves.

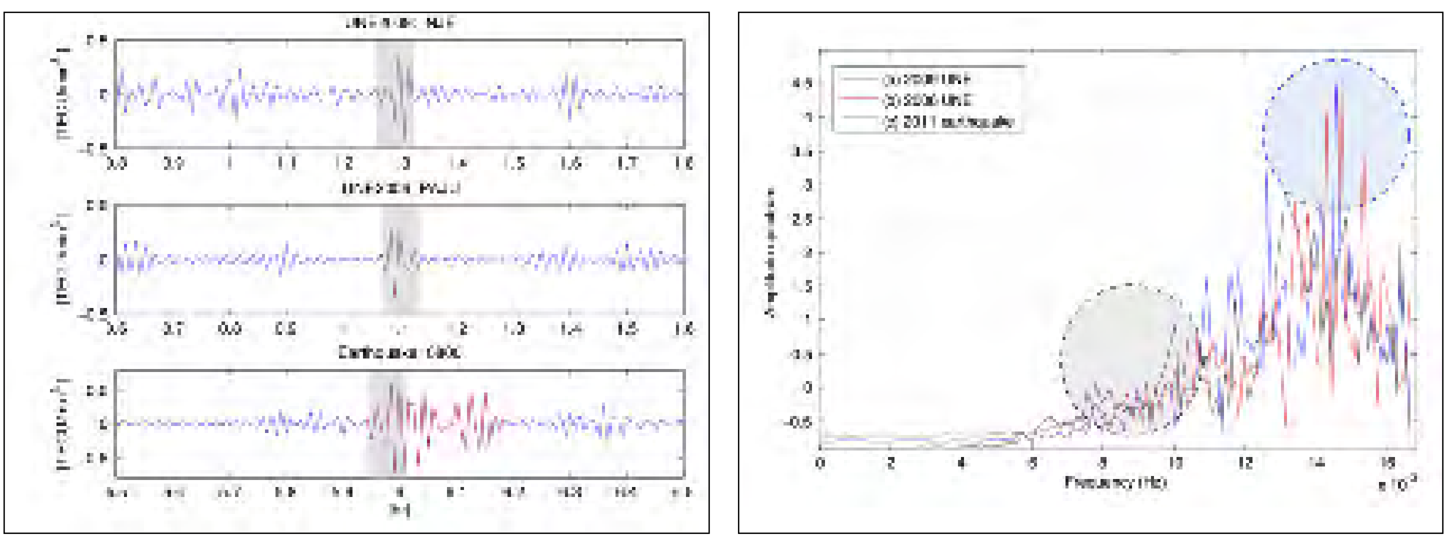

Figure 3: On the left are three time series plots illustrating the detected TID waves from the 2009 (top) and 2006 (middle) UNEs relative to those from the 2011 Tohoku earthquake (bottom). The right plot provides the amplitude spectra of these STEC derivatives. [10] (Released)

TIDs can be excited by various sources. In other words, the selected TID candidate is not necessarily from a certain event of interest. Consequently, careful analysis is required to isolate meaningful TIDs associated with a target event and to discriminate TIDs from different event types. One strategy to relate candidate TIDs to a specific event is the observation of the propagation velocity from the point source. Selecting appropriate TIDs is based on the apparent propagation of the signals. In particular, we focused on TID propagation velocities ranging roughly between a few hundred meters per second to about 1 kilometer per second to mark possible TIDs from high-energy point source events like explosions and mine collapses. [13,14]

Figure 2 presents examples of TID propagation after two U.S. UNEs in 1992, Hunters Trophy and Divider. [12] The travel distance of TID is the slant distance between the location of the UNE and the ionospheric pierce point of the GNSS ray path at the moment of TID peak appearance. Considering the constant propagation velocity of TIDs from a point source, the detected TIDs, which form a linear model for travel time-distance, are regarded as the TIDs associated with the point source. The set of TIDs which satisfy this condition is an array signature for a specific event.

From the fitted lines in the plots, the TID travel velocity of the Hunters Trophy event was about 573.00 m/s with the standard deviation of 84.68 m/s, whereas the travel velocity of the Divider event was roughly 739.76 m/s with standard deviation of 134.50 m/s. [12]

Figure 3 compares three TIDs from three different sources. Within the time series plots on the left, the top plot shows a TID signature generated by the UNE in 2009. The middle plot shows a TID generated by the UNE in 2006, and the bottom plot shows a TID generated by the earthquake in 2011. The right panel shows their amplitude spectra. In this figure, some similarity between the same type of events, UNEs, and dissimilarity between two different types of events can be found in time series plots as well as the spectral analysis where the local maximum of each type of event is shown at different frequency range.

Understanding the results of these events and the application of the associated methodologies to measure UNEs could provide the U.S. government and DoD with an additional platform to support detection in North Korea and other growing areas of interest. Additionally, DoD analysis of recent developments regarding despot regimes and violent extremist organizations in Syria, Iraq, Afghanistan and other locations could potentially benefit from incorporating these capabilities.

Smaller, man-made events such as mine collapses, mine blasts and large chemical explosions also generate TIDs that are detectable using this technique. The Crandall Canyon Mine collapse near Huntington in Emery County, Utah, occurred Aug. 6, 2007, at 8:48:40 Coordinated Universal Time (UTC) at geographic coordinates (39.4600° N, 111.1676° W). The mine collapse resulted in a "magnitude 3.9 mining-induced seismic event," [15] and the reported body wave magnitude was 5.2MB.

Figure 4 shows the travel velocity of the TIDs from the Crandall Canyon Mine collapse. The left plot shows the travel time-distance curve and the right plot shows the propagation velocity of each TID by using colored symbols and the geographical locations of the mine in pink star.

Mine blasts also release significant energy to the atmosphere. Two mine blasts in NE Wyoming were selected as case studies. On March 24, 2000, cast blasting at a NE Wyoming mine occurred at 20:04.21.89 UTC at geographic coordinates (43.721oN, 105.0549oW). In 2001, another mine blast was conducted at the same mine (L. Triplett, personal communication, May 15, 2014). The reported body-wave and local magnitudes for both events were 4.8 MB and 3.5 ML, respectively. Figures 5 and 6 show the travel velocity of TIDs from the two events.

The approximate propagation velocities of these events can be computed based on the linear model of travel time-distance on the left panel of each figure, that are 291.076 m/s (standard deviation 66.747 m/s) for the 2000 event and 226.678 m/s (standard deviation 33.441 m/s) for the 2001 event.

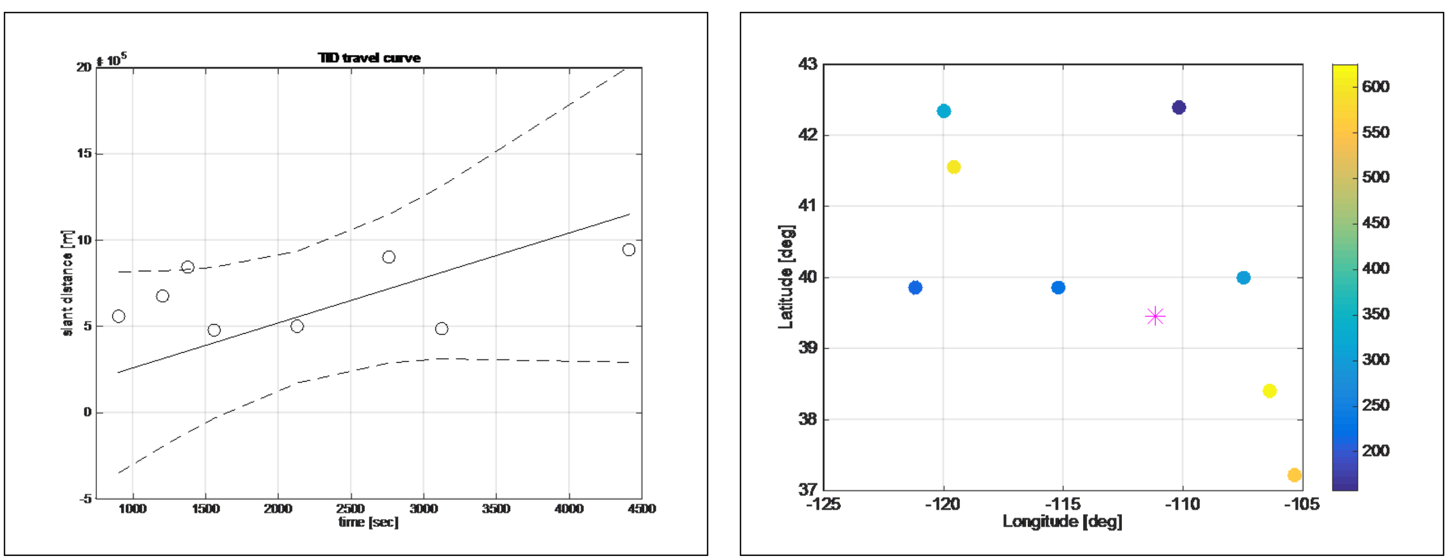

Figure 4: TID velocity propagated from the 2007 Crandall Canyon Mine collapse; travel time curve with the 99 percent confidence interval (left) and TIDs at their ionospheric pierce points (right) where the color of each dot represents its travel velocity in m/s from the color bar. The pink star indicates the location of mine collapse. (Released)

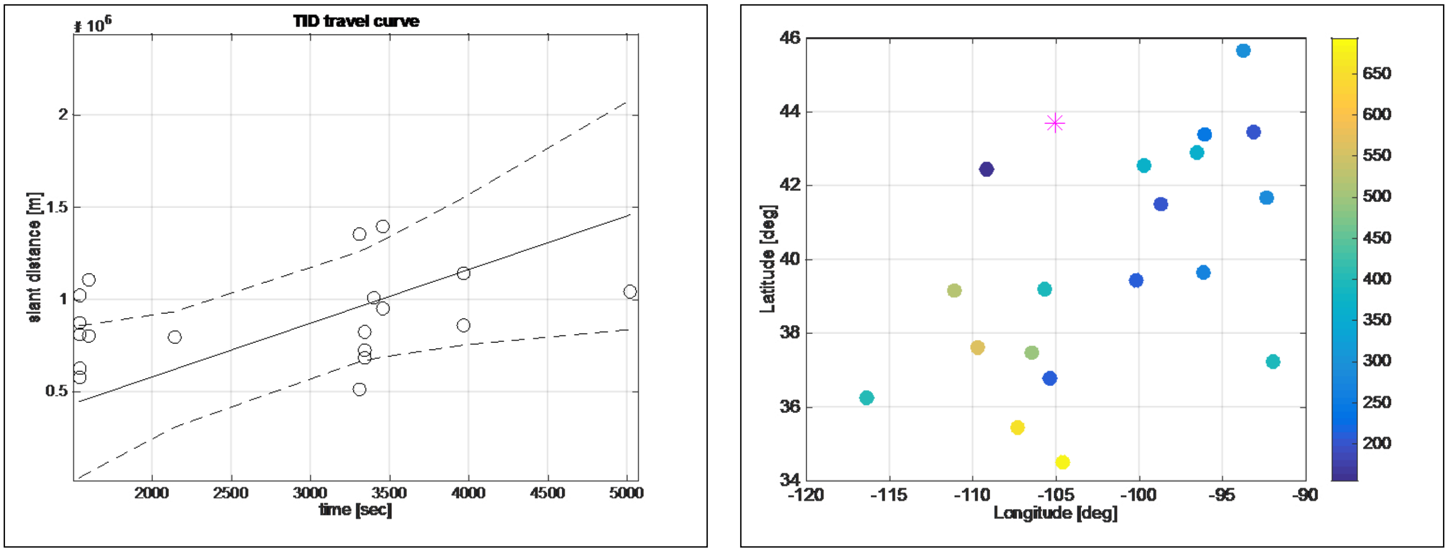

Figure 5: TID velocity propagated from the NW Wyoming mine blast in 2000; travel time curve with the 99 percent confidence interval (left) and TIDs at their IPPs (right) where the color of each dot represents its travel velocity in m/s from the color bar. The pink star indicates the location of mine collapse. (Released)

It should be noted that more TID waves were detected from the NE Wyoming mine blasts than the Crandall Canyon Mine collapse case with higher correlation between the travel time and travel distance of their propagation pattern. Considering the nature of these two types of events, it may be easier to detect the propagated waves emanating from mine blasts because such blasts emit energy from the ground into the air whereas the explosive energy from a mine collapse tends to be absorbed underground.

In addition to the Crandall Canyon Mine collapse and NE Wyoming mine blasts, another type of man-made event was also observed. A series of chemical explosive tests, known as the Source Physics Experiment (SPE), were conducted in the granitic rock of the Climax stock in northern Yucca Flat at the Nevada National Security Site in 2010–2011. [16] The SPE test series was designed to study the generation and propagation of seismic waves to improve the predictive capability of detecting and characterizing underground explosions. [17] As a case study, one of the events on Oct. 25, 2011, (DOY 298) was selected to monitor the TIDs from the SPE, and the result is shown in Figure 7.

Summary and Discussion

With the advent of GPS, or more generally the GNSS, ionospheric observations in high spatial and temporal resolutions are possible to better detect and verify the ionospheric signatures of these geophysical events. This study focused on artificially conducted anthropogenic events including UNEs, mine collapses, mine blasts and LCEs. As such, the analysis of these events could support future U.S. government research into the efficacy of this approach to augment existing U.S. government and DoD detection capabilities. Additionally, this platform and associated methodologies could provide future insights to the DoD regarding our adversaries' testing of new capabilities and threat detection for deploying military units.

The results of this work show the potential

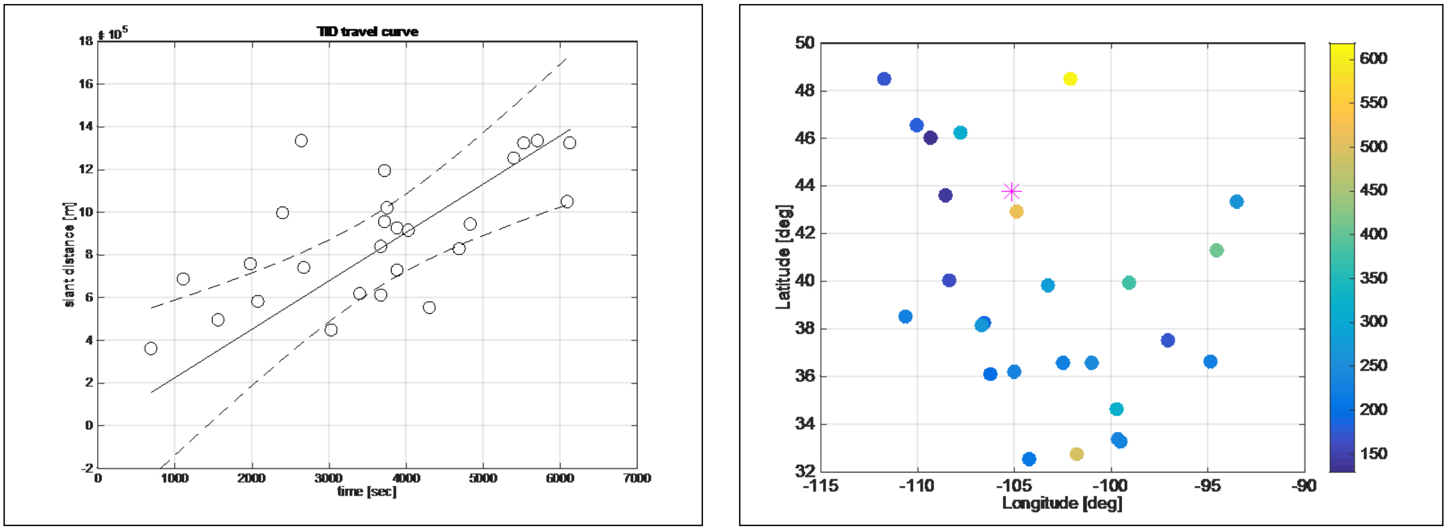

Figure 6: TID velocity propagated from the NW Wyoming mine blast in 2001; Travel time curve with the 99 percent confidence interval (left) and TIDs at their IPPs (right) where the color of each dot represents its travel velocity in m/s from the color bar. The pink star indicates the location of mine collapse. (Released)

utility of GNSS observations for detecting and mapping the ionospheric signatures of large-energy anthropological explosions and subsurface collapses. Although this study successfully detected various types of artificial events across underground, near surface and surface explosions, the study mostly focused on the array signature of the TID propagation.

In future development, additional detection and analysis approaches should be investigated for better discrimination among the types of events, as well as for constraining the poorly known properties of ionospheric winds that may affect the signatures of these events in the ionosphere. ■

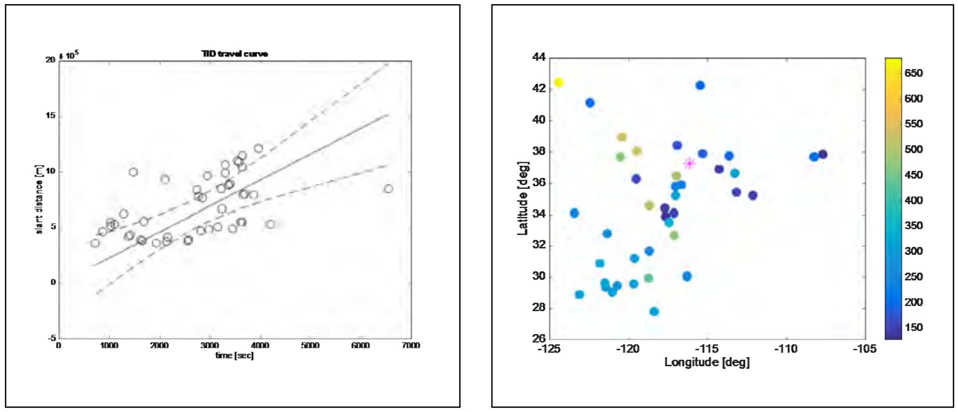

Figure 7: Travel time curve with the 99 percent confidence interval (left), and the TIDs at their IPPs (right) for the USA LCE (pink star). The dot color represents its travel velocity in m/s from the color bar. (Released)

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Calendar of Events

July 2017

07/16/17 - 07/18/17 • **Dallas, TX**
CIP 2017 Symposium on Managed Lanes and All Electronic Tolling

07/17/17 - 07/19/17 • **Arlington, VA**
HDS, M Summer Workshop on Pandemics, Bioterrorism, and Global Health Security: From Anthrax to Zika

07/22/17 - 07/27/17 • **Las Vegas, NV**
CIP, HDS Black Hat USA 2017

07/24/17 - 07/26/17 • **Evanston, IL**
CIP 22nd International Symposium on Transportation and Traffic Theory

07/27/17 - 07/28/17 • **Auburn, AL**
HDS, M Tactical Athlete Human Factors Summit

August 2017

08/07/17 - 08/09/2017 • **Austin, TX**
HDS 28th Annual International Solid Freeform Fabrication Symposium

08/08/17 - 08/09/2017 • **N. Bethesda, MD**
CBRN, CIP HDS 2017 Global Explosive Ordnance Disposal Symposium & Exhibition

08/15/17 - 08/16/2017 • **Wilmington, DE**
CBRN CBRN Defense Conference & Exhibition

08/15/17 - 08/17/2017 • **Warrenton, OR**
HDS 2017 Strike Challenge

September 2017

09/14/17 - 09/15/2017 • **Washington, DC**
M World Anti-Microbial Resistance Congress

09/18/17 - 09/20/2017 • **San Diego, CA**
CIP Power Grid Resilience

09/19/17 - 09/21/2017 • **Washington, DC**
CBRN NCT CBRNe USA Conference

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(Publish Dec. 2017)
Abstract deadline: 7/15/17
Article deadline: 8/15/17

Volume 5; Issue 1
(Publish March 2018)
Abstract deadline: 10/13/17
Article deadline: 11/13/17

Volume 5; Issue 2
(Publish June 2018)
Abstract deadline: 1/5/18
Article deadline: 2/2/18