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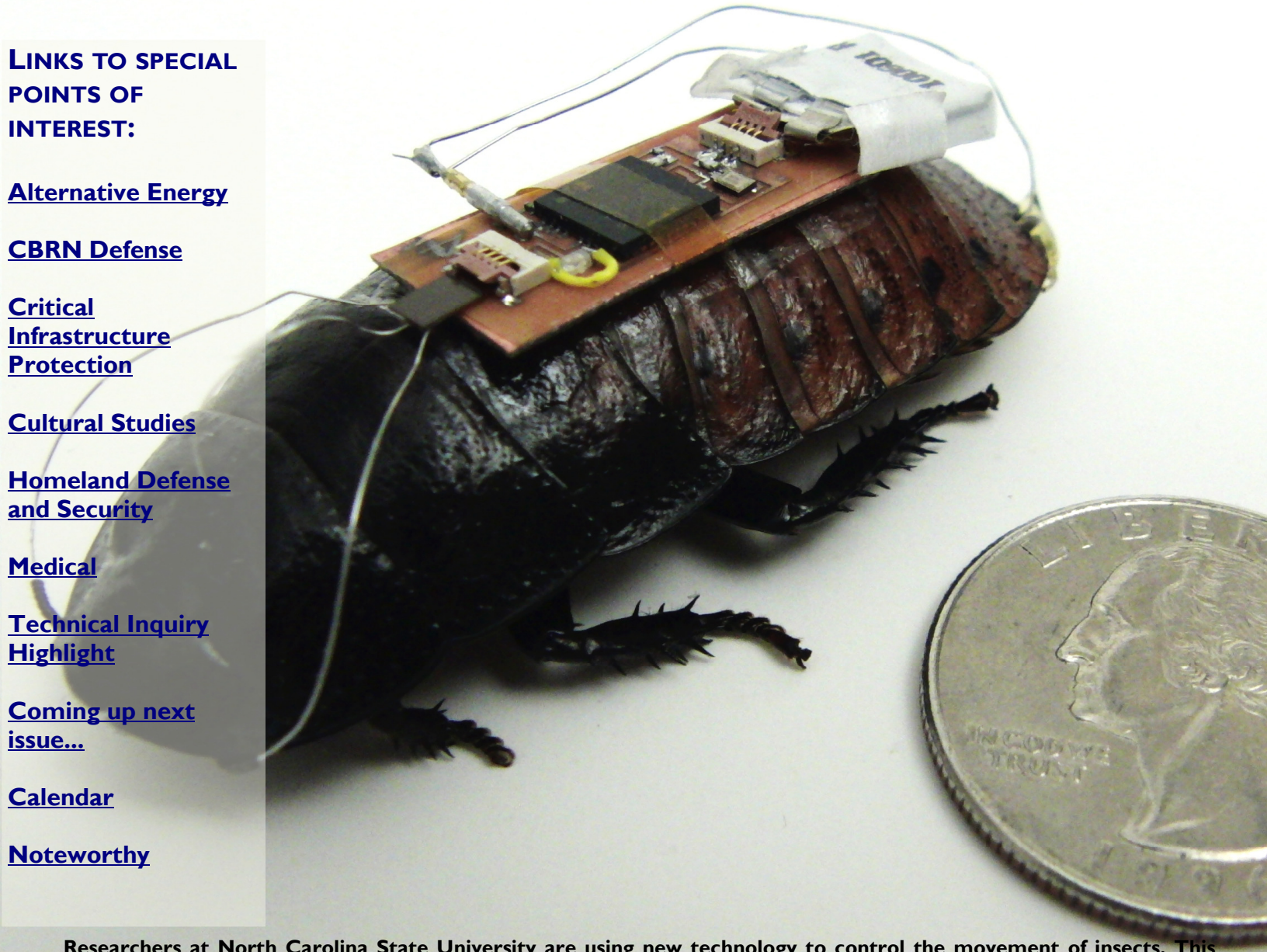
LINKS TO SPECIAL POINTS OF INTEREST:



Researchers at North Carolina State University are using new technology to control the movement of insects. This cockroach is fitted with electrodes and a backpack for wireless control. (Photo by A. Bozkurt/Released)

HDIAC Journal

Volume 2, Issue 2

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About This Publication: The Journal of the Homeland Defense and Security Information Analysis Center (HDIAC) is published quarterly by the HDIAC staff. The HDIAC is a DoD sponsored Information Analysis Center (IAC), with policy oversight provided by the Assistant Secretary of Defense for Research and Engineering (ASD(R&E)), and administratively managed by the Defense Technical Information Center (DTIC). The HDIAC is operated by Information International Associates (IIA) in Oak Ridge, Tenn.

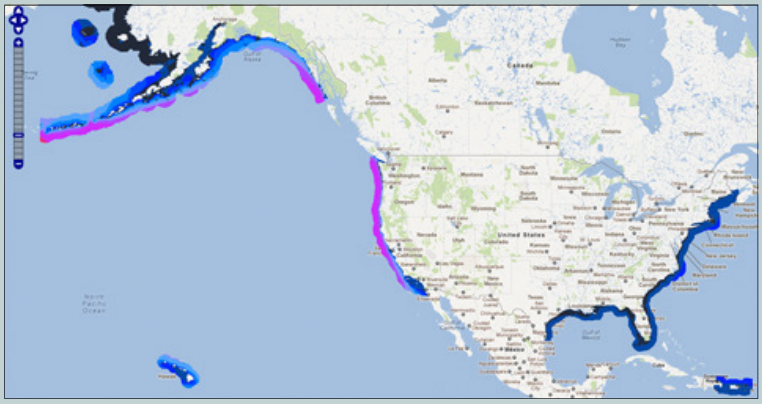
Power From the Sea

C. Doran

Humankind has extracted energy from the sea throughout civilized history. For millennia, the sea's currents and winds have pushed ships and filled sails to provide transportation. For centuries, the sea's role as a heat sink and moisture source has provided the wind and precipitation patterns that spin windmills and water wheels, providing mechanical work. Presently, researchers are exploring the sea's ability to generate the energetic currency of our generation: electricity.

Extracting power directly from the ocean makes a lot of sense considering its forceful waves, currents, tides and vast surface area for thermal absorption. The ocean also comprises 71 percent of the Earth's surface, and as such, should not be lightly brushed aside in the search for a sustainable energy strategy. According to the National Oceanic and Atmospheric Association, 39 percent of the U.S. population lives in a coastal county, and this population is expected to increase over the coming decade. Combined with the observation that coastal states have higher average electricity prices nationwide, the case for ocean power continues to build. [1] The U.S. Department of Energy estimates that the ocean has a theoretical capacity of more than 2,100 terawatt-hours of electricity per year, which is more than half the 4,000 terawatt hours of annual domestic consumption. [2]

Using the ocean for energy generation is not new; the first patent for wave power extraction was filed in 1799 by Frenchman Monsieur Girard and his son. This device was designed to use direct mechanical action to drive tools such as pumps or rotary machines. Interest waned over the following centuries as ample supplies of hydrocarbons reduced the drive for ocean energy research. This trend reversed sharply during the 1970s oil crisis, and marine energy conversion became a hot topic in a population jarred by the realization fossil energy will not always be cheap and abundant. [3]



A color-coded map showing the recoverable wave and tidal resources for the costal areas. The Electrical Power Research Institute estimates the recoverable amount of energy is 1,170 TWh/yr. (Courtesy of the National Renewable Energy Laboratory/ Released)

Ocean waves are formed by winds over the course of lengthy fetches and travel long distances with very low energy losses. Therefore, when waves reach the shore, they represent the integration of wind energy from vast areas over a period of many days. This gives wave energy the comparative advantage of consistency over resources such as wind or solar. Consistency is an important factor when integrating a resource into the grid, and its value is reflected by the cost of reserve generation needed to compensate for lulls in generation. [4] With wave power, the inevitable flat days can be predicted at least a week or more in advance by offshore buoys that detect swell direction, amplitude and period, giving the utility time to prepare energy reserves.

The technologies

There are four main types of wave energy converters: attenuators, point absorbers, overtopping devices and terminators. [3,5]

The attenuator is a multi-jointed series of floating segments with its primary axis aligned perpendicularly to the oncoming wave front. Attenuators are built with lengths comparable to, or greater than, the wavelength so the floating segments move up and down with respect to each other as the wave propagates beneath. The energy is extracted at the moving joints by hydraulic or other mechanisms. The first appreciable-sized wave farm was an attenuator-type deployed in Portugal. [6] The devices resembled massive, bobbing, segmented worms on the water.

Point absorbers rely on motion along the vertical axis without respect to the wave direction. A large number of wave energy converters fall into this category. The conceptually simplest design features an inertial linear generator inside a buoy; but point absorber designs vary greatly in their level of sophistication. For example, oscillating water columns use vertical water movement to drive air through a piston or Wells turbine for energy conversion. These water columns can be implemented in buoys or on shore-mounted installations. [7]

For shallower depths, floor-mounted point absorbers become practical. In one such implementation, a generator is placed on the ocean floor and driven by a bobbing buoy. [8] A floor-mounted generator is also possible without a floating element. In this variant, modulating fluid pressure from the surface waves is picked up by the device and converted to electrical energy. [9] This latter example has particular appeal since it is the least obtrusive to navigation and aesthetics; however, serviceability could be a particular challenge.

It is perhaps the periodic miniature waterfalls occurring between each wave on rocky seashores that inspired overtopping devices for wave energy conversion. These designs direct water flow such that the splash over from wave crests is guided to the mouth of a turbine to feed a generator-connected turbine.

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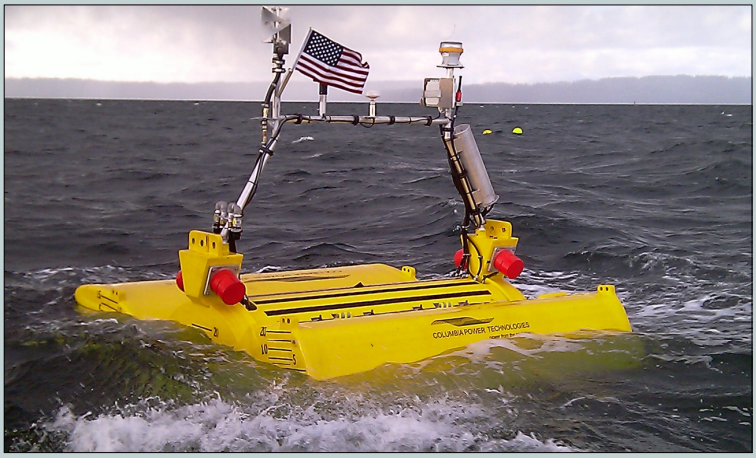

Columbine Power deployed an intermediate-scale prototype point absorber, code named SeaRay near Seattle, Wash. to conduct sea trials. (Photo by Columbia Power Technologies, courtesy of NREL/Released)

Terminators are wave energy converters with high extraction factors that can leave a visible wake of flatness behind them. The so-called Salter's Duck, invented at the University of Edinburgh in the 1970s, is the best-known example of a terminator. It is a teardrop-shaped rotary float that extracts energy from waves with proportionally-sized wavelengths when aligned appropriately. Although the duck's research was stalled after the 1970s, renewed interest has been found recently with optimized designs. [10]

Currents represent another source of kinetic energy that can be extracted from the ocean. This steady water movement can arise from a surprising number of factors, including tides, wind stress, gradients in temperature/pressure/solute concentration, river effusion, the Coriolis Effect and/or bathymetry. Analysis from Georgia Tech concluded that the Gulf Stream system from Florida to North Carolina within 200 miles of the coastline dissipates an average of 163 terawatt-hours per year. [11] Tides, which create the most predictable currents, can be harnessed in regions where water channels are long and narrow for increased water velocities. Alaska has the highest number of these regions, with the Cook Inlet representing the flagship location for large area tidal stream power density. Although implementations vary significantly, tidal power extraction is typically performed by a fixed, submerged turbine.

Ocean waves and currents are a source of kinetic energy, but the sea also stores massive amounts of thermal energy. This is the basis of Ocean Thermal Energy Conversion, which exploits the temperature gradient between deep and shallow waters. OTEC is most feasible in tropical waters with sufficient depth (typically over half kilometer) to achieve a temperature delta substantial enough to run a Rankine engine. OTEC plants can employ open-cycle or closed-cycle designs. Open-cycle plants utilize vacuum-assistance to vaporize warm seawater into steam that drives a turbine. This steam is then condensed by cold water pumped from below. Closed-system OTEC plants use an intermediary heat exchanger and a working fluid such as ammonia or carbon dioxide. Most closed-cycle designs to date also employ a cold water pipe and pumping system, but a recent design utilizes existing pressure differentials to eliminate the need for that expensive component. [12]

The challenges

The current maturity level of ocean energy conversion is low compared to other forms of renewable energy. One reason for this is a lack of convergence across the broad spectrum of nascent technologies, which is evident from the diverse sampling of technologies listed so far. [2] Some argue a diversity of generating technologies is the best method to capture energy from diverse conditions; however, at the same time, the lack of industrial focus is a challenge for a technology that needs significant capital outlay to conduct meaningful pilot projects.

Ocean energy conversion faces a host of unique challenges that will likely continue to burden the technology's adoption. Often, these problems lie within the engineering domain. For example, the devices must be capable of weathering the 20, 50 or 100–year storms that are likely to arise across its expected lifespan. The Verdant Power installation in the New York East River suffered turbine damage in 2006 from unexpectedly swift currents, exemplifying the need for an extra degree of structural robustness in aqueous environments. [13] Even in calm seas, the ocean presents a very harsh environment for machinery. Salt corrosion must be mitigated, and material choice plays a big part in addressing

Laying of the cold water pipe at Keahole Point, Hawaii. The pipe supplies the cold water for the OTEC experiment at Hawaii's Natural Energy Lab (Photo by A. Resnick, courtesy of NREL/Released)

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that. Biofouling is a big concern for all ocean-faring systems. It is critical to avoid even microscopically thin layers of microbial build up on heat exchangers on OTEC devices because they can interfere with the transfer of heat, reducing efficiency. [14] As with corrosion resistance, material choice helps with biofouling. Bio-resistant coatings that do not leach toxic chemicals into the surrounding environment, which had previously been a concern, have been recently formulated. [15] In all cases, regular maintenance is the key.

Offshore wind is an unsurprising vanguard in the field of ocean-based generation because much of the technology matured on land before moving to the ocean for its long uninterrupted fetch and cheap real estate. Ocean energy conversion does not enjoy the benefit of starting on the shoulders of land-based technology like offshore wind. However, looking to technologies that adapted wind from a landlocked capability to an offshore one can solve many of the general-case challenges ocean energy conversion faces. Inexpensive underwater transmission infrastructure is one. Another is operation, maintenance techniques and equipment that can quickly, cheaply and safely service deployed installations.

In some sense, engineering challenges are easier to tackle than social and environmental challenges. As a shared resource, the sea is utilized by energy interests, militaries, fishermen, merchant shipping and tourists. Energy installations can affect visibility above the sea surface and acoustic behavior below. If not charted, floating devices can damage (or be damaged by) vessels, and anchored devices can be destroyed by trawling or dredging. In many cases, the very coastal features that make tidal estuaries attractive for energy extraction also make them attractive for shipping lanes, creating a sharp spatial conflict.

It is ironic that the environmental motivation for pursuing ocean energy extraction butts against the conflicting environmental motivation of keeping the sea unblemished by machinery.

It is ironic that the environmental motivation for pursuing ocean energy extraction butts against the conflicting environmental motivation of keeping the sea unblemished by machinery. Aesthetic impacts are a matter of social preference, mirroring the debate over whether wind turbines are elegant landmarks of towering white or intrusive eyesores of industrial sprawl. While effects to native fauna are objective concerns, artificial noise emitted from devices is a potential concern to animal navigation or communication, but these effects are not yet well understood. The potential for mechanical

Verdant testing its tidal energy device in New York's East River. (Photo courtesy of Verdant Power/Released)

movement of turbine blades to wound or kill fish has been studied for certain classes of turbines and fish. Because of the primarily low speed and cross-sectional profile at which hydrokinetic turbines typically operate, fish damage was determined to be a small concern in one flume-based study. [16] However, new studies must continually be conducted as turbine designs evolve.

Despite the challenges associated with ocean energy conversion, the ocean's sheer capacity for energy capture indicates that all of these engineering and social challenges are worth solving. Ocean energy conversion has been deemed cost competitive in some situations, even at its early stage of technology readiness and dilute energy density. A very recent study shows that in the Pacific Northwest, wave energy conversion already tops wind energy for expected cost -competitiveness within the local balancing authority. [17]

As an interesting side note, ocean energy conversion is in a particularly intriguing position with respect to climate change. On the one hand, it works to reduce carbon emissions by offsetting fossil fuel combustion, but ocean energy conversion is also well-positioned to enjoy the benefits of a higher mean global temperature. Warmer waters could enable higher thermal extraction potential, and higher offshore storm frequency could allow for more wave generation.

There is no doubt, after surveying the diversity of technical approaches being pursued, these are exciting times for wave, current and ocean thermal energy conversion. In accordance with the "all options on the table" approach to sustainably meeting the world's energy needs, the field of ocean energy conversion by itself represents a diverse set of options in renewable energy generation.

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The Powerbuoy. The next generation of renewable energy technologies floats three-fourths of a mile off the north east coast of Oahu, Hawaii. Ocean Power Technologies Inc., in conjunction with Marine Corps Base Hawaii, is testing renewable energy sources for the Marine base. (U.S. Marine Corps photo by Cpl. Jody Lee Smith/Released)

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Chris Doran supports the HDIAC on behalf of Northrop Grumman Corporation to contribute subject matter expertise for Alternative Energy. He earned a Bachelor of Science in electrical engineering and a Master of Science in nanoelectronics with a focus on energy materials from the University of California, San Diego. His background includes laboratory research in nanoelectronics and flexible photovoltaics, as well as systems engineering for electric utility and defense industries.

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U.S. National Biosurveillance: An Integrated Enterprise

T. Karpetsky

Biosurveillance: Threat, purposes and requirements

Since the 1970s, newly emerging diseases have been identified at a rate of one or more per year. Further, terrorism experts warn that both terrorists and nations seek to obtain biological weapons. [1,2] The National Strategy for Countering Biological Threats notes: (i) risk is evolving in unpredictable ways; (ii) advances in enabling technologies will continue to be globally available and (iii) the ability to exploit such advances will become increasingly accessible to those with ill intent as the technical expertise and monetary cost barriers decline. [3] Finally, the nation's food and agriculture systems face threats from natural and intentional origin. These threats could have devastating consequences in terms of both health and economic loss. [2,4]

Biosurveillance is performed for two major reasons: to reduce the time it takes to recognize and characterize biological events with potentially catastrophic consequences and to provide situational awareness (i.e., information that signals an event might be occurring, what those signals mean, and how events will likely unfold in the near future). [2] It enables better decision making by gathering, integrating, interpreting and communicating essential information to achieve early detection and warning. [5] Biosurveillance spans boundaries between surveillance for public health threats, protection and monitoring and bioterrorism. Accordingly, traditional demarcations are increasingly fading among public health, animal health, ecological health and biosecurity and bioterrorism defense surveillance capabilities. [6]

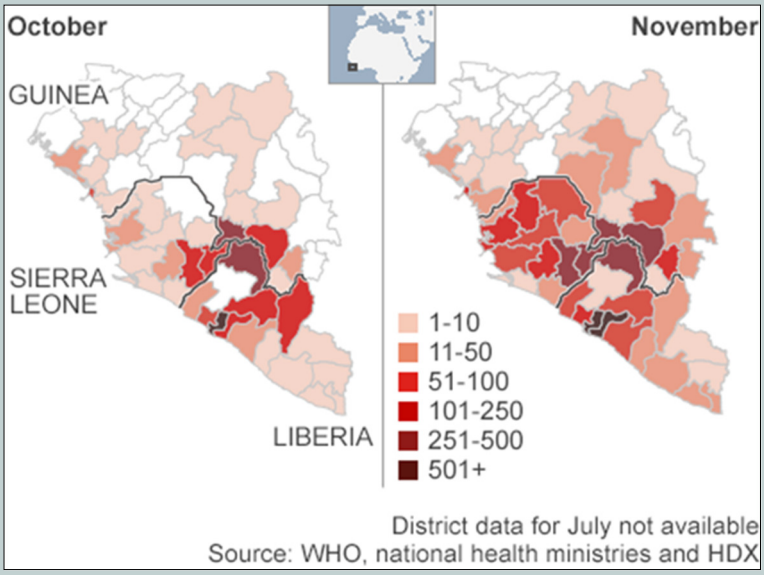

Figure 1. Biosurveillance showing an increase in Ebola cases reported in West African areas from October to November 2014. (Released)

The backbone of biosurveillance is comprised of traditional disease surveillance systems, which help professionals recognize unusual disease signals and analyze their meaning. These systems generally have inherent limitations that affect the speed at which results can be determined, communicated and acted upon. Numerous federal, state, local and private sector entities with responsibility for monitoring plant, animal and human health, food and the environment have roles to play both in supporting traditional surveillance activities and in designing systems to focus specifically on enhancing detection and situational awareness. Because of the array of activities and entities associated with effective biosurveillance, ongoing interagency, international, and intergovernmental collaboration is crucial. [2]

The national biosurveillance strategy

The National Strategy for Biosurveillance is based on four core functions: [5]

- **Scan and discern the environment**: Rapidly evaluate information to speed incident detection, confirm conditions and identify the emergence of new patterns or trends while assessing their significance.
- **Identify and integrate essential information**: Derive, integrate and share useful and essential information and speed up incident awareness. Detect the earliest signs of potential health threats, focus biosurveillance activities on the characterization and validation of the identified threat, track the threat and provide ongoing awareness.
- **Inform and alert decision makers**: Rapidly inform decision makers of potential incidents of national significance and provide early warning and updates throughout an emerging incident.
- **Forecast/advise of potential impacts**: Inspire new thinking and methodologies to forecast. Forecast the probable trajectory, duration and magnitude of the incident into the future, enabling rapid response to save lives and prevent negative economic consequences, even amidst great uncertainty and ambiguity.

The strategy identifies four enablers for strengthening biosurveillance:

- **Integrate capabilities**: Establish regional information sharing arrangements combining human, animal and plant health trends. Transcend regular boundaries and traditional organizational lines. Consider social media as a force multiplier that can empower individuals and communities to provide early warning and global situational awareness.
- **Build capacity**: Use point-of-care and multipathogen diagnostics, law enforcement, intelligence and other information collection/sharing activities. For example, the

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Disease	Potential to Generate Acutely Disruptive Event?	Probability of Actually Generating Acutely Disruptive Event	Time Frame of Risk: Short Term (now-30 days)	Time Frame of Risk: Intermediate Term (within the next 3 mos)	Time Frame of Risk: Long Term (within 12 mos)	Biosurveillance Operational Posture
AIDS	No	Zero				Not monitoring
Anthrax	Yes	Low	X	X	X	Monitoring closely
Cholera	Yes	Low		X	X	Monitoring
Dengue	Yes	Moderate		X	X	Monitoring closely
Diarrheal Disease	Yes	High	X	X	X	Monitoring closely
Diphtheria	Yes	Low-Moderate	X	X	X	Monitoring
Influenza	Yes	Moderate	X	X	X	Monitoring closely
Leptospirosis	Yes	Low-Moderate		X	X	Monitoring
Malaria	No	Zero				Monitoring
Measles	Yes	Low	X	X	X	Monitoring
Rabies	Yes	Low	X	X	X	Monitoring
Tuberculosis	No	Zero				Not monitoring
Typhoid	Yes	Low	X	X	X	Monitoring

Figure 2. Example of biosurveillance operational posture in Haiti post-earthquake, relative to risk and timing of acute disruptive events. (Released)

Global Biosurveillance Technology Initiative Exemplar laboratory located at Edgewood Chemical Biological Center will serve as a resource for many stakeholders as a test bed for component, reagent and bioinformatics upgrades. [7]

- **Foster innovation**: Identify capabilities to facilitate biosurveillance activities. Create distributed networks and empower individuals to enhance the value of biosurveillance information. Encourage new thinking and methodologies to forecast likely incidents, food-borne illness, environmental disasters and outbreak trajectories in the absence of definitive data.
- **Strengthen partnerships**: Pursue biosurveillance activities that promote the sharing of information between/among federal, state, local and other national enterprise participants. For example, the National Association of City and Community Health Organizations supports local biosurveillance efforts by sharing critical information regarding systems, practices and resources that will enhance the local health department's ability to detect and prevent the spread of disease in an effective and timely manner. [8] Successful partnering was demonstrated in the Early Alerting and Reporting project that interfaced a biosurveillance portal and an international network of institutional analysts working with a common standard operating procedure and risk assessment tools to constantly screen and assess public information on the web for events that could suggest an intentional release of biological agents. [9]

The National Biosurveillance Integration Center

The National Biosurveillance Integration Center, chartered by the recommendations of the 9/11 Commission Act of 2007 and housed in the Department of Homeland Security, responds to the requirements of Homeland Security Presidential Directives 9, 10 and 21. [2] The center implements the core functions discussed above and oversees the development and operation of the National Biosurveillance Integration System. The system promotes collaboration among federal partners and state stakeholders for the collection, analysis and sharing of human, animal, plant, food and environmental biosurveillance information with the center. [10,11]

For example, BioWatch is a federally-managed, locally-operated, nationwide biosurveillance system designed to detect the intentional release of aerosolized biological agents and act as an interface for state and local public health and responder communities to jointly respond to a bioterrorism event. The BioWatch system collects air samples in more than 30 cities, and a network of local, state and federal laboratories analyze samples on a daily basis to provide warnings within 12 to 36 hours of an agent's

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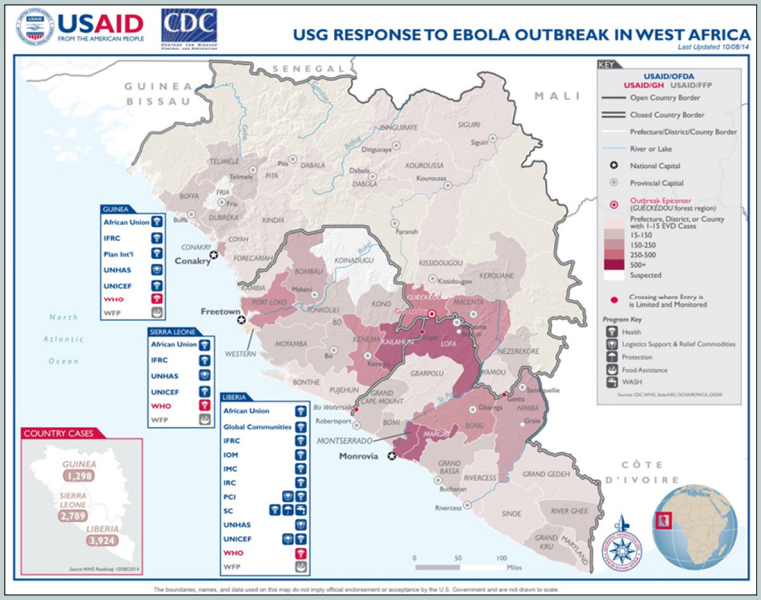

Figure 3. Biosurveillance provides a focus for U.S. aid during the Ebola outbreak in West Africa. (Released)

release for possible biological attacks. BioWatch has operated continuously for more than 10 years. The program began exploring technologies to reduce false positives and detection and response times in a cost-effective manner. This would involve an autonomous detector, a "lab-in-a-box," where the sampling and analysis processes would take place within the device, generating results as soon as four to six hours after the release of a biological agent. However, it was concluded the system would not meet objectives at a reasonable cost, and the acquisition was cancelled. [12]

The DoD Biosurveillance Enterprise

The Department of Defense Biosurveillance Enterprise undertakes a variety of biosurveillance activities in the United States and internationally. It also supports collaborative surveillance with foreign governments in countries and regions of interest for the countries' own situational awareness and reporting. DoD, the U.S. government and international policy makers and responders are the consumers of information produced by the DoD Biosurveillance Enterprise. [13, 14]

Since emerging infectious diseases became part of the chemical and biological defense mission, the Defense Threat Reduction Agency has advanced its biosurveillance capabilities. [15] On June 13, 2013, the deputy secretary of defense issued Interim Guidance for Implementing the National Strategy for Biosurveillance. [16] It provides guidance "to improve the integration, synchronization, and coordination of biosurveillance-related activities in support of national and DoD priorities." This involves collecting, integrating and analyzing data and reporting information produced by DoD biosurveillance-related activities supporting requirements identified by military departments and combatant commands. The biosurveillance-related data is then available for integration at the tactical, operational and strategic levels.

DoD has several programs involving global biosurveillance, including the Global Emerging Infections Surveillance and Response System, a division of the Armed Forces Health Surveillance Center. [17] GEIS embraces 33 partners, including military laboratories, academic institutions and non-governmental organizations around the world, that support service members and population-based surveillance and capacity building in 62 countries. [18] AFHSC-GEIS goals are to: (i) conduct surveillance and outbreak response activities, (ii) improve the capacity of partner countries to perform disease surveillance, (iii) support research initiatives that will result in new capabilities in support of force health protection and (iv) assess and communicate through its worldwide network. [19] AFHSC is collaborating with the Johns Hopkins University Applied Physics Laboratory to create the Suite for Automated Global Electronic Biosurveillance, a collection of modular, flexible, open source software tools for electronic disease surveillance. [20] Also, a team of scientists from the Applied Physics Laboratory has developed a novel capability to predict the outbreak of infectious diseases, known as PRISM, Predicting Infectious Disease Scalable Model, which extracts relationships among clinical, meteorological, climatic and socio-political data. Outputs from the model predict disease incidence in regions of interest, enhancing awareness and providing critical lead times for preemptive public health actions. [21]

A recent RAND report examined biosurveillance efforts from the viewpoint of a logic model that flows from inputs (enabling functions and funding) to processes (biosurveillance systems and assets), outputs (reports and alerts), outcomes (desired outcomes from biosurveillance) and impacts (strategic missions served). [13] DoD's biosurveillance efforts support several outcomes: early warning of threats and early detection of events; situational awareness; decision making at all levels, including acute response, policy and research and development; and forecasting impacts.

The inter-agency Biosurveillance Science and Technology Working Group

The inter-agency Biosurveillance Science and Technology Working Group develops national biosurveillance research and development priorities to enable the core functions of the National Strategy for Biosurveillance. It also addresses deficiencies noted in a report of the National Biosurveillance Advisory Subcommittee. [22] In four separate but interrelated areas, specific capability needs were identified as follows: [23]

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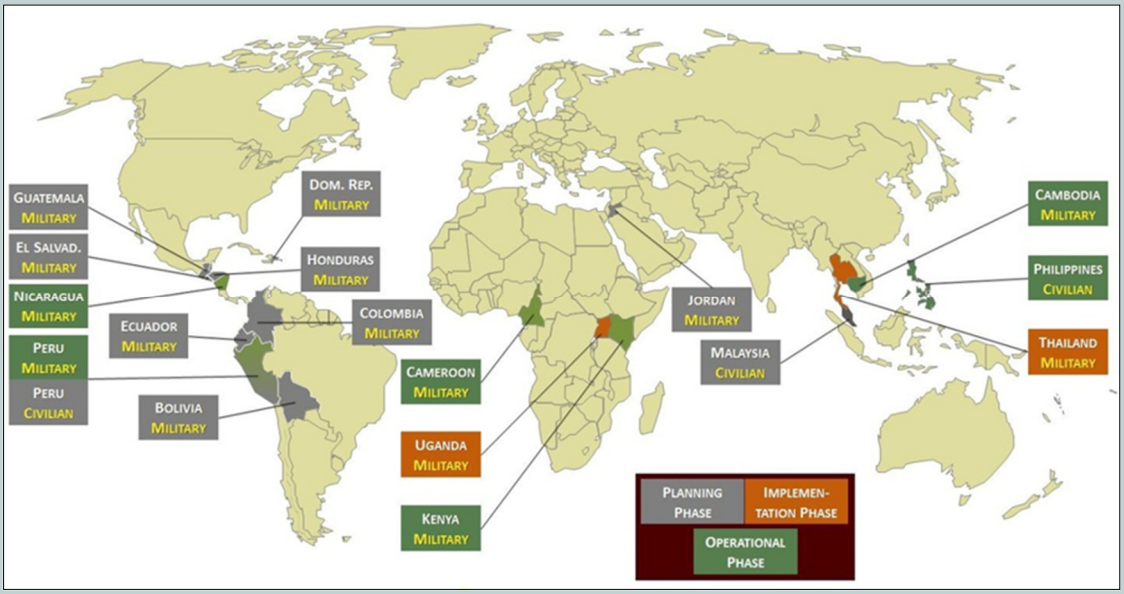

Figure 4: Promotion of emerging infectious disease outbreak surveillance and response capacity. In consultation and coordination with the Johns Hopkins University Applied Physics Laboratory, electronic disease surveillance systems have been piloted and fully implemented by many host nation civilian and military health authorities in the past three years. (Released)

Aberration detection

- Surveillance methodologies that integrate traditional monitoring (pathogen, environmental and health) with background data (meteorological and population dynamics) that may influence risk;
- Ability to detect early warning signs of changes occurring at different and changing spatial and temporal scales; and
- Advancements in data sharing and integration and communication technologies including assessment methods and education and training to meet anticipated needs for biosurveillance professionals.

Risk anticipation

- Understanding the antecedent conditions at appropriate spatial and temporal scales; and
- Ability to forecast the dynamics of novel disease emergence or exploitation of biological agents by adversaries.

Threat identification and characterization

- Improving the sensitivity, specificity and portability of multiplexed technologies capable of identifying, with confidence, known and unknown threats in complex samples;
- Improved sample collection, preservation, transport, preparation technologies and protocols, standards for testing, evaluation of detection tools and validated testing and evaluation protocols;
- Improved diagnostic technologies and access to signatures, reagents, strains, sequence data, informatics and computational capabilities; and
- Improved surveillance techniques, data sharing and interoperability for plants, animals and food.

Information sharing, integration and analysis

- Aggregate analyzed health data from different health sources, syndromic surveillance systems and sectors to detect aberrations/discover spatial and temporal disease trends;
- Determine what data/information sources are relevant to biosurveillance;
- Sustained and appropriate multilateral information sharing.
- Integration of all existing and emerging biosurveillance efforts and cross-domain information sources into a coherent biosurveillance enterprise; and
- Standardized methods for determining the uncertainty in biosurveillance data and clearly communicating the limits of the data and analytical techniques. [23]

The integrated biosurveillance enterprise called for in the strategy will require collaboration and coordination across federal organizations, academia, industry and the international community. An example of this is the support the DoD Rapid Reaction Technology Office provides to DHS and Department of Health and Human Services by looking for emerging technologies to increase the nation's preparedness against chemical, biological and agricultural threats in several specific areas: [24]

- **Real time, indoor and outdoor environmental sensing:** Chemical and biological threat detection and characterization; wearable and handheld sensors; trigger sensors.
- **Data analytics:** Predictive modeling in behavioral responses; indirect detection of chemical/biological events; decision

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support and planning; social media monitoring; real-time collaboration; unstructured data capture; structured data visualization.

- **Internet of things:** Personnel tagging, tracking and locating; wearable personal sensors; ad hoc networking.
- **Information technology and communications:** Personally identifiable information protection; public alerting and warning; integrated and interoperable communications; virtual network management, modeling and simulation.

Biosurveillance exercises

Large-scale biosurveillance exercises are in progress or have been completed. Typically, these involve inter-agency collaboration or cooperation and some involve international partners. For example, DoD and South Korea ran the Able Response Exercise in May 2011 and May 2012. "This is a whole-of-government to whole-of-government tabletop exercise focused on a biological incident, not during a conventional war but some type of a covert release that could have a major impact on the civilian population … but also on our 28,000 forces deployed on the peninsula." [25]

The Joint USFK Portal and Integrated Threat Recognition program uses new instrumentation that increases the speed and ease of biosurveillance equipment for the United States Forces Korea. [26] It comes at a lower cost with less training/burden to the soldier but higher performance results.

JUPITR combines advanced communications with cutting-edge detection capabilities for rapid and efficient biosurveillance. The program is comprised of four legs: (i) an information portal, similar to a health surveillance web management tool, housing a library of identified biological substances that authorized personnel can access; (ii) Edgewood Chemical Biological Center researchers going to Korea to improve USFK laboratory capabilities; (iii) testing biological detectors and sending the best one to Korea and (iv) Integrated Base Defense: a large multifunctional, all seeing sensor that can rapidly design a defensive perimeter.

JUPITR will fuse the capability of the networked suite of force protection sensors (radars, cameras, acoustic sensors, met sensors, etc.) with proven chemical/biological standoff and point sensors to demonstrate early warning. [27] The Distance Detection Devices, or D3 program, are a part of the JUPITR Advanced Technology Demonstration. The goal is to provide the most effective handheld biological detectors needed for a given mission. The D3 component is part of a multi-year effort designed to introduce warfighters to new, inexpensive, rapid and easy to operate chemical and biological detection technologies. It also integrates equipment to form a complete system that can automate and correlate data for improved detection insights. For example, Edgewood Chemical Biological Center scientists have designed and produced a more efficient and

Figure 5. The Joint USFK Portal and Integrated Threat Recognition will provide unique biological detection capabilities and stronger biosurveillance capabilities. (Released)

lower cost detector known as the TAC-BIO Gen II. This next generation tactical biological detector costs 80 percent less and is three times lighter than its predecessor. This new design captures the performance and cost advantages associated with plastic parts and uses an energy efficient power source. TAC-BIO Gen II exploits the fact that biological aerosols fluoresce and scatter light when exposed to ultraviolet light. These signals can be used to detect a threat by using a light-emitting diode developed under the Defense Advanced Research Projects Agency that replaces the larger and more costly ultraviolet lasers used previously. Further, lower costs enable multiple detectors to be set out, resulting in fewer false positives for biological detection, and ensuring that users can make accurate and fast decisions based on the detector results. [28,29]

Conclusions

Biosurveillance is key for detecting and limiting the consequences of a natural or man-made biological event, and its importance is recognized in national policy directives. Biosurveillance is intended to provide real-time information to decision makers regarding specifics on the type of biological material and location as a function of immediate and future time. Mounting a global biosurveillance capability is not a simple or inexpensive task. It involves a multitude of different technologies and capabilities that can rapidly detect targeted biological materials within defined temporal and spatial domains. This allows a clear understanding of the scope of the threat and its likely spread in the future. Data from many different sources and their fusion into a coherent useful present and future picture, with defined risk, are keys to useful and predictive biosurveillance. Capability gaps are being recognized, and solutions are being worked on/implemented. This must be a collaborative effort involving international, national, state, local and other partners that form the biosurveillance enterprise to allow for early, rapid and appropriate responses, limiting consequences.

U.S. National Biosurveillance—continued

T. Karpetsky

About the Author:

Timothy Karpetsky, Ph.D., has more than 40 years hands-on experience with CBRNE materials. He has conceived, developed and produced diverse equipment for the detection, identification of, and surveillance for such materials. Over this time, he has worked for and with the U.S. government and private companies, including heading a detection innovation skunk works. Originator of 14 published patents, he has written many technical papers, including readiness assessments for manufacturing CBRNE defense equipment.

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Death by Technology: The Need for Law to Mitigate Risk

C. Richardson

Barnaby Jack was a brilliant New Zealand grey hat hacker, a subclass of ethical hackers. "In general terms, ethical hackers are authorized to break into supposedly 'secure' computer systems without malicious intent, but with the aim of discovering vulnerabilities in order to bring about improved protection." [1] Jack was not typically authorized to hack the systems he infiltrated, but he informed the companies he hacked about his knowledge of the software vulnerabilities and made them more secure. Jack demonstrated his ability to control an insulin pump using radio waves to distribute a lethal dose of insulin. Jack's next trick was to show the hacker community he could "hack into a wireless communications system that linked implanted pacemakers and defibrillators with bedside monitors that gather information about their operations." [2] By gaining access to the system, Jack could control what the machine told the pacemaker or defibrillator to do with potentially lethal consequences. [2] A couple weeks before he was to present his findings about how to hack a pacemaker and cardiac defibrillator at the 2013 Black Hat Conference, an annual hacker convention, Jack died from an accidental drug overdose. His work, however, started the discussion on the security of implanted medical devices.

Pacemakers are known to be vulnerable to electronic magnetic pulses. Although standard electromagnetic fields, such as metal detectors, usually have no effect on pacemakers, an intentional electronic magnetic pulse attack is fairly simple to carry out. Other implanted cardiac defibrillators and insulin pumps are vulnerable to hacking with the potential for fatal consequences as well. The holy trinity of technical security is confidentiality, integrity and availability. In biomedical devices, a compromise in integrity and/or availability can cause the device to be unpredictable or a patient to be misdiagnosed, resulting in injury or death. The Food and Drug Administration suggests manufactures take pertinent measures to ensure their devices are hardened against cyberattack.

"In general terms, ethical hackers are authorized to break into supposedly 'secure' computer systems without malicious intent, but with the aim of discovering vulnerabilities in order to bring about improved protection."

The FDA audits unintentional threats of cardiac defibrillators and insulin pumps, but does not reprimand manufactures when vulnerabilities are exploited in their devices via cyberattacks that could endanger the patient or compromise patient data. As networked biomedical devices become more commonplace, it is critical that the government develop and enforce security standards to reduce the risk of cybersecurity vulnerabilities in these devices. Should security standards for implanted medical devices have legal ramifications to ensure medical manufactures follow security best practices? If the government does not enforce security in today's implanted medical devices, the situation could worsen with future advanced technology.

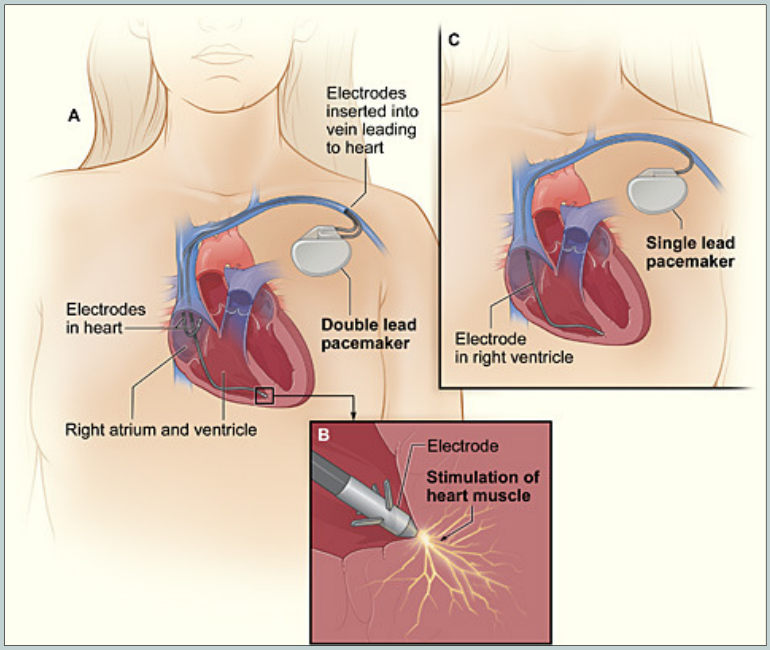

Figure 1. The image shows a cross-section of a chest with a pacemaker. Image A shows the location and general size of a double-lead, or dual-chamber, pacemaker in the upper chest. The wires with electrodes are inserted into the heart's right atrium and ventricle through a vein in the upper chest. Image B shows an electrode electrically stimulating the heart muscle. Image C shows the location and general size of a single-lead, or single-chamber, pacemaker in the upper chest. (Released)

Weak standards

July 14, 2013 (11 days before the death of Barnaby Jack), the FDA admitted:

"The need for effective cyber security to assure medical device functionality has become more important with the increasing use of wireless Internet- and network-connected devices and the frequent electronic exchange of medical device-related health information. Failure to maintain cyber security can result in compromised device

Death by Technology—continued

C. Richardson

The Revo MRI SureScan Pacing System delivers standard pacing therapy to patients with slow heart rates. This particular pacemaker permits patients meeting certain criteria to receive MRI scan. (Courtesy of the U.S. FDA/ Released)

functionality, loss of data availability or integrity or exposure of other connected devices or networks to security threats. These, in turn, have the potential to result in patient illness, injury or death." [3]

As of February 2015, the FDA has only released recommendations, not requirements, for implanted medical device security. The FDA says the recommendations "can help provide reasonable assurance of safety and effectiveness for medical devices that incorporate radio frequency wireless technology." [3] Reasonable is undefined. The FDA does define "should" as "something suggested or recommended, but not required." [3] Should comes up in sentences such as "issues relating to the integrity of the data transmitted wirelessly and safety-related requirements of your device should be considered." [3]

In 1990, Congress passed the Safe Medical Device Act. This act makes it mandatory that facilities and manufactures report problems with medical devices. The Act has been revised several times, and in some respects, the latest revision seems to give medical manufactures more leeway. The changes made in the 1998 revision are as follows:

"Manufacturers and distributors/importers do not need to submit annual certification.

Domestic distributors are no longer required to file [Medical Device Reporting] reports, but must continue to maintain complaint files. [Importers (initial distributors for devices manufactured overseas and imported into the USA) must continue to file MDR reports.]

User facilities must now file an annual report instead of semiannual reports to summarize their adverse event reports." [4]

The highest civil penalty for violating this act is $1 million, and there are no criminal penalties in place. The act has not been updated to specifically cover cybersecurity issues.

International Organization for Standardization 14971 does address risk management for medical devices. The standard makes determining, defining and announcing the risk a manufacture obligation. However, there is no penalty for not meeting these standards. Companies can be ISO certified, which means they proved they met the standard. Once companies are certified, they become more attractive as a business partner or vendor. Hospitals are not required to work with only certified medical manufactures. In most cases, insurance companies determine the medical device that will be covered for patient use.

International Electrotechnical Commission 60601-1-2 standard states electronic medical devices should be accompanied by a usability document. This should ensure users are using the product correctly, but adding security best practices is not part of this standard. Jay Radcliff recalls changing the battery in his implanted insulin pump one night before bed and nearly dying because he did not read the sentence on page 147 of 300 of his user manual which stated changing the battery would change user settings. [5] The company's response was "It's in the manual," and the FDA did not take an actionable response either.

It is important to note that many of these standards are not freely available to the public. To view International Electrotechnical Commission Technical Report 80001-2-3, for example, it costs around $239.48, and to view ISO 14708 costs about $185. These, and other, standards are issued by private organizations. These organizations help guide the industry so consumers can expect the same level of service nationally and internationally. Companies benefit following these standards when trading or collaborating with other companies. While these standards have commendable intentions, they cannot now, or ever be, legally enforced because the standard comes from a privately owned entity.

Issues, suggested standards and law

Securing implanted medical devices is a very challenging task due to their very limiting resource constraints in terms of energy supply, processing power and storage space. Adding any security application to the device may drain the battery. Unlike general medical sensors that may use AA-type of renewable batteries, an IMD typically uses silver vanadium oxide batteries. [6]

These batteries are vulnerable to resource depletion due to extra code, and changing the battery inside an IMD requires surgery.

Another unique problem with wireless security in implanted medical devices is the need for emergency access. For machines like laptops

Death by Technology—continued

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When dealing with implanted medical devices, a doctor or first responder may need to access the device to save a life, leading to the possibility of encryption and passwords stopping critical access.

and cell phones, there is no life or death situation for emergency access. When dealing with IMDs, a doctor or first responder may need to access the device to save a life, leading to the possibility of encryption and passwords stopping critical access. Common practice security measures, such as passwords, to encrypt traffic to and from these devices cannot be used in this situation.

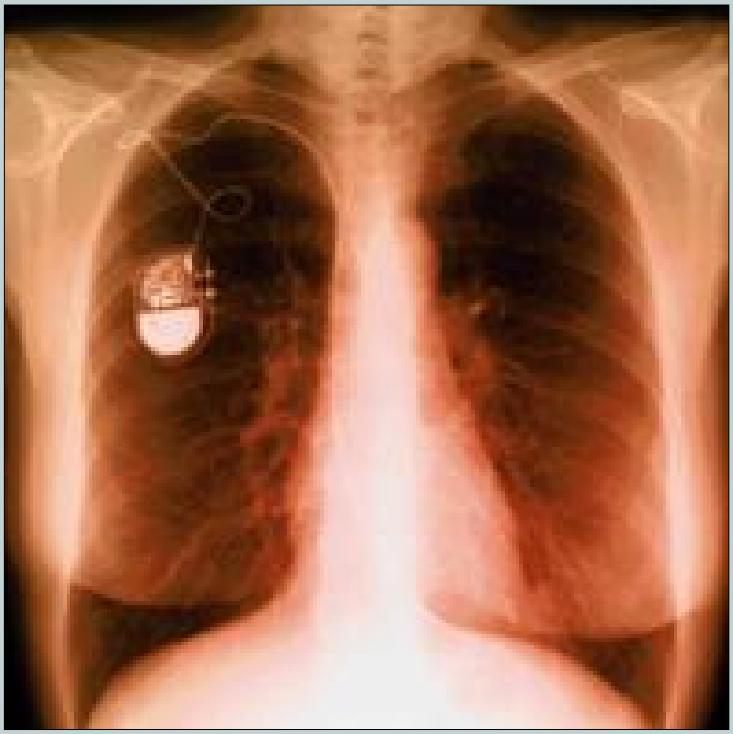
One possible solution to this security issue is to moderate access based on distance. If an external device, such as a bracelet the user wears, is nearby, the device will not accept incoming commands. When the device is not within a couple meters of the patient, the IMD will accept incoming commands. Emergency responders would then have access to the IMD during an emergency when the external device is not sensed. The user will wear the bracelet daily to protect the IMD from attacks. During an emergency, the doctor can remove the bracelet and have full access to the device. The idea was created by researchers, Tamara Denning, Kevin Fu and Tadayoshi Kohno. The team calls the external device a Communication Cloaker. The concept of a Communication Cloaker solves many of the unique issues with IMD security, "safety and open access in emergencies, security and privacy under adversarial conditions, battery life and response time" [7]

An additional issue with IMD security is upgrading the current hardware already in use. In many cases, access to current medical devices means surgery or risky operations. Security standards must be made, not only for future devices, but also for devices already in use. Shyamnath Gollakota, Haitham Hassanieh, Benjamin Ransford, Dina Katabi and Kevin Fu created a shield that can provide IMD security for current medical devices by using "a novel radio design that can act as a jammer-cum-receiver. This design allows it to jam the implanted medical device's messages, preventing others from decoding them while being able to decode them itself." [8] The shield is similar to the Communication Cloaker, but it works on radio frequencies that are currently used.

In any crime, forensic evidence must be collected to bring the perpetrator to justice. When dealing with cybersecurity, the only way to investigate a crime is to use reverse engineering. Security analysts use audit trails to piece together what happened during a cybersecurity incident. IMDs should also contain audit trails so the culprit can be captured in case of a breech. IMD storage does not contain the space needed to keep archived data of audit trails. An external device, such as a cell phone or wearable technology, could be used to complete this function.

Conclusion

Security should not slow the progression of technology, only complement its use. Without fail, an insecure system will yield unpredictable results, no matter the intent of the creator. Healthcare technology should not be unpredictable. These devices should allow patients to feel more secure. Strict laws with repercussions for manufactures in the case of security neglect and standards that focus on cybersecurity issues need to be implemented for networked implanted medical devices today to protect the patients of tomorrow.



Chest X-Ray with implanted pacemaker device. (Courtesy of the U.S. FDA/Released).

Death by Technology—continued

C. Richardson

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Celeste Richardson began her career and education as a cybersecurity analyst with a Bachelor of Science in computer science from Hampton University. She obtained her master's degree in Healthcare Informatics from Northeastern University. Richardson has a passion for being on the forefront of emerging cybersecurity issues and enjoys all phases of the cyberincident management process. She is pursuing of her doctorate in emergency management from Jacksonville State University and works for the Federal Emergency Management Agency in a security role.

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Cultural Studies

Unresolved Questions of Cultural Awareness and Sensitivity Regarding the Development and Use of Nanotechnology in Medical Applications

G. Nichols

In his seminal work, "Democracy in America," Alexis de Tocqueville warned against "the tyranny of the majority" – the idea that decisions would be made by a majority who placed their interests above those of individuals or minority groups. While this term usually refers to political decisions, the principle can be applied to a number of scenarios in which a ruling group makes decisions that must be followed by the non-majority. These types of decisions often occur in medicine as a physician typically recommends a course of treatment based on his training and the published advice of experts. The modern practice of medicine is keenly focused on administering treatment based on scientific evidence. While heralded as the gold standard, scientific practice often overlooks other important deciding factors in a patient's care, such as religion, ethnicity and cultural knowledge. The debate on vaccination is a signature example of the conflict between science and belief, and another emerging debate could involve the use of nanotechnology in medical applications, often termed nanomedicine.

Nanotechnology is the manipulation of matter on an atomic scale, typically the creation and use of materials between one and 100 nanometers. These materials are referred to as engineered nanomaterials. The concept was first introduced in 1959 by the famed physicist and Nobel Laureate Richard Feynman during a lecture he gave at the California Institute of Technology titled "There's Plenty of Room at the Bottom." Although the word nanotechnology was never used, his speech laid the groundwork for what would become another technological revolution. In this speech, Feynman declared, "It would be interesting in surgery if you could swallow the surgeon. You put the mechanical surgeon inside the blood vessel, and it goes into the heart and 'looks' around. It finds out which valve is the faulty one and takes a little knife and slices it out. Other small machines might be permanently incorporated in the body to assist some inadequately-functioning organ." [1]

Medical applications of nanotechnology span a range of possibilities, but they generally fall into four categories:

- Diagnostics and imaging;
- Pharmaceutical and drug-delivery systems;
- Regenerative medicine/tissue engineering/surgery; and
- Implantable devices

While the scope of this article is to explore the nature of cultural awareness regarding nanomedicine, it is important to note the ongoing debate as to what constitutes a nanotechnology-related product for medical use and how it should be regulated. The lack of clarity on these issues will only further complicate explaining, using and competently practicing nanomedicine in the near future. A primary concern with engineered nanomaterials is their potential to cause health problems under certain circumstances. The same

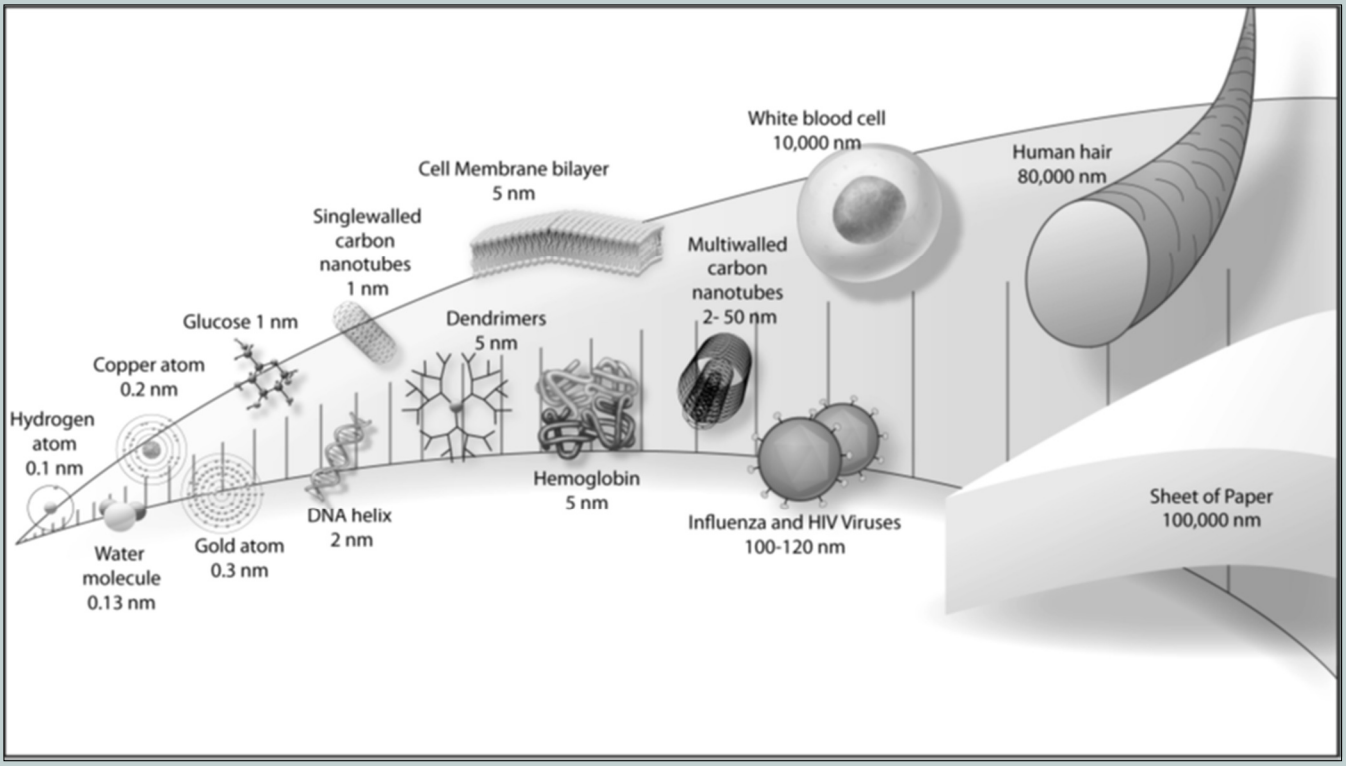

Figure 1: Comparison of nanoscale materials with common objects. [16] (Released)

Nanotechnology in Medical Applications—continued

G. Nichols

properties that make engineered nanomaterials so useful (shape, size and reactivity) can also make them dangerous.

It is unclear how devices and products composed of nanomaterials might affect human tissue once placed in the body. Forty-three nanopharmaceuticals are available in the global market, and countless other nano-products are being developed. [2] Although the European Commission recently issued guidance on the potential health effects of nanomaterials in medical devices, [3] the U.S. Food and Drug Administration, the U.S. government agency responsible for the approval and regulation of medical devices and pharmaceuticals, said in 2008 it did not see the need to have specific regulations for nano-engineered materials. [4] Last year, the FDA issued guidance on the use of nanotechnology in the products it regulates. While the FDA reiterated it has not developed a regulatory definition of nanotechnology, it did issue points for consideration; however, these were purely scientific in nature: [5]

1. Whether a material or end product is engineered to have at least one external dimension, or an internal or surface structure, in the nanoscale range (approximately one nm to 100 nm)
2. Whether a material or end product is engineered to exhibit properties or phenomena, including physical or chemical properties or biological effects that are attributable to its dimension(s), even if these dimensions fall outside the nanoscale range, up to one micrometer (1,000 nm)

Nanomaterials have become ubiquitous in society, and their use will rapidly increase. The United States is one of the leaders in nanotechnology research. However, the general lack of knowledge most patients have regarding nanotechnology is a prime issue. An even greater issue and challenge is how to understand, explain, respect and manage personal belief systems and normative values in regards to medical treatment pertaining to nanotechnology. Nanotechnology is a difficult concept to explain to the average person, and the United States is a pluralistic society in terms of its cultural makeup. This makeup will make addressing nanotechnology, while also being mindful of language barriers and cultural and religious values, in medical care difficult.

Culture is the shared language, beliefs, values, norms, behaviors and material objects that are passed from one generation to the next. Race is a group of people with inherited physical characteristics distinguishing them from another group, and ethnicity refers to people who identify with one another on the basis of common ancestry and cultural heritage. Although they are often used interchangeably, race and ethnicity are different; this is a critical point to remember. A fundamentally important part of most societies is religion, and this is especially true in the United States

Religious Group	Number of Members	% of U.S. Adults
Christian	**176,000,000**	**78.4%**
Protestant	115,000,000	51.3%
Evangelical churches	59,000,000	26.3%
Mainline churches	41,000,000	18.1%
Historical black churches	16,000,000	6.9%
Roman Catholic	54,000,000	23.9%
Mormon	3,800,000	1.7%
Jehovah's Witness	1,600,000	0.7%
Orthodox, Greek, Russian	1,400,000	0.6%
Other Christian	700,000	0.3%
Other Religions	**11,000,000**	**4.7%**
Jewish	3,800,000	1.7%
Reform		0.7%
Conservative		0.5%
Orthodox		<0.3%
Other		0.3%
Buddhist	1,600,000	0.7%
Zen Buddhist		<0.3%
Theravada Buddhist		<0.3%
Tibetan Buddhist		<0.3%
Other		0.3%
Muslim	1,400,000	0.6%
Sunni		0.3%
Shia		<0.3%
Other		<0.3%
Hindu	900,000	0.4%
Other faiths	2,700,000	1.2%
Unitarians and other liberal faiths		0.7%
New Age		0.4%
Native American religions		<0.3%
Unaffiliated	**36,000,000**	**16.1%**
Nothing in particular	27,000,000	12.1%
Secular unaffiliated		6.3%
Religious unaffiliated		5.8%
Agnostic	5,400,000	2.4%
Atheist	3,600,000	1.6%
Don't Know or Refused	**1,800,000**	**0.8%**

Table 1: How U.S. adults identify with religion. [8] (Released)

Nanotechnology in Medical Applications—continued

G. Nichols

where more than 80 percent of the population has some sort of religious affiliation. [Table1]

This has major implications in the practice of medicine, as science and faith often conflict. One of the key figures in modern sociology, Emile Durkheim, described religion as "A unified system of beliefs and practices relative to sacred things…which unite into one single moral community…all those who adhere to them." [6]

A minority group is a group of people who are singled out for unequal treatment and who regard themselves as objects of collective discrimination. Dominance does not necessarily reflect the numerical majority. The dominant group is the one that controls the greatest power and privilege. Though both the Afrikaners in South Africa and the British in colonial India were vastly outnumbered by their constituents, these two groups were clearly dominant for hundreds of years. In the United States, whites comprise nearly 78 percent of the population, [7] and they have historically been the dominant racial group. However, men still hold a significant amount of power and influence even though the gender distribution is roughly equal. In regard to religion, more than 78 percent of the population identifies as Christian, and the clear majority, 51 percent, are Protestant. [8] Except for gender, power is equivalent to numerical superiority in the United States, which is rare in the world. This is reflective of a representative democracy, and a good reason why de Tocqueville and others warned against the tyranny of the majority.

Very little has been published specifically addressing how religions and certain ethnic groups perceive the use of nanotechnology in medical applications. A few studies have addressed general perceptions of nanotechnology and stratified those results by various categories including religion, race and ethnicity. However, very little writing has been specifically aimed at addressing minority views. The majority of the literature either generally addresses religious and ethical views of nanotechnology (or technology in general) or overall cultural competence in the practice of medicine. As nanotechnology is used more frequently in medicine, there will be a need to integrate the concept into cultural training and practice. In 2006, the Commission of the Catholic Bishops' Conference of the European Community released a statement on nanomedicine. The statement presented a fairly scientifically accurate account of nanomedicine and also raised concerns regarding how the use of nanotechnology could lead to abortion or euthanasia. Catholic Doctrine upholds the sanctity of life at all costs, and this is a concern that will most likely need to be addressed considering more than one billion people (16 percent) world-wide practice Catholicism, including 24 percent of the U.S. population. [9] In addition to the specific medical concerns raised by the Catholic Bishops' commission, two other key issues regarding the use of nanotechnology in medicine have raised concerns among religious leaders. The issue of human enhancement is concerning because the development of devices and regenerative techniques could unnaturally produce human beings that are smarter, faster and stronger than the current species. Images of the Six Million Dollar Man, the Bionic Woman and RoboCop come to mind. In particular, this undermines the Christian notion of embodiment, in which human beings are to be comfortable with their imperfect bodies.

In addition, a more philosophical issue lies with the possibility that nanotechnology in medical applications could somehow reengineer humanity and lead to transhumanism, using human technology to accelerate natural processes in evolution, undermining the notion of creation. This would certainly shake the very fabric of most religious beliefs.

Another issue is the potential for the creation of some sort of inhuman creature or monster. In traditional Jewish cautionary tales, this is known as a golem, a creature created for either a destructive or protective purpose, and complete control rests with the creator. In modern society, Frankenstein's monster would be the equivalent. While this aspect of nanomedicine is more mythological and derived from a primal fear of the unknown, the notion must be considered at least for potential violations of ethical codes. Either way, human enhancement or abhorrent creation would clearly violate most religious codes, especially in Western monotheistic religious tradition, as it would put humanity in the creator seat.

Some other religious considerations involve the uniquely American religions: Latter Day Saint Movement, Seventh-day Adventist Church, Christian Science and Jehovah's Witnesses. All of these religions believe in Western medical treatment but with restrictions. For example, Jehovah's Witnesses refuse blood products. It is assumed this belief will also include any future nanomedical use involving blood or blood products. Rastafarians are adamantly opposed to consuming any unnatural products, and while certain nanoparticles, such as carbon nanotubes, are made of commonly occurring natural substances, it is unclear whether there would be prohibitions regarding the unnatural manipulation of natural substances.

Moving past religion, there is a paucity of research regarding ethnic and other cultural views and beliefs regarding nanotechnology, certainly in medical applications, for both minority groups and all peoples and traditions in general. Studies have provided some knowledge on which cultural groups are more aware of nanotechnology versus others, but very few studies have actually looked at specific viewpoints and needs. Considering the lack of available information in this area, most discussions center around what is currently known about typical patient reactions to medical

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practices based on culture and how those reactions might be aggravated by nanotechnology. Historically, African-Americans have been cautious regarding the use of new technologies in clinical settings, especially if the technology is not clearly explained. This is an unfortunate fallout from the "Tuskegee Study of Untreated Syphilis in the Negro Male," a tragic experiment funded by the Public Health Service from 1932 to 1972 in which 399 African-American males with syphilis in the rural South were left untreated, even though there was a well known cure, and followed until their death to study the progression of the disease. [10] While skepticism may still be present, being transparent and clearly explaining the use of nanotechnology and its purpose will be crucial for this group.

Symbolism plays an integral role in the mythos of all cultures. The symbolic perception of engineered nanomaterials themselves raises interesting questions. For example, Korean culture prohibits the presence of white chrysanthemums in hospital rooms because they are only used for funerals. A common type of nanomaterial structure is a nanoflower. Nanoflowers are so named because they are chemical structures that microscopically resemble flowers. The similarity between chrysanthemums and certain nanoflowers is uncanny.

Figure 3: A white chrysanthemum (left) compared with a ZnO nanoflower developed by ultrasonication method (right). (Released)

Explaining the concept of a nanoflower to a Korean-American who might be uncomfortable with a funerary object being placed inside his body is truly a unique situation, and one that most, if not all, providers are unprepared to face. Often overlooked societies include institutions such as the military. Though made up of different multicultural groups, the military has its own distinct culture. A key issue with military medicine is the lack of autonomy that combatants have during the course of war. This is known as enforced treatment. There are certain conditions where enforced treatment is necessary but difficult to understand. During the Persian Gulf War, it was determined that the threat of an attack with a nerve agent was likely imminent, and commanders made the decision to administer pyridostigmine bromide for prophylaxis. [11] Pyridostigmine bromide has side effects, and commanders denied the autonomous taking of it, knowing some soldiers would likely refuse treatment on their own. This is a common practice in the military. The argument is based on a patriarchal foundation that those in charge know best and will make decisions for the greater good, even if that undermines personal choice. Although providers may disagree, they often have less choice than their patients, which does not create an encouraging environment that embraces cultural awareness.

Perhaps one of the least understood uses of nanomedical technologies in military practice is for human performance modification. This would certainly have combat implications since the armed forces could potentially create a Captain America-type figure to fight battles. Many techniques exist that could improve warfighters. In 2012, Nokia filed a patent for a nano-enabled tattoo that would vibrate when a cell-phone is active. Although strange and unique, this could improve communications capabilities on the battlefield. Similar devices could be used on the battlefield as sensors to alert soldiers to the presence of chemical or biological agents. [12]

The use of nanotechnology in medical applications may create scenarios in which new ethical problems, or exaggerated concerns of old problems, must be evaluated with respect to ethical, legal and social aspects. [4] At times, traditional theories of bioethics neglect social and cultural factors. [13] In order to accommodate the introduction of nanotechnology in traditional medical models, the concept must be introduced into the healthcare lexicon. This can be done by infusing the concept of nanotechnology into models of cultural competence. A well-known model of cultural competence in healthcare was developed. This model postulated that becoming culturally competent was a developmental process, and a culturally competent system would consist of five elements: [14]

1. Value diversity;
2. The capacity for cultural self-assessment;
3. Being conscious of the dynamics inherent when cultures interact;
4. Institutionalized cultural knowledge; and
5. Developed adaptations to diversity.

Furthermore, attitudes, policies and practices must be congruent within all levels of the system. This can be achieved by developing and implementing specific plans to incorporate the topic of nanotechnology into current culturally competent practices. Additionally, infusing the issues and basic concepts of nanomedicine into curricula approved by associations responsible for credentialing provider education, such as the Association of American Medical Colleges, would inform future providers entering into practice.

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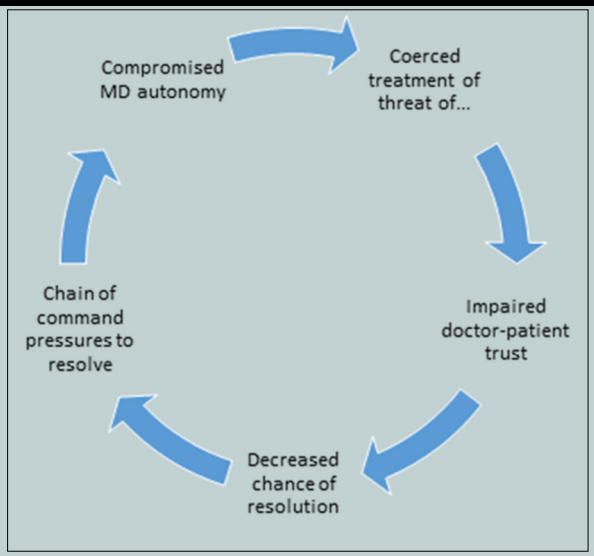

Figure 4: Potential for a spiral of impaired trust in military medicine. (Released) [17]

It is important providers be aware of nanomedicine and how they will communicate this to their patients. Patient education is a critical component to developing trust, and healthcare organizations will need to incorporate explanations for nanotechnology and other emerging technologies into their conversations. It is crucial that healthcare workers of all types avoid ethnocentrism, the act of judging another culture solely by the values and standards of one's own culture. As nanotechnology develops further and becomes pervasive in society, healthcare systems, the military and prisons will need to be familiar with techniques, applications and potential ethical and health issues. Currently, most healthcare systems and facilities in the United States are ill-prepared to accommodate any discussion, let alone the presence of engineered nanomaterials in practice. Feynman warned later in his career that "for a successful technology, reality must take precedence over public relations, for nature cannot be fooled." [15] As nanomedical applications become more prominent, these are certainly wise words to heed.

About the Author:

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ISIL as the Militarized Arm of the Arab Spring: How Crises of Authority Are Clearing the Path to Violence

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Traffic police at work before De-Baathification. Baghdad, June 2003. (Courtesy of Holly Hughson/Released)

Calling itself the Islamic State may one day be known as the greatest propaganda coup the Islamic State in Iraq and Levant achieved. [1] It triggered a legion of debate by media pundits, reinvigorated the Islamophobia industry and transitioned individuals fearful of difference into hardened killers around the world. Misunderstanding ISIL's relationship to religion misdirects the efforts being used to defeat it.

In the name of religion, ISIL exploits three factors in the furtherance of their goal: local power vacuums in Iraq and Syria, regional disillusionment with power surplus in the Middle East and conceptual alienation from power in Western countries. Whether a jihadist deferential to al-Qaeda, Western country deferential to sectarian regimes in Syria and Iraq or families and friends deferential to non-Muslim cultures, ISIL appears strong where others appear weak.

To defeat ISIL and further the cause of stability in the Middle East, the United States must understand ISIL's ideology functions across different lines of identity. Defeating or even degrading the geographical control of ISIL is not sufficient; as long as they have local support, ISIL can hold or retake ground. A viable strategy for victory asks the United States to orient to certain uncomfortable, yet powerful and well-understood dynamics in play that are not easily reversed: Sunni opposition to the systemic abuses of the Shia dominated Iraqi and Syrian regimes and the absence of credible, representative authority generally in the Middle East.

Maj. Gen. Michael Nagata, commander of Special Operations Command Central forces in the Middle East, who is leading the U.S. fight against ISIL, has expressed his frustration in trying to understand the appeal of the complex enemy presented by ISIL. In 2014, he assembled a non-traditional group of experts [2] through the Pentagon, State Department and intelligence agencies. These experts were charged with examining this complex, dynamic terrorist organization by looking at religious influences, psychological tactics, marketing manipulation and economic resource control. Whatever insights the group provides, there must be high-level political will to back the military campaign while simultaneously navigating dynamics from which ISIL gains strength.

Saddam Hussein is missing. Baghdad, June 2003. (Courtesy of Holly Hughson/Released)

Authority issues

Mounting evidence shows support for ISIL has as much to do with issues of authority itself and as it does with personal belief in the authority of religion. One analogy to explain ISIL's success is the mafia. Members of the mafia are not necessarily anarchists who reject the principle of state authority to govern, regulate, tax and protect its citizens. Rather, individuals join or find it hard to resist a mafia organization because they feel under-represented and vulnerable, outside of the protection of the formal state's authority. Therefore, a parallel system of governance, staffed by a bureaucracy with leadership, junior enforcers, tax collectors and soldiers, arises.

French journalist and former ISIL hostage, Didier Francois, told CNN he knew he was held by ISIL because they openly claimed they were the Islamic State. [3] He clarified, "It was not a religious discussion. It was a political discussion." Francois describes a politically shrewd ISIL leader in al-Baghdadi, whose strategy is honed from a sectarian legacy sharpened by the past 12 years since losing

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the protection of Saddam Hussein's government. "He always tries to push the Sunni tribes, the Bedouins to fight against the Shia, or the Yazidi or the Christians. He always tried to play communities, one against the other. That is how he survives. That is how he recruits." Acknowledging the foreign fighters recruited, Francois explains that by far "the strongest part of his organization are the tribes, the local Sunni tribes who are actually following him for political reasons."

Only one journalist has been allowed to travel into ISIL controlled territory and safely return home. In 2014, Juergen Todenhoefer spent six days in Mosul, where he interviewed and filmed ISIL fighters. On return, he said, "I thought I would find a brutal terrorist group and I met a brutal country." Most disturbing for him was to hear their enthusiasm for killing their enemies, which he listed as anyone who does not follow their interpretation of pure Islam. In an interview, Todenhoefer confirmed what is broadly understood, ISIL's enemies include Shia, Christians, Yazidis, Hindus and atheists. [4] He offered an additional insight, "They (ISIL) even want to kill all the Muslims in the Arab countries and in the Western world which are democratic. Because to be democratic means for them, that is somebody puts the laws of human beings above the law of God." For ISIL, there is no separation of religion and the state, but there is absolutely a separation of their religious state and any alternative political ideology.

These rare eyewitnesses who lived to relate their experiences with ISIL counter the argument that ISIL derives its success and power to recruit because it is Islamic. Its primary appeal and success, distinguishing it from fellow jihadists, is that it aspires to be a state that is Islamic. The threat to Iraq, the Middle East and global security is the existence of the state, not the religion. The United States and its allies must defeat the state ISIL has become.

What ISIL believes is not important for the fight against them. Whether they believe they are Islamic and this belief translates into a dress code for women, personal hygiene requirements for men or using children as executioners makes no difference when fighting them. The question is: Why does their ideology work at all? CNN contributor Fareed Zakaria recently posed this question in an opinion column entitled, "The limits of the 'Islamic' label." [5] He quoted Barnard College professor Sheri Berman, "An ideology succeeds when it replaces some other set of ideas that have failed." Taking this as a working thesis, the question becomes: What are the failed ideas that ISIL is able to exploit? By looking at ISIL's record of relative success in recruiting fighters as well as civilians and exporting a brand beyond the Middle East, a distinct pattern of a mafia-esque counter-narrative emerges.

At once, there is an adolescent boldness twinned with moral outrage at a record of abuse and alienation along lines of identity. Even ISIL's enemies acknowledge it succeeds in the wake of gross abuse of power and ethno-sectarian violence to which all parties have committed. The extraordinarily fine line ISIL's ideology exploits is one of an illegitimate, yet justifiable, challenge to authority.

Graffiti in Freedom Square. Baghdad, June 2003. (Courtesy of Holly Hughson/Released)

Defiance

ISIL evolved from the Islamic State in Iraq, formed in 2006 by Abu Musab al-Zarqawi as al-Qaeda's presence in Iraq. When al-Zarqai's successor, Umar al-Baghdadi, was killed in a military strike in April 2010, Abu Bakr al-Baghdadi succeeded him. The group was fairly quiet for the next couple years and part of the opposition groups fighting the Syrian government. The death of Osama bin Laden in 2012 was the death of charismatic leadership for al-Qaeda once Ayman al-Zawahiri was in charge. This leadership void provided a strategic opportunity for al-Baghdadi.

In a recent report for the Brookings Institute, Princeton scholar and ISIL expert, Cole Bunzel, traced the group's ideological journey as their self-declared caliphate emerged from direct confrontation and challenge of al-Qaeda's leadership. [6] On April 9, 2013, al-Baghdadi released an audio statement announcing that Islamic State in Iraq was expanding to Sham, the Arabic word for greater Syria. It was now Islamic State of Iraq and Sham. In his message, al-Baghdadi took the liberty to absorb the al-Qaeda affiliate fighting in Syria, Jabhat al-Nusra, declaring it subordinate. Abu Muhammad al-Jawlani, Jabhat al-Nusra's leader, immediately rejected the announcement and reaffirmed his loyalty to al-Zawahiri. However, none of this mattered to ISI, which moved into Syria and begin drawing al-Nusra's fighters to its ranks.

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Several months into this fratricidal dispute, al-Zawahiri intervened and ruled that ISI and al-Nursra should remain separate. In his letter leaked to Al Jazeera, al-Zawahiri reveals the al-Qaeda leadership did not anticipate the scale of al-Baghdadi's aspirations by admitting they had "neither been asked for authorization or advice, nor have we been notified of what had occurred between both sides." [7] Like an aging father trying to separate his sons from fighting, he lays out explicit faults on both sides and confers approval for the two groups' leadership and area of responsibility.

Al-Baghdadi simply rejected the order, indicating al-Zawahiri was no longer in charge. [8] Without al-Qaeda's authority or influence, ISIL entered a new era with seemingly no outer limits. Their flagrant defiance of authority sent a powerful signal to the global jihadist community. Combined with an unprecedented media campaign in terms of professional quality and psychological manipulation, the core of ISIL's ideological appeal comes from its claim to stand up to weak leadership.

In parallel with ISIL's dispute of al-Qaeda's authority, the person of al-Baghdadi himself makes a more subtle yet distinct challenge to the religious establishment. Through his biographer, al-Baghdadi is styled as an outsider authority. Amongst the requirements for validating a claim to caliph, the biographer delineates al-Baghdadi's lineage to the Prophet Mohammed as well as his basis for religious authority to interpret the Quran. [9] Instead of receiving his theological training at the bastion of Sunni religious authority, al-Azhar University in Cairo or the Islamic University of Medina in Saudi Arabia, al-Baghdadi received his Ph.D. from the Islamic University of Baghdad.

Al-Baghdadi presents a more modest Sunni pathway to caliph, evoking the humble origins of the Prophet Mohammed. He claims a far more traditional, religious education on Islamic culture, history, sharia and jurisprudence, than either of al-Qaeda's leaders: Bin Laden was trained as an engineer and al-Zawahiri as a medical doctor. Virtues of religious purity and humility are paired with defiance of theological and political establishment and serve as symbolic and literal rejection of both failed and despotic power, even as they replace it with their own authoritarian regime.

In one fell swoop of declaring a caliphate with al-Baghdadi as caliph, ISIL usurped both the Sunni and al-Qaeda established elite. It is the perfect formula to appeal to a disaffected, politically unrepresented demographic worldwide. Even more powerful, their righteous indignation at the failure of unchecked abuses by regional regimes is broadly shared by millions, if not their choice for violence.

Authority crisis

The symbolism of al-Baghdadi as a rogue caliph who does not need the approval of the Sunni religious or political elite is central to the appeal of ISIL itself. Its upstart ability to challenge established

Spiral descent over Baghdad, June 2003. (Courtesy of Holly Hughson/Released)

religious and ideological authorities is symptomatic of a much broader breakdown of religious authority within Islam. H. A. Hellyer explains this crisis of authority in an essay responding to the high profile debate over whether ISIL was Islamic. [10] While there is no hierarchical ecclesiastical structure within Sunni Islam, interpretation of texts to establish legitimacy, has traditionally required the ability to demonstrate a historical pedigree. Individual interpretation was unthinkable as a basis for argument. Rather, when a scholar puts forth an interpretation, he includes the "master x" with whom he studied, who was himself a student of "master y," who had the privilege of studying with "master z, whom all acknowledge" and so it continues back to the Prophet himself. The stronger this "chain" or *sanad,* the greater the chance of the interpretation gaining broad support. Hellyer explains, "These systems do not simply establish the transmission of texts between successive generations, but also the *understanding* of those texts."

Islam joins its forerunners of Christianity and Judaism in being a "religion of the book." All three religions have a history of engagement with sacred texts in a dynamic relationship of interpretation by established authorities, reformers and revolutionaries alike. As a result, systems of authority have emerged over time. It is precisely these systems of authority that radical Islamic groups rejected in favor of their own interpretation of both Islam and the state. ISIL's declaration of a caliphate with al-Baghdadi as caliph did not have any of the checks and balances of dialogue with Islamic theological and legal tradition. The result is an anti-establishment authoritarian upstart that has fostered a raw, unbridled jihad.

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ISIL's oxygen

The Syrian government's prosecution of war against its own citizens has inadvertently mobilized tens of thousands of foreign fighters for its opposition, which in turn has empowered ISIL. Through its social media presence, ISIL has successfully portrayed itself as the "most pure" of the jihadist opposition and most capable of standing up to the Assad regime.

The unchecked record of Syrian civil war is a daily reminder and signal of the impotence of foreign powers to enforce even their own United Nations Security Council Resolutions. [11] The perceived lack of action, despite the humanitarian crisis, has been a significant and powerful recruitment force for both jihadists and opposition forces alike. As long as the Syrian regime can perpetuate its brutal, indiscriminate attacks on its own civilian non-combatants with impunity, ISIL will continue to co-opt foreign and domestic recruitment for jihad and make its case as the protector of targeted, marginalized Sunnis worldwide.

In parallel to its role in Syria, ISIL's growth, geographic and political success in Iraq cannot be separated from the years of abusive sectarian rule by the Shiite-dominated Iraqi government since it assumed power in 2004. The brief respite from this rule, when Sunnis chose to support the American military surge over the radical jihad of al-Qaeda in Iraq, was a risk that did not ultimately pay off. Sunni communities were met with continued marginalization and betrayal from their government. Even the former leader of the Sons of Iraq admits a second awakening cannot now be replicated because of how systematic alienation has been incorporated into the legal framework. [12] Iraq's counterterrorism laws can be interpreted so that, "any Sunni can be arrested and accused of terrorism without cause, convicted without due process and pass years in jail without a trial."

Satellite dish in Iraq. (Courtesy of Holly Hughson/Released)

Cleaning karez in Kirkuk. (Courtesy of Holly Hughson/ Released)

Powerful dynamics complicate effective, decisive action in the fight against ISIL, starting with the escalation of direct conflict between both state and non-state regional powers. The lack of will at the UNSC to enforce its own resolutions regarding Syria and the broader design flaw whereby Cold War rivals block action by veto, render the mechanism broken. Nuclear negotiations with Iran have complicated the formation of the coalition fighting ISIL, which only serves to affirm their appeal. Gross human rights violations are committed by all sides of the political, ethnic sectarian divides and it is difficult to imagine who will be first to put down their weapons in the name of diplomatic resolution. As long as Syrian and Iraqi Sunnis have no viable alternative, and the present Shia-dominated Syrian and Iraqi governments operate with impunity, ISIL's ideology has oxygen to remain alive.

Revisiting responsibility and renewal

Maj. Gen. Nagata's task is re-setting a compound fracture amongst mortal enemies whose fissures are deepened every single day as Middle Eastern regimes, ISIL and its jihadist ilk, and sectarian militias

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prosecute their campaigns of terror. While he has been honest about the bewildering, complex challenge ahead, has the nation had the courage to define the fight against ISIL?

Given the operational environment of a sustained, catastrophic humanitarian crisis overlapped with unstable states unwilling or unable to govern and protect all of their citizens, the United States risks defining the mission either too narrowly or too broadly. The narrow mission is to defeat ISIL as a landowning entity, foreign fighter jihadist recruitment base, and immediate threat to the governments of Iraq and Syria. The complex challenge of the fight is understanding and countering the ideological framework which ISIL has so effectively captured. The key to their appeal is found in what unites their broad demographic of support that defies categorization apart from a consistent pattern of alienation from and willingness to challenge established authority.

ISIL's ideology does not eliminate challenges from within its organization. Tensions are increasingly reported between foreign and domestic fighters and their relative privileges. [13] Nor is ISIL's ideology immune to the challenge of hierarchy inherent within Islam or what has been termed, second-class jihad. [14] They must deal with the pressure of battlefield reversals as Kurdish and Iraqi forces have regained territory and the tedious responsibility of managing and providing for a population facing shortages of gas for cooking or medical supplies. [15]

Regardless of these vulnerabilities, the West should not be lulled into viewing ISIL's relative setbacks as a triumph. ISIL is only one manifestation of a crisis of religious and political authority in which nations worldwide are participating to a varying degree. First, the protracted, civil wars and failed or floundering states of Syria, Iraq, Libya and Yemen present the most obvious case for crisis. Second, the failure of the Arab Spring to gain traction through peaceful demonstration and the demand for representation has the majority populations simmering under reinforced authoritarian control. Third, Western nations who espouse democracy and representative government have failed to support the courageous masses who stood up for their right to be represented. Instead of open support of this democratic call and echo of our own political origins, Western governments have appeared hypocritical about their own values in choosing instead the preservation of strategically powerful alliances and abiding by a broken UNSC whose resolutions appear to be the token gestures of the entitled.

Caught in a Cold War paradigm

Traditionally, when a national security challenge arises in the Middle East, the United States has a single point of contact. Substantive dialogue could occur through a single phone call to the strongman in charge who, with an investment in his military or economy, allowed the United States to manage by proxy, the actions supportive of its national interests. In return, the United States turned a blind eye to tactics of population control. The United States is paying a price for this relationship in terms of the populations' perceptions of our duality: Preach democracy and freedom until a security concern or economic interest supersedes our proclaimed values.

Clean-up campaign in Kirkuk. August, 2003. (Courtesy of Holly Hughson/Released)

The conventional, asymmetric, insurgent wars being fought in the Middle East are along multiple lines of identities and are easily overwhelming. However, as any shrewd practitioner of strategy would say, crisis begets great opportunity.

Time to take responsibility

In terms of governance in Iraq and Syria, the West must revisit mistakes made over the past decade. The immediate vacuum ISIL and regional powers exploit today was created in 2003 with the invasion of Iraq, but the vacuum is also a product of a much longer historical record in Iraq and the region. As part of the international community and signatories to the Geneva Conventions and International Humanitarian Law, the United States has an opportunity to support a framework that protects civilian non-combatants and provides a mechanism to disarm and demobilize those on all sides of sectarian and ethnic division in Iraq and Syria.

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In the fight against ISIL and the instability in the Middle East, the United States has a unique opportunity, which is twofold. First, it may send a powerful signal to its allies and to the overwhelming majority of the population in the Middle East, that it affirms the commitment to democratic values and representative governance. In order to do this credibly, the United States must acknowledge a record to the contrary, of supporting non-democratic regimes which the Arab Spring attempted to unseat. Next, the United States may address its own domestic divisions through bipartisan acknowledgement that both parties made critical mistakes and costly errors in judgment in Iraq and the region. Showing it has the maturity and capacity as legislators and elected officials to accept lessons learned would be a politically savvy move and opportunity to show bi-partisan humility.

Thinking of ISIL as the militarized arm of the Arab Spring provides a very productive angle on defeating it and a unique perspective of the fuel that has ignited each of the present conflicts in the Middle East. In order to counter the appeal of ISIL's outsider ideology, the United States bears responsibility for its leading role in the breakdown of authority in the region.

Boys outside an ice cream shop in Erbil. August, 2003. (Courtesy of Holly Hughson/Released).

Only through empathy and the honest cultural self-examination that such a strategy demands can questions be identified and asked and find the unity (and subsequent loss of paralysis) to defeat the common enemy that is ISIL. Without this process, its ideology will metastasize, with franchise jihad adopted by the marginalized, alienated individuals everywhere. Any ideology that forcefully draws lines and division amongst society, whether it comes from the state or the backyard, is a malignancy that cannot be ignored. The United States must keep unity as the goal of diversity, promote acceptance within a framework of human rights, and check instinctive perceptions in order to build bridges across even the greatest differences.

Defeating ISIL will continue to be a military fight for some time to come. Defeating ISIL's political ideology must result in credible, representative governance in the Middle East. This will not be an easy path as U.S. history, including civil war, reminds us. The traditional relationships between the United States and regional power brokers must be re-examined. Attempts to preserve or restore the former status quo are naïve, hypocritical, and will sustain the ideology of ISIL.

There are no easy answers to how stable, representative government will occur in Iraq, Syria and the region. Enforced buffer zones to simply halt the atrocities and establish humanitarian access will be politically fraught with complicated risks yet may be unavoidable. A critical step on the pathway to peace may be found in a truth and reconciliation process. This process would involve representation from Sunni, Shia, Kurdish and other minorities with the twinned goals of each community owning its actions that were divisive and to stimulate equitable, representative distribution of resources. The greatest challenges hold the greatest opportunities. In the end, all sides have an interest in viable governance. The Arab Spring was a reminder that the Cold War is over; it is time for a new paradigm.

Admitting weakness or vulnerability is not easy. Not as an individual, not as a nation. But only in an honest assessment of limitations, can the United States clearly see its strengths and thus identify a credible pathway forward for national security.

ISIL as the Militarized Arm of the Arab Spring—continued

H. Hughson

About the Author

Holly Hughson is a humanitarian aid worker and civil-military trainer with an extensive background in rapid assessment, program design, management and monitoring of operations in both humanitarian emergencies and post-conflict settings. Her experience includes work in Kosovo, Sudan, Iraq, Russian Federation and Afghanistan. Presently she is writing a personal history of war from the perspective of a Western female living and working in Muslim countries. She works as an instructor and advisor on humanitarian aid and early recovery to joint, coalition and inter-agency training exercises at multiple U.S. bases in the United States and Europe.

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[1] The organization known as ISIL, ISIS and Daesh are all names which evolved from the earlier al-Qaeda affiliate "Islamic State of Iraq". For the sake of continuity with Department of Defense preference, ISIL is used in this article.

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Biobotic Insect Sensor Networks for Search and Rescue

A. Bozkurt, E. Lobaton, M. Sichitiu

The relatively recent developments in swarm robotics have found a variety of applications in areas ranging from military to environmental fields, where the superiority of swarm based distributed systems on certain tasks such as exploration, mapping and large-area sensing is indisputable. In these applications, the success of distributed robotic systems highly depends on the robotic agents' capability to cope with uncertain and dynamic environmental conditions. Present day technology falls short in offering mobile robotic agents that function effectively under complex environmental conditions, such as those emerging after a natural disaster. On the other hand, insects exhibit an unmatched ability to navigate through a wide variety of environments and overcome perturbations by successfully maintaining control and stability.

Stimulation of neural system for remote control of navigation in insects

Neuromechanical response of cockroaches' musculoskeletal structures provides a system level locomotive stability during their natural locomotion. Through the tactile guidance of antennae, cockroaches formulate their escape responses to avoid obstacles, where the optical cues may not be processed fast enough. [9] Among the many structures of the peripheral nervous system, the antennae was selected as the targeted stimulation location for this study. *Gromphadorhina portentosa*, Madagascar hissing cockroach, was selected as the terrestrial model animal for this study because of its easy rearing and maintenance conditions and commercial availability in the United States. The relatively large sizes and slower speed of these insects also enable larger payload capacities and easier biobotic manipulation of their locomotion.

Demonstrations of biobotic control

Fine wire electrodes were surgically implanted into the antenna to supply stimulation pulses through a radio frequency link. Insects followed an S-shaped line drawn on the floor through the right and left turn commands sent by the human operator via a manual remote controller. [3,4] To provide an objective test platform and assess the capability of each insect biobot, the control was automated using a Microsoft Kinect sensor. [1,4] In this platform, the PC uses the video feed from the Kinect to locate the insects and send neurostimulation pulses via a radio transmitter to automatically steer the insects along a predetermined test path. [Fig. 1] The infrared-based depth image provided by the Kinect also allows experiments to be conducted in the dark, when the insects are more active. Once an insect is implanted with the backpack technologies, the successful steering along a semicircular path [Fig.1] within the test arena was used to assess the biobotic control capability. [1,3] The biobots that passed the Kinect test (success rate ~70 percent) were then used for navigation experiments. The unsuccessful ones were further tested to characterize the failure modes of biobotic implantation of electronics.

The insect biobots were introduced into a maze environment to further test their biobotic capability. Walls were erected in the test arena, and a path was defined through the maze. The additional walls and corners distract the insect from completing the task, as cockroaches are naturally attracted to cool, dark areas and tend to stay close to wall corners. The insect biobots were placed in a designated start location and remotely navigated through this maze to the end location with a success rate of 75 percent. [Fig. 2]

Another biobotic capability test was to hold the position of a roach-bot within a particular region of interest. Much like a modern invisible fence designed to keep pets within a backyard, the virtual fences in the test platform were designed to maintain the position of the roach biobot within a particular region. Moving outside the region results in automated stimulation pulses initiated by the PC to turn the biobot around. This was accomplished at a success rate of 85 percent. [Fig. 2]

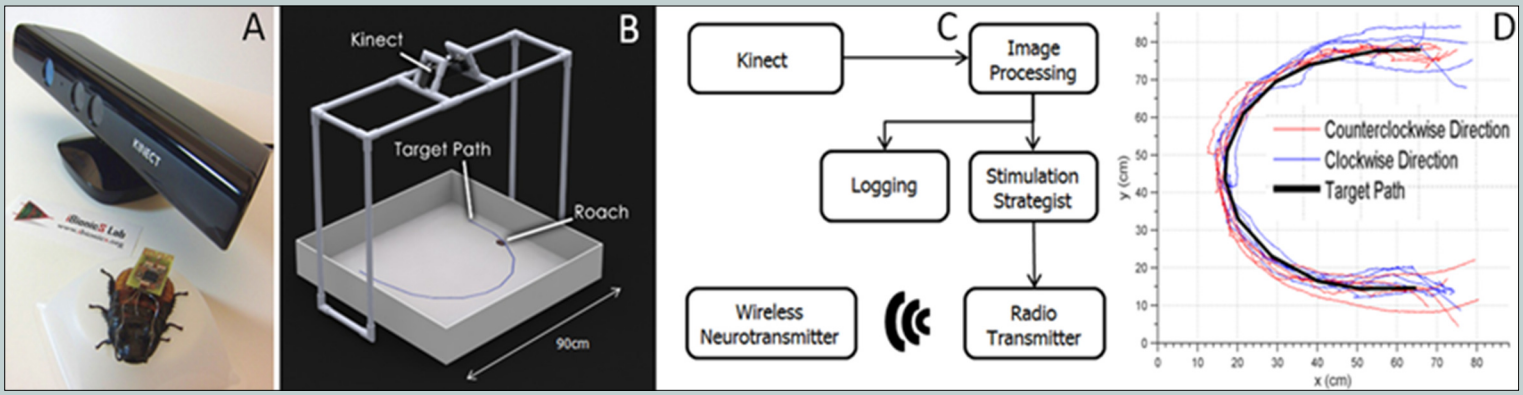

Figure 1. (A) The Kinect camera and insect biobot backpack. (B) Kinect based automated biobot evaluation platform. (C) The closed feedback loop. (D) representative trajectories that insect biobots followed. (Courtesy of A. Bozkurt, E. Lobaton, M. Sichitiu/Released)

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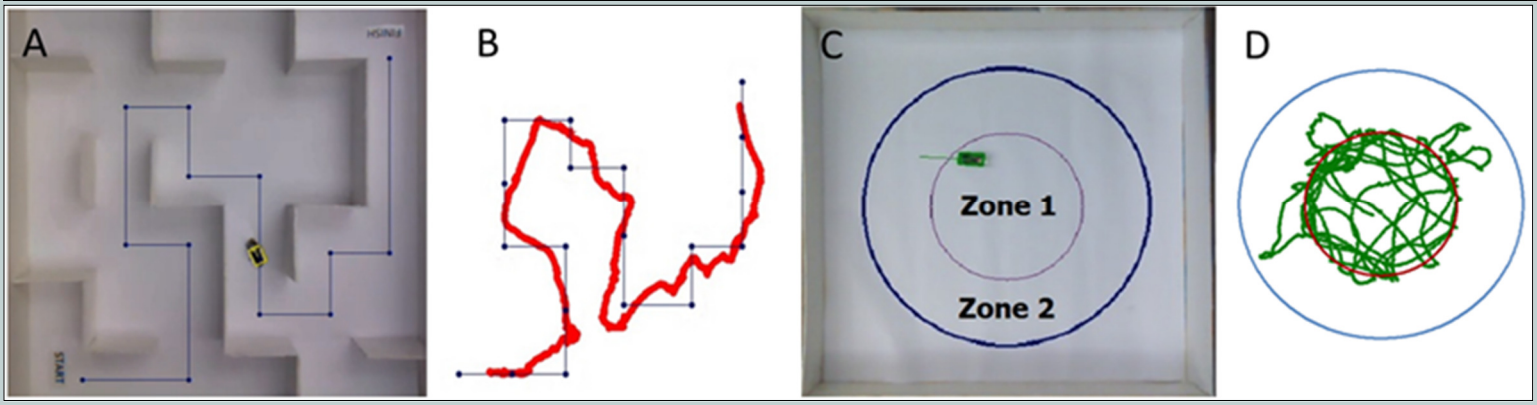

Figure 2 (A) The Kinect view of a roach biobot in the maze and targeted trajectory. (B) A typical trajectory followed. (C) Invisible fence's zone 1 and the buffer area around it (zone 2). (D) A representative trajectory in virtual fence. (Courtesy of A. Bozkurt, E. Lobaton, M. Sichitiu/Released)

Backpack technologies for biobots

The insect backpacks previously proposed in the literature were mostly used for telemetry applications, rather than stimulation. Their goal was to record neural potentials or electromyography signals and transmit these signals to remote computers to further understanding of insects' neural system functions. In this study, an electronic backpack was developed for wireless control and communication. [Fig.1] To minimize the cost, a commercial-off-the-shelf system-on-chip solution from Texas Instruments that combines analog, digital and mixed-signal with radio-frequency functions on a single substrate level was used. Being tailored for IEEE 802.15.4/ ZigBee and ZigBee RF4CE applications, CC2530 combines an 8051 microcontroller with a high performance RF transceiver, while providing 8 KB of RAM and up to 256 KB of flash memory. This single-chip system is an ideal solution for the insect backpack with its 21 general-purpose I/O pins and 8 channel 12-Bit ADC. The assembled backpack weighs around 300 mg without the batteries, and lithium-polymer batteries were added according to mission durations (20 mAh at 400 mg or 100 mAh at 2 g). Roach biobots were able to carry payloads on the order of 5 g in total.

To extend the propagation range of the sensor signal and minimize the transmission power, an ad hoc communications network was established by using the Zigbee-based connectivity provided by the Texas Instruments' solution on the biobot backpack. This allows the biobotic swarm to cover a target area with their sensors located on the backpack. Once the targeted signal is detected, the information is passed from one node to another until it reaches a delivery point.

Autonomous sound localization

A miniature custom microphone array was mounted on the backpack to allow for detection and localization of a sound source with the aim of localizing victims under rubble. [Fig. 3] For this, three directional microphones were connected to three dedicated preamplifiers on a thin printed circuit board where conditioned audio signals were sampled by CC2530 at a rate of nearly 2 kHz. In order to evaluate the performance of this system, all audio data was streamed over the ZigBee network to a nearby PC. Initially, the PC is being used for audio processing, but the processing will eventually be implemented on the system-on-chip solution.

Wireless communication optimization and localization of biobots

The efficiency of biobot communication and using it for localization is the bottleneck for aiding earthquake or other disaster victims. Power efficient communications can and have to be addressed at many layers in the communication stack: each layer has to be power conscious and each layer can contribute to the overall power savings by careful design and tuning for the proposed application and resulting traffic patterns. Applications can employ compression as well as aggregation of sensed data to reduce traffic. Transport protocols can be tuned to minimize power consumption (at the cost of a potentially reduced throughput). Routing protocols can find routes that do not deplete the energy of a few key nodes leading to premature network disconnection. However, medium access control is the layer that has the largest potential for power savings as it has fine control over the radio transceiver, which is one of the major consumers in any wireless sensor system.

In the current state of the art, the most power-efficient medium access control layer solutions do not support a broadcast service, as broadcast tends to increase overhearing, which is a major source of power inefficiency. [10]

Contrariwise, most localization systems, especially those for mobile nodes, rely on broadcast for neighbor discovery and efficient transfer of information as a single transmission is capable of reaching

Biobotic Insect Sensor Networks—continued

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any number of listening neighbors. Most routing protocols also rely on broadcast for exchanges of "Hello" messages to detect the availability of new links and degradation of existing links. Many time synchronization protocols (including Reference Broadcast Time Synchronization, a particularly accurate time synchronization protocol [11]) also rely on broadcast. The challenge is to design and implement a power efficient medium access control that supports broadcast while remaining power efficient over a large range of traffic patterns and network topologies.

The other problem to consider is localization, both for the biobots as well as the victims. Using the time of arrival of sound beacons has been considered for both tasks. Using the omnidirectional microphone array [Fig. 3] and one buzzer on each biobot has also been considered. The microphones are used in two different ways: on one hand, since three microphones forming a local array are available on each biobot, an approximate angle of arrival can be approximated from each biobot. The achievable resolution is, however, limited by the relatively small distance between microphones, the sampling rate of the microcontroller and available buffer size. On the other hand, microphones on different biobots are potentially spaced out one to two orders of magnitude more than those collocated on the same biobot. However, since the audio samples are now collected on different microcontrollers, accurate time synchronization and efficient data communication are required and compression is likely key in reducing the amount of data transferred.

The relevant research questions for the localization of nodes and sound sources are first related to the localization precision achievable from a single biobot considering the relatively low sampling rate and buffer size; the second interesting research question is to explore the trade-off between power efficiency in running the time synchronization algorithm between neighboring biobots and corresponding precision in localization. Finally, fusing the information obtained from the local microphone array and the information from neighboring biobots is expected to result in higher precision than either of the two approaches alone, potentially at the cost of an increase in energy consumption.

Mapping of the under-rubble environment

Another essential task in a variety of applications, including search and rescue for emergency response, is the mapping of an unknown environment. This task becomes extremely challenging when localization information is not available (e.g., agents are indoor, underground, or do not have the necessary hardware or power requirements to implement traditional localization schemes). We have explored [12] how stochastic motion models and weak encounter information can be exploited to learn topological information about an unknown environment. A probabilistic motion model is assumed for the biobots [13], and tools from algebraic topology can be employed to extract spatial information of the environment based on inter-agent neighbor to neighbor interactions with no need for localization data.

A robust approach to obtain a topological map of an unknown environment using the coordinate free sensory data obtained from the biobot network is proposed.

The natural behavior of insects is used to an advantage to estimate a topological model of the environment based only on neighbor-to-neighbor interactions to minimize control input. The random walk of the agents is modeled as piecewise linear movements with fixed orientation, interrupted by isotropic changes in direction. Figure 4

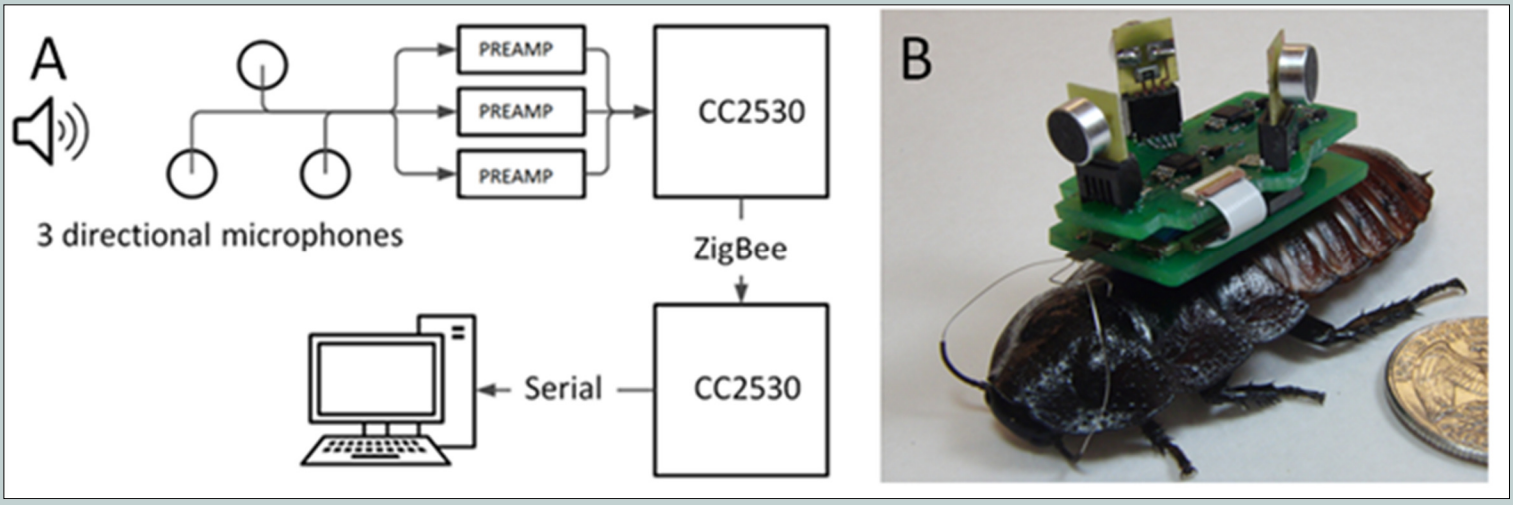

Figure 3 (A) The sound localization system. (B) The backpack with the microphone array. (Courtesy of A. Bozkurt, E. Lobaton, M. Sichitiu/Released)

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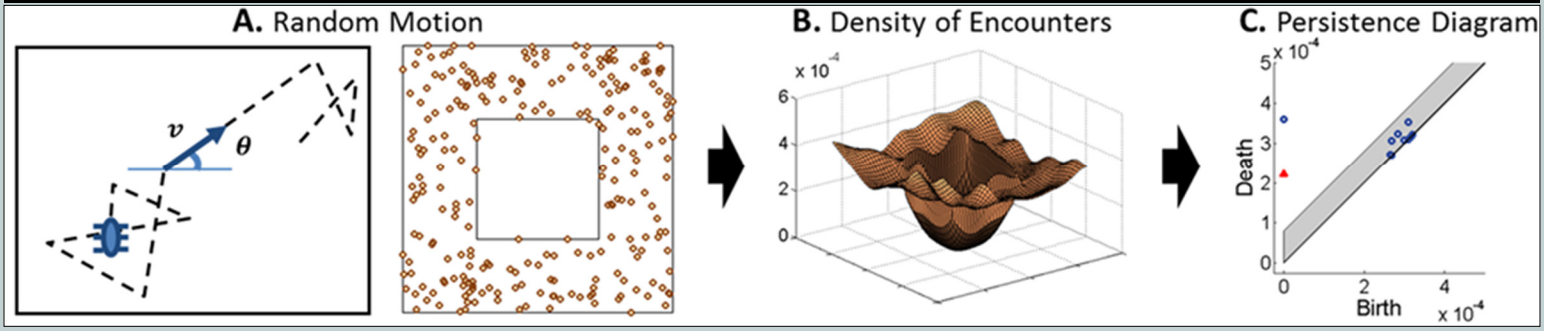

Figure 4. (A) Random motion of a single agent and a snapshot of a swarm in an environment. (B) Density estimation of encounter events in the space. (C) Persistence diagram showing one persistent connected component (blue circle) and a persistent hole (red triangle). (Courtesy of A. Bozkurt, E. Lobaton, M. Sichitiu/Released)

illustrates a snapshot of agents moving under this motion model. Each agent is distinguished by its unique ID and assumed to have a limited sensing capability. It is assumed the agents are able to record their encounters with each other and the corresponding times as encounter events. The set of encounter nodes, together with the corresponding estimated metric, can be used to construct a filtration of simplicial complexes [14], denoted as encounter complexes. This filtration is obtained by computing the Vietoris-Rips complexes [15] from the encounter metric on *G* as a function of distance. From this filtration, the so-called persistence diagram can be computed [14]. This diagram quantifies the persistence of topological features extracted from the set of sample points corresponding to the encounter events. Figure 4 illustrates an example of such diagrams. In this illustration, density of the encounters observed is estimated from interactions of agents. The persistence diagrams are extracted by thresholding the density estimates and keeping track of when topological features are born and die. Features that are most robust (shown outside the gray uncertainty region) correspond to some geometric information of the space. The blue circles represent connected components and the red triangles holes in the environment. In this scenario, the diagram identifies one persistent connected component and a hole in the domain. Nevertheless, estimating the density of events requires knowledge of location, so the density computation is bypassed to go directly to the persistence diagram [12].

Besides testing the approach on simulations, the algorithms were implemented on an educational and research swarm robotic platform, WolfBot. [16] This platform is open-source and open-hardware with an accessible software interface. The robots are programmed to mimic the probabilistic motion model of the biobots and collect the encounter data to construct a map of the environment in a distributed manner relying only on local interactions.

Conclusions

We have demonstrated novel neural prosthetics methodologies and tools that can be used to control the locomotion of insects [1-8]. In these, we applied proprioceptive inputs in the form of electrical excitation directly to the central or peripheral nervous system through implanted payloads and produced guided behavioral responses. These demonstrations have set the basis to control individual insect's behavior and benefit from its muscle power in a biobotic manner. In the meantime, we performed research to establish the fundamental physical and algorithmic building blocks of a biobotic swarm and produce a cyber-physical sensor network among the individuals of non-eusocial insects such as cockroaches. The areas of applicability for biobotic swarms are extremely diverse. In this case, the focus was on the problem of signal source localization and environment mapping, such as finding a surviving earthquake victim in a rubble pile.

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Biobotic Insect Sensor Networks—continued

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Battlefield MRI

M. Epsy

Magnetic Resonance Imaging is the best method for non-invasive imaging of soft tissue anatomy, saving countless lives each year. It is regarded as the gold standard for diagnosis of mild to moderate traumatic brain injuries. However, conventional MRI relies on very high, fixed strength magnetic fields (> 1.5 T) with parts-per-million homogeneity, which requires very large and expensive magnets. The overwhelming technological trend in MRI has been toward ever higher magnetic fields [1] because the signal (sample magnetization) and sensitivity of the Faraday detectors traditionally used scale with the applied magnetic field (readout frequency). [2] Thus, bigger fields have been widely accepted as the only way to obtain quality images, but they come with a price. High-field MRI is a method that can only be used in highly controlled settings in well-funded medical centers where such large magnetic fields can be generated and do not pose a hazard. [3,4] MRI machines weigh many tons, cost $3-5 million, and typically require 100-1,000 liters of cryogens annually. The high magnetic fields also restrict access in other ways. Traditional high-field MRI is not available in rural settings, is not deployable to emergency situations or battlefield hospitals and is more expensive than what poor and developing countries can afford—leaving billions of people without access to this powerful diagnostic tool. Subjects with unknown medical histories, such as unconscious soldiers with possible shrapnel injuries, cannot be imaged because of the potential hazards of heating or moving metal in the body, due to the radio-frequency fields and the strong magnetic gradients. Even non-ferrous metal significantly distorts a high-field MRI, precluding imaging of those with medical implants. In this article, progress toward developing a portable Battlefield MRI machine based on Superconducting Quantum Interference Device sensor technology and ultra-low-field MRI techniques developed at Los Alamos National Laboratory will be discussed. This device requires only 10s of liters of cryogens annually, makes use very simple, and has light field generation, 10-100 times less than a traditional MRI machine. Imaging of the human brain at fields 10,000 times lower than traditional MRI, using a pulsed-field method, will be demonstrated along with the capability for imaging injuries as small as a few millimeters, including brain bleeding and hydrocephalus, via the use of a validated model. Operation in the presence of metal, or even through metal, compatibility with other medical equipment and brain imaging modalities as well as the potential for systems that can be easily deployed (e.g. truck or helicopter) will be discussed.

Background:

Traumatic brain injuries are among the most devastating injuries on the battlefield, accounting for 15-25 percent of battlefield injuries since WWII. [5] The increasing incidence and effectiveness of improvised explosive devices in contemporary conflict suggests the problem is likely to get worse. [6] Since 2000, more than 300,000 U.S. military service members worldwide have sustained a TBI.

Illustration of MRI of the abdomen. (Image from the National Institutes of Health/Released)

Soldiers today have stronger armor and can survive close range explosions that would have killed soldiers in earlier wars. They also have access to rapid medical care for other injuries and many quickly return to combat. However, head injuries that do not involve obvious wounds or loss of consciousness, which is often the case for mild TBIs, or concussions, may go unnoticed. Although many patients completely recover from concussions, a fraction can have long-term effects, including mood disorders and depression. Some studies suggest TBIs can increase the risk of post-traumatic stress. [7]

Even when a head injury is suspected, there are few options for detection in a combat setting. Computerized tomography scanners, which use x-rays, are available in many combat support hospitals, but are not efficient at detecting the swelling or microscopic bleeding that may be associated with concussions. MRI is often better at identifying these microscopic changes. [8] However, the closest MRI to currently deployed service members in the Middle East and Afghanistan is at the U.S. military medical center in Landstuhl, Germany. An experiment in using traditional MRI in Afghanistan showed the machines were effective, but had to be pulled because of the high cost of maintaining conventional MRI in theater. [9]

Traditional MRI machines have multiple advantages for detecting changes in soft tissue, and it has been shown early intervention for even mild brain injuries can significantly improve a patient's long-term prognosis. However, these machines are expensive, and the high magnetic fields are not safe for injuries involving metal (e.g., shrapnel), which rules out unconscious patients with an unknown medical history. Can weaker magnetic fields be used to image changes in soft tissue?

Battlefield MRI—continued

M. Epsy

In the early years of MRI, lower field systems were used. MRIs had fields in the range of 10 to 100 mT and were largely based on permanent magnets, but these systems were expensive to maintain and very heavy. As superconducting magnet technology became available, systems stayed heavy and expensive, but the magnetic field strength, and thus image quality, went higher. What happens if the fields are even lower than mT? At much lower magnetic field strengths, it seemed that the signal was so poor true imaging would be impossible. That is until about 10 years ago when convergence or breakthroughs in sensor technology and magnetic field cycling methods made imaging at very low readout (i.e., earth's magnetic field), ultra-low field MRI possible and practical.

In the early 2000s, John Clarke's group at University of California, Berkeley showed MRI at ultra-low magnetic fields of ~100 mT and Larmor frequencies of kHz was possible by combining detection based on the superconducting quantum interference device, SQUID, with pre-polarization methods. [2] The SQUID is arguably the world's most sensitive detector of magnetic fields. [10] Pre-polarization (or field cycling) relies on using a higher magnetic field for a brief (a few seconds or less) amount of time to recruit signal. The actual MRI imaging, however, is done at a much lower magnetic field [11] that is easier to support, safer and much less homogeneous. [12] Since that time, Los Alamos National Laboratory and others have performed several compelling demonstrations of ULF MRI, especially for anatomical imaging of the brain. [13-16] Although the trend in MRI justifiably continues to be towards higher and higher magnetic fields, with 3 T now routine, to benefit from signal that scales as the magnetic field is squared, B^2, the promise of unique applications enabled by the benefits of the ULF regime remains. These include narrow line widths, unique tissue contrast, reduced susceptibility artifacts, compatibility with magnetoencephalography (MEG, a sensitive technique for measuring brain activity by the magnetic fields produced from active neurons) and imaging in the presence of metal to name a few. It remains to be seen, one might speculate these benefits combined with the relaxed requirements for magnetic field generation will enable ULF MRI systems to be utilized clinically or perhaps in situations where traditional MRI cannot go. Examples include emergency response where the exclusion of metal is not possible or places where the cost and infrastructure of high-field MRI systems cannot be borne. To be able to achieve a diagnostic quality MRI at ultra-low fields would be truly revolutionary with regard to where MRI could go and who could have access.

However, to make such speculations reality, a few key facts must be overcome. Although much of the required core technology has been demonstrated, ULF MRI systems still suffer from long imaging times and relatively poor quality images, and they have been confined to the research and development laboratory because of the strict requirements for a low noise environment isolated from almost all ambient electromagnetic fields. The goal of the work presented here was to develop a ULF MRI system functional prototype that will exploit the inherent advantages of the approach with an eye toward enabling increased accessibility. The results from a seven-channel, SQUID-based system that achieves a pre-polarization field of 100 mT over a 20 x 20 x 20 cm^3 volume, powers all magnetic field generation from standard MRI amplifier technology, and uses off-the-shelf data acquisition are presented. As the ultimate goal is unshielded operation, a seven-channel system that performs ULF MRI outside of a heavy magnetically-shielded enclosure will also be demonstrated. In this paper, preliminary images and characterization of the performance in the context of a model are presented.

How MRI works

The fundamental principle behind MRI is to magnetize (polarize) a sample with non-zero nuclear spin in a large magnetic field. In our case, as in the majority of MRI machines, the nucleus in question is the proton found in the water, which is abundant in human tissue. Simply, one can think of the protons (or hydrogen nuclei in water) as being tiny bar magnets. When an external magnetic field is applied, a small number of the protons line up with the field, producing a magnetization. This magnetization can then be manipulated by subsequent application of magnetic fields to produce a measurable signal at a unique (Larmor) frequency w_0, which is specific to the measurement (readout) magnetic field B_0 and the type of nuclei,

$$\omega_0 = \gamma B_0 , \qquad (1)$$

where g is the gyromagnetic ratio of the nuclei. In nearly all anatomical MRI, the sample is typically the spin ½ protons (hydrogen) found in water inside the body, thus g = 42.6 MHz/T. In our subsequent discussion, we will largely rely on the more general term "spin," but for all the anatomical imaging described below, we mean the proton signal from water in the subject under study.

In traditional high field MRI typically found in hospitals, the subject is placed inside a large, highly uniform (parts per million), fixed strength, usually a superconducting, magnet of 1.5 or 3 T. Once in the field, the spins align to produce a net magnetization over a period of time, T_1, which is very sensitive to the local chemical environment of the spins. After aligning, the spins can be "tipped" by an appropriately applied magnetic field pulse at the Larmor frequency. Once tipped, the spins rotate at the Larmor frequency, producing a time varying magnetic field that can be measured. The magnetization decays as the spins de-phase (relax) or get out of alignment due to local variations in the magnetic field. This relaxation time is known as T_2. It is sensitive to both the uniformity of the applied fields and the chemical environment. Nearly all MRIs

Battlefield MRI—continued

M. Epsy

derive their information from a combination of spin density (how much hydrogen) and differences in T_1 and T_2 between tissues. It is T_1 and T_2 that make MRI so effective at distinguishing between tissue types.

In traditional MRI, the polarization, B_p, and measurement, B_m, magnetic field are the same and referred to as B_0. A typical high field MRI would have a proton Larmor frequency of ~ 64 – 128 MHz. Practically, the higher the polarizing magnetic field achieved the better the signal. This is because the sample equilibrium magnetization, B_p

The increased signal can be used for faster acquisition and higher resolution images.

An additional motivation for high magnetic fields is that the performance of Faraday coils used as detectors in high field MRI, increases with magnetic field strength. [17] Thus, trying to perform conventional MRI at lower magnetic field strengths, where coil noise dominates, results in a penalty in acquired signal that scales as

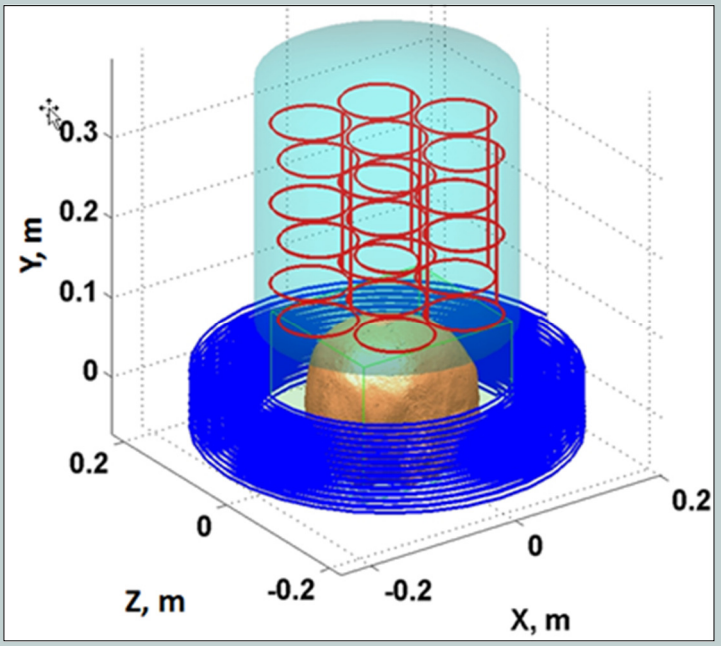
$$\sim B_0^2 .$$

The principal aim of all MRI is to spatially encode the signal properties (e.g. T_1, T_2, or spin density) underlying the information available in the images. In general, the physical principles used for ULF MRI are similar to those for traditional MRI. The main differences are: less signal and longer measurement time; different requirements for generation and manipulation of magnetic fields (which enable novel pulse sequences, but introduce new demands); differences in detector technology (i.e. SQUID vs. Faraday coil); and differences in T_1 contrast. Here, we briefly review some fundamental concepts in MRI that will be helpful in highlighting the differences between HF and ULF approaches. An excellent and far more complete description of conventional MRI is found in Ref. [18].

Because the Larmor frequency over the sample depends on the spatial profile of the applied magnetic field over the sample (see Equation (1)) to produce an image, a magnetic field gradient $\mathbf{G}(t)$ (assumed to be a linear gradient for these discussions) that causes the frequency to vary in a known way was intentionally applied, such that

$$\omega(\mathbf{r},t) = \omega_0 + \gamma \mathbf{G}(t)\cdot\mathbf{r} \qquad (2)$$

The fact that the frequency of the MRI signal varies in space and a judicious application of field gradients, known as a pulse sequence, are used to develop a trajectory through image space and acquire a spatially encoded representation of the magnetization. By appropriate choice of pulse sequence, certain tissues can be highlighted or suppressed based on their T_1 or T_2.



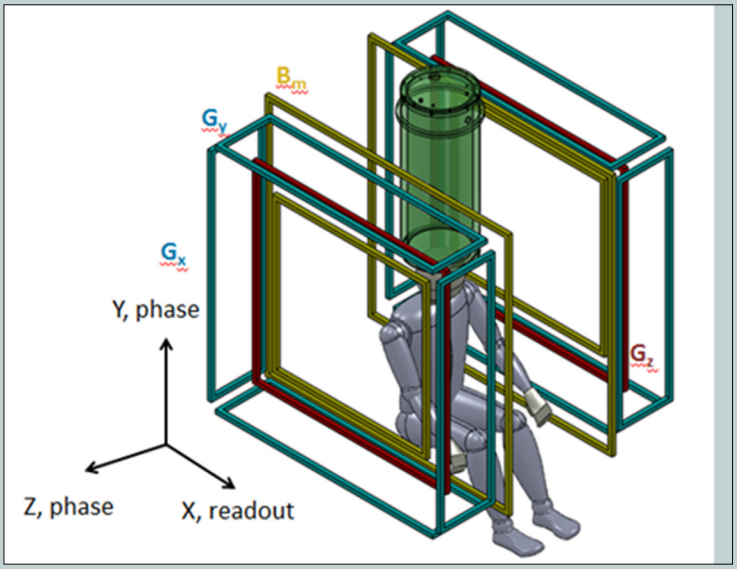


Figure 1. a) The sensor system (red) and cryostat (cyan), as well as the pre-polarization coil (blue) and location of the top of the head being imaged are shown. b) Schematic of the MRI coil set. Note the polarization field coil is not shown for simplicity. The figure is from Reference 24. (Released)

Battlefield MRI—continued

M. Epsy

About ULF MRI

To make MRI work at ULF, requires addressing the loss of signal with magnetic field in two primary ways. First, there is a method of pulsed pre-polarization at higher fields (0.01 - 0.1 T) to increase the signal by increasing magnetization [19]. Unlike pulsed field applications with a tuned Faraday coil, in which signal scales as $B_m B_p$, [20] an un-tuned SQUID detects the signal that scales as B_p, while sensor noise is ~ 1 fT/√Hz from Hz – MHz. [17]

To help frame the discussion, in Figure 1 a schematic of the ULF MRI system [21] that was used for obtaining brain images is presented. A photograph of the system is shown in Figure 2. In the upper panel of Figure 1, a model depicting the layout of the cryostat, which holds the SQUID sensors (cooled with ~ 10 L of liquid helium), the pre-polarizaton coil, and the location of the human head being imaged, is shown. The sensor array [21] of seven SQUIDs connected to second-order axial gradiometers with pick-up loop diameter and baseline ~90 mm are arranged as in the upper panel of Figure 1. An array of seven SQUIDs is used to improve the signal-to-noise and/or enable implementation of parallel imaging methods to speed the image acquisition [22].

Figure 2. Photograph of the shielded system. (Courtesy of Michelle Epsy, LANL/Released)

The upper panel of Figure 1 and 2 also show the pre-polarization, or B_p coil, used to generate the sample magnetization. In the lower panel of Figure 1, the geometry of the remainder of magnetic field generation coils used to produce and spatially encode the MRI signal is presented. B_m denotes the measurement of the magnetic field coils along the z-axis. The additional $G_{x,y,z}$ coils are for gradient encoding in the $dB_z/dx,y,z$ directions, respectively. As shown in Figure 2, the two coils wrapping around the outside of the system can also be seen (not shown in the lower panel of Figure 1 for simplicity). These are field cancellation coils designed to counteract any transient magnetic fields induced by pulsing the B_p coil. In HF MRI, there is a single fixed field providing both B_p and B_m, typically provided by a large superconducting magnet. In ULF MRI, the field generation is typically produced by simple electromagnets. This allows for different field orientations and strengths provided by separate B_p and B_m coils. Although it is not obvious from the photograph, the MRI system shown in Figure 2 resides inside a large, magnetically shielded enclosure made of sandwiched layers of aluminum and a high permeability metal known as "mu-metal." This provides a pristine magnetic field environment, but makes the system quite large and not mobile. Thus, removal of the requirement for shielding becomes quite important for mobility. However, it is important to first see what ULF MRI can do under "ideal" circumstances. A more complete discussion of this system is found in Ref. [21], and the issues and opportunities in ULF MRI can be found in Refs. [2] [23] or [24].

Results for shielded MRI

Almost everything about a ULF MRI system can be modeled, with the exception of the values of T_1 and T_2 at ULF, which can be complicated to predict and need to be measured. What then is the absolute best one can expect? Current state of the art research has shown that achieving pre-polarization fields of ~ 100 mT over the sample volume are challenging but reasonable. While, in principle, SQUIDs are capable of < 1 fT/√Hz noise, in practice it has been a struggle to see better than ~ 1.5 fT/√Hz in the presence of the energized field coils. That is taken to be the starting point. Using the parameters listed in Table I for the ULF MRI system shown in Figures 1 and 2, a model can be developed to determine the best image that could be obtained. The result is shown in Figure 3. The model is described more completely in Reference 21. The T_1 and T_2

Battlefield MRI—continued

M. Epsy

TABLE I
PARAMETERS USED IN THE MODEL

Physical quantity and unit	Value
Polarization field at center B_p, mT	100
Measurement field B_m , mTkHz	0.2
Larmor frequency, ω_0, kHz	8.5
Polarization time T_p, ms	4000
Encoding time T_e, ms	35
Readout time T_{acq}, ms	70
Readout gradient G_x, Hz/mm	8.2
Phase encoding gradient range G_y, Hz/mm	1
Phase encoding gradient range G_z, Hz/mm	8.9
Number of phase encoding steps, N_y	5
Number of phase encoding steps, N_z	91
Voxel size ΔV, mm^3	2.0×15×2.4
System noise, fT/ÖHz	1.8
Blood T_1/T_2, ms	450/190
Grey Matter T_1/T_2, ms	635/83
White Matter T_1/T_2, ms	360/70
CSF T_1/T_2, ms	4360/329

T_1 TIMES ARE IN THE POLARIZATION FIELD, WHILE T_2 IS FOR THE READOUT FIELD.

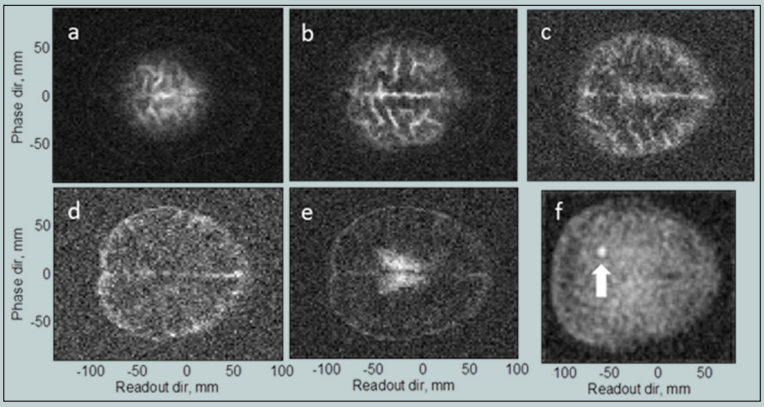


Fig. 3 a–e). Simulated ULF MRI of the brain with parameters from Table I. (f). Slice at 30–45 mm depth for pre-polarization of 0.5 s shows sensitivity to a one cm diameter inclusion (arrow) simulating bleeding. Data are from Reference 24. (Released)

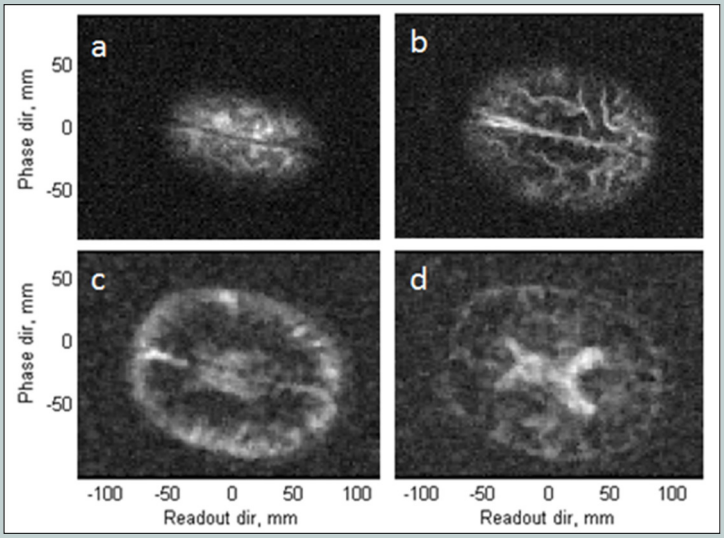


Figure 4. a–d) ULF MRI of the human brain, 15 mm thick transverse slices progressing in depth. The lower two slices are de-noised with a Golay filter. Data are from Reference 24. (Released)

contrast times used were experimentally measured previously [13,25]. The values from [13] were used in the model. The image quality is still rather poor. However, a sequence with a polarization time of 0.5 s, Fig. 3f, shows good contrast for a 1 cc inclusion with the relaxation properties of 50 percent blood and 50 percent brain tissue, indicating sensitivity to bleeding in the brain.

In Figure 4, the experimental results for the same pulse sequence are presented. The long polarization time (4 s) means the images are primarily sensitive to cerebral spinal fluid. The total imaging time was 67 minutes compared to the ~10s of minutes typical for high field MRI. The length was due to long polarization and a 50% duty cycle to avoid overheating the B_p coil. This could be reduced to ~ 30 minutes once those issues are addressed. The spatial resolution for a slice was 2.1 × 2.4 mm^2 with 15 mm slice thickness, whereas conventional MRI is able to achieve 1x1 mm^2 with 5 mm slice thickness. The image signal-to-noise ratio for the second slice of simulated and measured data, calculated using the single-image measurement method [26], [Figure 3b and Figure 4b] was ~ 10 for both. Although different brains are used in the model [Figure 3] and the experimental data [Figure 4], the agreement between them is excellent, indicating the system is performing as expected.

Battlefield MRI—continued

M. Epsy

Results for unshielded MRI

While the images shown in Figures 3 and 4 are able to distinguish major anatomical features and bleeding, the location of the system inside the 3x3x4 m^3 magnetically shielded room will not enable this system to be portable or inexpensive.

To this end, a second system with no external metal shielding was designed. Instead this system is surrounded by three pairs of coils located in x-y-z that are used to cancel out the earth's magnetic field and other unwanted ambient magnetic fields. A photograph of this system is shown in Figure 5. The ULF MRI working in an unshielded environment consisted of gradient and measurement field coils of the same kind as described in [27]. The cryostat and insert were the same 7-channel system as used in References 14 and 15. To test the performance of this system, a phantom brain was created using a mold [28] with the different compartments made from gelatin and agar designed to mimic the T_2 times of brain tissue. Figure 6 shows a photograph of the phantom. The T_2 was ~ 120 ms for the bulk and T_2 ~ 300 ms for inclusions. Food coloring was used for visual enhancement. Not visible in Figure 6 are small ~ 1cc inclusions also at 300 ms, designed to simulate bleeding.

Figure 5. The Los Alamos Battlefield MRI prototype. (Courtesy of LANL/Released)

Figure 6. Photograph of the gelatin-agar brain phantom. (Released)

A comparison of the phantom in the shielded system and unshielded system is shown in Figure 7. For the shielded system, the pulse sequence was similar to that in Table I. For the unshielded system, a 2D imaging sequence with B_p = 65 mT, t_p = 2.5 s, 100 ms encoding time, 200 ms readout time was used. The phase encoding gradient had 57 steps with a maximum gradient, G_z, of 1.62 Hz/mm. The readout (frequency encoding) gradient, G_x, was 1.63 Hz/mm. The resolution was ~3×3 mm^2. The Larmor frequency was 8590 Hz.

The most obvious difference between the shielded and unshielded images is the spatial resolution (2x2 vs 3x3 mm^2). This was dictated by the lower signal-to-noise available in the unshielded system. The polarization field in the shielded image was 100 mT as opposed to 65 mT in the unshielded. Also, the unshielded system has a noise floor of 5 fT/√Hz, which is higher than the 1.5 fT/√Hz for the unshielded system. However, both systems are adequate to visualize the primary anatomical features, including the inclusion.

One challenge for both the shielded and unshielded system is that the time delay between polarization coil ramp down and acquiring the image is ~ 100 ms. This is comparable to the tissue relaxation time, which means much signal is lost. There are several reasons for this, primarily related to induced ambient magnetic fields and increased noise in the SQUID gradiometer materials. The former is being actively addressed through the use of dynamic magnetic field cancellation and the later via new gradiometer materials. We anticipate at least factor of two in signal-to-noise can be had via

Battlefield MRI—continued

M. Epsy

Figure 7. A comparison of the phantom gelatin brain (left), the shielded ultra-low field MRI (center) and the unshielded ultra-low field MRI (right). The red circles indicate simulated regions of bleeding (center, and left). The shielded, ultra-low field MRI image (center) shows enough resolution to identify the major parts of the phantom brain as well as the simulated region of bleeding (circled). The unshielded battlefield MRI (right) has significantly less resolution; however, the bleeding is still visible, indicating that this system might be enough for a doctor in the field to determine the next step in treatment, from Reference 24. (Released)

these methods, which directly translates to reduced imaging time or increased spatial resolution.

Discussion and conclusions

A ultra-low field MRI system that is sensitive to anatomical features of interest including regions of bleeding has been developed. While the image quality will likely never compete with traditional MRI, as seen in Figure 5, the ultra-low field MRI system that is a footprint that is conducive to being delivered by a truck or light vehicle and does not require heavy magnets or shielding. This makes for a system is radically different from traditional MRI. Another significant benefit is that the fields can be completely removed for safety. Finally, the low fields (even the 100 mT pre-polarization field) are not adequate to put significant force on metal. Unlike high field MRI, where even a hair pin can be accelerated to 40 mph, it is relatively safe to use in the presence of metal. This means that MRI can be performed in the presence of medical equipment, or on subjects that may contain metal implants or fragments. The low measurement field means that imaging can even be performed through metal, which has been demonstrated for an application in using ultra-low field MRI for the screening of liquids at security checkpoints. [29,30] For example, one can perform MRI through unopened soda cans. It has also been shown that ultra-low field MRI combined with x-ray is an incredibly effective method for telling threat liquids from benign liquids in security screening. [31] It is important to note, in fact, that the development of ultra-low field MRI for anatomical imaging and deployable systems for the detection of threat liquids has been very synergistic.

One notable hurdle that remains is that the SQUID sensor still requires a small amount of cryogens (~ 10 L). It is possible to run with cryo-coolers, which would eliminate the need for refilling within a six month maintenance period. Ultimately, however, sensors that are as sensitive as the SQUID but do not require cryogens will be developed. A promising candidate is the atomic magnetometer, which does not require cryogens and relies on laser -based readout of atomic vapors. We have already begun to demonstrate ultra-low field MRI with such sensors. [32] Ultimately, it may be possible to imagine light and portable MRI systems in an ultra-low field regime. And this, in turn, may bring MRI where it has never been able to go before.

About the Author:

Michelle Espy received her Bachelor of Science in physics from the University of California, Riverside, and her doctorate in experimental nuclear physics from the University of Minnesota. After completing her doctorate she has pursued the application of nuclear physics techniques to biomedical and applied physics research based on detection of weak electromagnetic fields. She has worked for the past 16 years as

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part of the SQUID team at Los Alamos National Laboratory. She has more than 55 publications since 1996, four patents and several awards in the field of MEG and ultra-low field NMR and MRI. She was made a Fellow of the American Physical Society in 2015.

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Technical Inquiry Highlight

Ma'rib Governorate, Yemin

HDIAC recently analyzed the demographic make-up of Ma'rib Governorate in Yemen. Marib Governorate is the source of a substantial portion of state oil, gas revenues and the country's electricity supply. At least half of Yemen's oil is produced in Marib and it is also the location of the main natural gas fields and power plants that provide much of the electricity for Northern Yemen. Yemen is being fragmented with two separate governments claiming legitimacy: President Hadi, establishing a government in Aden and the Houthis attempting to govern from Sana'a. Disputes and clashes with the central government over contracting services and employment with the gas and oil companies often occur.

More than 60 percent of Yemen's population is affected by humanitarian issues. Over the last 10 years, water scarcity has led to conflict because there is insufficient water to grow both food and qat. Disputes over dam construction and water projects have caused violence in the governorate. In the Harib and Sirwah districts, unemployment is a major cause of conflict. Marib also has a significant problem with revenge killings. Many of these conflicts can be traced to a lack of infrastructure and support from the government and endemic poverty. Corporations are seen as one of the few sources for employment and training. Unfortunately, corporations are unlikely to hire unskilled workers, resulting in very few jobs for the local people. At least one gas company has invested heavily in Marib, funding projects implemented by non-governmental organizations partners and making choices based on assessments of their community relations teams. Projects have included education, agriculture, gender, water, electricity, fisheries, aviculture and small enterprise. The company also funds a major youth association.

Yemen is dominated by several tribal confederations that include tribes, clans and extended families that provide stability and order in the absence of a strong central government. The importance of each federation constantly changes as alliances shift and intermarriage occurs. Yemen's tribes will continue to play an important role in rebuilding the country as long as the tribal system remains intact.

Iran and Saudi Arabia have influenced events in Yemen. The Houthis tribe is backed by Tehran as part of Iran's efforts to expand its network of proxies across the region. Saudi Arabia is anxious about the effect that a Houthi takeover in Yemen would have on the Bab al Mandeb strait, which is a conduit for approximately five percent of all world oil trade. The United States is concerned with maintaining a regime in Sana'a that is able and willing to cooperate with the ongoing efforts to weaken and destroy the al-Qaida in the Arabian Peninsula, a Sunni extremist group based in Yemin. Yemeni and Western officials believe that Iran's ties with the anti-establishment groups in Yemen extend to leading members of the Southern Movement. The Southern Movement is a coalition of secessionist groups that want to split Yemen down pre-unification lines. The Southern secession would have a potential impact on maritime security in the Indian Ocean. Iran would have more influence in southern Yemen, which could affect Gulf trade. Both Saudi Arabia and the United States will be challenged to find a way to work with a key power broker in a strategically important country.

Map showing the Marib Governorate. (Released)

Yemen's conflict with the Houthis arose within a complex set of circumstances including the rise of Salafism and the effects of the Iraq War. These are embedded in a web of larger issues that include the nature of political power in Yemen. The social contracts made with the various tribes have sustained a weak government through many crises. Unless the tribal system and its use of customary law remains intact, there will never be a transition to any emerging regime. Yemen will remain fragmented and embroiled in civil conflict.

Coming up next issue...

CBRN Defense

Lab-on-paper for rapid, inexpensive medical diagnostics

A new paper-based platform for conducting a wide range of complex medical diagnostics could change the way we perform medical tests. The platform technology can potentially be applied to a variety of diagnostics from Lyme disease and HIV to Ebola and malaria. The key development was the invention of fluid actuated valves embedded in the paper that allow for sequential manipulation of sample fluids and multiple reagents in a controlled manner to perform complex multi-step, immune-detection tests without human intervention.

This article will discuss how the new paper-based platform was developed. The engineers combined knowledge from well -established test strip technology with micro-patterning techniques and their own innovative paper-based valves to create strips able to autonomously handle multiple reagents.

Paper-based lateral flow test strips, such as pregnancy tests, have been commercially successful for many years. In these devices, a sample fluid wicks along a strip of paper, reacts with embedded reagents, and produces a colored signal result. However, more complex medical diagnostics, such as enzymatic assay protocols, require multiple reagents triggered at particular times during the process, which can only be accomplished autonomously using the proprietary microfluidic valve technology created by the URI research team. The flow of the reagents are activated by the sample fluid in a predetermined sequence and timeframe. Using an optical reader, the lab-on-paper device will provide accurate quantitative results.

This new paper-based technology is the next generation of the lab-on-a-chip device the research team reported in 2011, which has been further refined since then. That device is now smaller and employs an innovative micropump for precise fluid movement within the cartridge's microchannels. The new paper-based system does not require pumping because the fluid flows naturally, via wicking, along the paper channels.

Cultural Studies

A first look at disaster management challenges in Lagos, Nigeria

A disaster occurring in Lagos, Nigeria, where more than half of an estimated 20 million people live in alternately-governed slums, would play havoc with humanitarian assistance and disaster response (HADR) operations. An increasing number of Lagosian stakeholders, government, businesses and a kaleidoscopic civil society, is aware that Lagos' recent infrastructure and livelihood improvements require intentional safeguarding. As a result, not all non-state actors in the Nigerian megacity are nefarious. This study suggests to international actors that successful HADR operations in megacities must leverage informal governance and security entities. This first look at Lagos' disaster management challenges addresses a strategic knowledge gap. In a megacity disaster scenario that lacks a robust host nation government presence, the civil society actors whose assistance could contribute to HADR mission success must be identified

Coming up next issue...

Homeland Defense

Red Dragons of Operation Desert Storm: Lessons from operating in a complex decisive action mission

After defeating Iraqi forces in 2003, and more than 12 years fighting counterinsurgency and stability operations in Afghanistan and Iraq, our military forces became expert at operating from Forward Operating Bases (FOB), Combat Outposts (COP), and relying on logistics situated in these dispersed static positions to conduct and sustain this long fight. Our forces have had the luxury of time and controlled routes to build up critical supplies, and government contractors to accomplish many of the site logistical requirements. What do we at the tactical Army level know about tactics, techniques and procedures (TTP) needed to fight a Joint Air/ Land battle?

Operation Desert Storm in 1991 provides a rich backdrop for Joint air/ land and sea forces employing mobile maneuver warfare to decisively defeat Iraqi forces in Iraq and Kuwait. The article of "Red Dragons of Operation Desert Storm" will provide a glimpse, at the tactical battalion level, on actions needed to support complex Combined Decisive Action Operations.

Homeland Defense

GTRI's autonomous capabilities combining to improve homeland defense

Researchers at the Georgia Tech Research Institute (GTRI) are on the cutting edge of unmanned aerial vehicle (UAV) research for protecting the country and its warfighters.

In current deployment, UAVs typically fly solo with a team of ground operators controlling their activities through teleoperation or waypoint-based routing. However, one aircraft can only carry so many sensors, limiting its capabilities. GTRI researchers have developed a method by which autonomous aircraft with different sensors can communicate. Autonomous systems working in teams have numerous future applications designed to improve lives and reduce costs.

In addition, the researchers are working on improving military applications for UAVs. Every day, U.S. military and security units receive vast amounts of data collected by intelligence, surveillance and reconnaissance (ISR) sensors, including information gathered by autonomous systems. Human analysts review the data, searching for possible threats. GTRI's researchers are developing ways to improve sensors and monitor data from these UAVs.

Medical

Feeling through a bionic hand

Two key innovations in the twenty first century have revolutionized neuroprosthetics: The development of anthropomorphic robotic limbs that replicate much of the function of a native human arm and the refinement of algorithms that decode intended movements from muscle, nerve, or brain activity. However, skilled manipulation of objects requires somatosensory feedback, for which vision is a poor substitute. For upper-limb neuroprostheses to be clinically viable, they must therefore provide for the restoration of touch and proprioception. In my laboratory, we are developing ways to elicit meaningful tactile sensations through stimulation of neurons in the somatosensory nerve and in somatosensory cortex. Our approach consists in leveraging what we know about how information about grasped objects is encoded in the nervous system of intact individuals to attempt to reproduce these natural patterns of neuronal activation through electrical stimulation.

Coming up next issue...

WMD

Multi-phase ceramic composites as hosts for nuclear waste

Efforts being conducted by the United States Department of Energy (DOE) under the Fuel Cycle Research and Development (FCR&D) program are aimed at making potential U.S. fuel cycle options more effective by the development of next generation waste management technologies. One envisioned fuel reprocessing technology would separate the fuel into several fractions, thus, partitioning the waste into groups with common chemistry. Ceramic (or crystalline) waste forms incorporate the radionuclides in the waste as part of the crystal structure. As such, ceramic forms are tailored to create certain minerals (i.e. unique crystalline structures) that will host the radionuclides by binding them in their specific crystalline network. Tailoring of a ceramic waste form is based on the knowledge that there are many naturally produced minerals containing radioactive and non-radioactive species very similar to the radionuclides of concern in wastes from fuel reprocessing. The research conducted in this work package is aimed at taking advantage of the long term thermodynamic stability of crystalline ceramics to create more durable waste forms (as compared to high level waste (HLW) glass) in order to reduce the reliance on engineered and natural barrier systems. Durable ceramic waste forms that incorporate a wide range of radionuclides have the potential to broaden the available disposal options and to lower the storage and disposal costs associated with advanced fuel cycles.

HDIAC Calendar of Events

8th Annual Special Operations Summit & Warfighter Expo
22-24 June 2015
Fort Bragg, NC

Biodefense World Summit 2015
22-26 June 2015
Bethesda, MD

Bioenergy 2015: Opportunities in a Changing Energy Landscape
23-24 June 2015
Washington, D.C.

Army Network Modernization
23-25 June 2015
Reston, VA

Energy Storage USA
07-08 July 2015
San Diego, CA

Extreme Events and Climate Adaptation Planning Workshop
14-15 July 2015
Des Moines, IA

NDIA Annual CBRN Defense Conference
21-23 July 2015
Edgewood, MD

International Hazard Mitigation Practitioners Symposium
22-23 July 2015
Broomfield, CO

Forensic Science Error Management
International Forensics Symposium
20-24 July 2015
Washington, D.C.

Defense Technology Contracting Summit
27-28 July 2015
Washington, D.C.

Next Generation Integrated ISR
27-29 July 2015
Washington, D.C.

Unmanned Aerial Systems Traffic Management Convention
28-30 July 2015
Moffett Field, CA

Energy Exchange
11-13 August 2015
Phoenix, AZ

Military Helicopters USA
24-26 August 2015
Pensacola, FL

Additive Manufacturing for Defense and Aerospace
31 August—2 September 2015
Washington, D.C.

IEEE 7th International Conference on Biometrics Theory, Applications and Systems
7-10 September 2015
Arlington, VA

Borderpol International Security Meeting
9-11 September 2015
Washington, D.C.

Smart Cities Week
14-16 September 2015
Washington, D.C.

Solar Power International
14-17 September 2015
Anaheim, CA

Evolve 2 Advance
28 September—01 October 2015
Anaheim, CA

Noteworthy

Alternative Energy

Diamond-like coatings save fuel
June 8, 2015

Stable perovskite solar cells developed through structural simplification
June 8, 2015

Biometrics

Iris scanners can now identify us from 40 feet away
May 21, 2015

Scottish Police admit to using facial recognition software, maintaining image database
May 26, 2015

CBRN Defense

Naval Research Lab's Laser Trace Vaporization Enhances Chemical Detection
June 2, 2015

Plutonium Studies Begin At National Ignition Facility
June 8, 2015

Critical Infrastructure Protection

Alstom, Penn State partner at Philly's Navy Yard to advance microgrid technology
June 3, 2015

FAA works with airports to improve runway safety
June 3, 2015

Cultural Studies

El Salvador's Gang Truce: A Lost Opportunity?
June 2, 2015

Jordan: Syrians Blocked, Stranded in Desert
June 3, 2015

Noteworthy

Homeland Defense and Security

ISIS Is Using Tunnel Bombs in Iraq
June 8, 2015

Will DARPA's Disaster Robots Ever Go to War? Never Say Never
June 8, 2015

Medical

Los Alamos is developing powerful medical tool
June 1, 2015

Nanosensor bandage measures wound oxygenation
June 4, 2015

Weapons of Mass Destruction

Schrödinger's Nuke: How Iran's Nuclear Weapons Program Exists – and Doesn't Exist – at the Same Time
June 1, 2105

Air Force scientists are working on hypersonic air vehicle
June 7, 2015

The Homeland Defense & Security Information Analysis Center (HDIAC) is a Department of Defense (DoD) sponsored organization through the Defense Technical Information Center. HDIAC utilizes expertise and knowledge from government agencies, research institutions, laboratories, industry and academia on topics relevant to DoD and other government entities. HDIAC's mission is to serve as a ready tool for strategic, operational and tactical organizations within the DoD and the broader community.

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