Journal Article Watch

By: Dr. Jeffrey Rolfes

U.S. Air Force Staff Sgt. Jordan Brookshire, 60th Maintenance Squadron nondestructive inspection craftsman, processes controls for a magnetic particle inspection Aug. 5, 2021, at Travis Air Force Base, California. NDI specialists detect flaws such as cracks, voids and heat damage utilizing various test equipment. (U.S. Air Force by Heide Couch)

The research presented in this issue reflects the diversity and complexity of the weapons of mass destruction (WMD) threat, with contributions from experts in fields ranging from biology and chemistry to physics. The articles included in this issue provide a comprehensive overview of the current state of knowledge in WMD countermeasures, highlighting key challenges, opportunities, and areas for future research. By bringing together literature from a range of disciplines, this review aims to facilitate a deeper understanding of the WMD threat and the development of effective countermeasures. The following sections will provide a detailed overview of the research presented in this issue, highlighting key findings, implications, and areas for future study.

AN INTEGRATED CELL ATLAS OF THE LUNG IN HEALTH AND DISEASE

Summary of research:

The "Human Lung Cell Atlas (HLCA)" study aimed to address the question of how to integrate and understand the diverse cell types and states within the human lung in both health and disease. The main research question focused on creating a comprehensive single-cell transcriptomic atlas that captures the variability present in the population and provides insights into lung function and disease mechanisms. Using single-cell RNA sequencing (scRNA-seq) data from 49 datasets encompassing 2.4 million cells from 486 individuals, the study employed data integration techniques to generate a consensus cell type reference. The key findings revealed the identification of rare and previously undescribed cell types, as well as gene modules associated with demographic covariates such as age, sex, and body mass index. The HLCA also identified shared cell states across multiple lung diseases, including SPP1+ profibrotic monocyte-derived macrophages in COVID-19, pulmonary fibrosis, and lung carcinoma. The study recommends using the HLCA as a reference for rapid data annotation and interpretation, which can improve our understanding of lung function and disease, and aid in the development of targeted therapies. These findings highlight the importance of large-scale, cross-dataset organ atlases in advancing biomedical research and clinical applications.

Why it matters to CWMD:

The "Human Lung Cell Atlas (HLCA)" study primarily focuses on understanding the cellular landscape of the human lung in health and disease through single-cell transcriptomic analysis. The HLCA provides a reference for identifying cellular changes and biomarkers associated with lung diseases. This could improve the detection and diagnosis of respiratory conditions resulting from exposure to chemical or biological agents, enabling quicker and more accurate responses in the event of a WMD attack. While the HLCA study is not directly related to WMD, its contributions to respiratory health research can indirectly support efforts in biological defense, detection, diagnosis, therapeutic development, risk assessment, and policy formulation related to WMD threats.

REFERENCE:

Lisa Sikkema, Ciro Ramírez-Suástegui, Daniel C. Strobl, Tessa E. Gillett, Luke Zappia, Elo Madissoon, Nikolay S. Markov et al., "An integrated cell atlas of the lung in health and disease," *Nature medicine* 29, no. 6 (2023): 1563-1577, https://doi.org/10.1038/s41591-023-02327-2.

NUCLEAR SHELL-MODEL SIMULATION IN DIGITAL QUANTUM COMPUTERS

Summary of research:

The research investigates the feasibility of using quantum computing, specifically through the Adaptive Variational Quantum Eigensolver (ADAPT-VQE), to accurately simulate the ground states of atomic nuclei within the nuclear shell model framework. The key finding is that the relative error in the ground-state energy decreases exponentially as the number of layers in the ADAPT-VQE ansatz increases, with simulations suggesting that no more than 150 CNOT gates per layer are required to achieve percent-level accuracy for various selected nuclei. The methodology involved calculating ground states for nuclei across the p-, sd-, and pf-shell valence spaces using up to qubits and benchmarking against classical methods. Additionally, the study emphasizes that while the proposed quantum circuits show promise for simulating lighter nuclei, achieving a significant quantum advantage over classical techniques remains a challenge, particularly as the complexity of the nuclei increases. This work not only provides insights into the scalability of nuclear shell-model simulations on quantum devices but also opens avenues for further research into optimizing fermionic encodings to reduce resource requirements.

Why it matters to CWMD:

Research in quantum computing and the nuclear shell model has some implications for CWMD. The exploration of advanced computational methods, such as those discussed in the context of the nuclear shell model, enhances our understanding of nuclear structures and decay processes. This knowledge could become crucial in several ways. Even at the basic research level, the development of algorithms that efficiently model nuclear interactions could lead to breakthroughs in computational capabilities, which in turn can be applied to security domains related to WMD. Advanced quantum simulations can provide tools for verifying compliance with nuclear non-proliferation treaties by making it easier to analyze the nuclear capabilities of different states. This enhanced precision in nuclear modeling can aid in the development of verification technologies, making it more difficult for states to conceal their nuclear activities.

REFERENCE:

Axel Pérez-Obiol, A. M. Romero, J. Menéndez, A. Rios, A. García-Sáez, and B. Juliá-Díaz, "Nuclear shell-model simulation in digital quantum computers," *Scientific Reports* 13, no. 1 (2023): 12291, https://doi.org/10.1038/s41598-023-39263-7.

ULTRA-LOW-COST MECHANICAL SMARTPHONE ATTACHMENT FOR NO-CALIBRATION BLOOD PRESSURE MEASUREMENT

Summary of research:

The primary research question addressed in this study is whether a low-cost, smartphone-compatible blood pressure monitoring device, named BPClip, can accurately measure blood pressure without requiring per-user calibration. The key findings indicate that BPClip, which utilizes a spring-loaded mechanism to apply pressure and measure blood volume oscillations at the fingertip, demonstrated a mean absolute error of 8.72 mmHg for systolic blood pressure and 5.49 mmHg for diastolic blood pressure when validated against standard cuff measurements. This innovative device is compatible with any smartphone featuring a camera and LED light, making it accessible and affordable, with estimated material costs of only $0.80 per unit at a small production scale. The methodology involved a feasibility study with participants using the BPClip to measure their blood pressure, guided by a smartphone application that provided real-time feedback on the required pressure levels. The study highlights the potential for BPClip to democratize blood pressure monitoring, particularly in low-income communities, by enabling widespread access to essential health measurements without the need for expensive clinical infrastructure or specialized devices. The researchers aim for the BPClip to contribute to improved public health outcomes by facilitating at-home blood pressure management.

Why it matters to CWMD:

This development of a low-cost, easy-to-use blood pressure monitoring device, the BPClip, plays a crucial role in biodefense by enhancing health capabilities, particularly in the resource constrained environment that the military is facing. Access to effective health monitoring tools can significantly reduce the health information gap, which are exacerbated during crises, including those resulting from WMD threats. The BPClip's design facilitates widespread adoption, as it leverages existing smartphone technology to provide essential health monitoring, enabling early detection and management of hypertension. This is particularly pertinent in the context of public health emergencies where stress and exposure to environmental toxins and WMDs can lead to increased cardiovascular disorders. By ensuring that blood pressure monitoring is both affordable and widespread, this research supports the resilience of the military to health crises, contributing to national security through the monitoring the health of warfighters. Furthermore, the ability to monitor vital signs remotely can aid in timely medical response in disaster or pandemic scenarios, thereby mitigating the impact of potential WMD incidents on health systems.

REFERENCE:

Yinan Xuan, Colin Barry, Jessica De Souza, Jessica H. Wen, Nick Antipa, Alison A. Moore, and Edward J. Wang, "Ultra-low-cost mechanical smartphone attachment for no-calibration blood pressure measurement." *Scientific Reports* 13, no. 1 (2023): 8105, https://doi.org/10.1038/s41598-023-34431-1.

A LOW-COST SMARTPHONE FLUORESCENCE MICROSCOPE FOR RESEARCH, LIFE SCIENCE EDUCATION, AND STEM OUTREACH

Summary of research:

This study focuses on developing a low-cost smartphone fluorescence imaging setup, referred to as "glowscopes," which aims to address the challenge of providing accessible fluorescence microscopy for educational and research settings, particularly where budget constraints limit access to traditional, expensive fluorescence microscopes. The key findings indicate that these glowscopes can effectively detect green and red fluorophores with a resolution of 10 micrometers, allowing users to monitor vital biological functions, such as heart rate in live specimens like zebrafish embryos. The methodology employed involved assembling components like recreational LED flashlights and theater stage lighting filters, resulting in a build cost of under $50 per unit. This innovative approach not only enhances the educational experience by facilitating hands-on learning activities but also encourages broader participation in STEM education by making fluorescence microscopy more accessible to K and undergraduate students. The study illustrates that advancements in smartphone camera technology can significantly enhance scientific education and outreach and provides a feasible alternative for institutions lacking sufficient funding for high-end microscopy equipment.

Why it matters to CWMD:

The development of low-cost fluorescence microscopy technology, such as the glowscopes, holds implications for countering weapons of mass destruction. By facilitating access to advanced imaging techniques, this research empowers the educational apparatus to engage in crucial biological and chemical studies that can inform counter-proliferation efforts. Enhanced understanding of cellular and molecular mechanisms through fluorescence microscopy can lead to better detection methods for biological agents and toxins, contributing to public health and safety. Moreover, the accessibility of these tools can foster a new generation of scientists who are equipped and knowledgeable to address global security challenges. As the Army's educational outreach improves, it also increases awareness and preparedness against potential biological threats, ultimately enhancing resilience. The integration of similar technologies into educational curricula can play a pivotal role in enhancing the scientific literacy necessary for addressing complex issues associated with biodefense.

REFERENCE:

Madison A. Schaefer, Heather N. Nelson, John L. Butrum, James R. Gronseth, and Jacob H. Hines, "A low-cost smartphone fluorescence microscope for research, life science education, and STEM outreach," *Scientific Reports* 13, no. 1 (2023): 2722, https://doi.org/10.1038/s41598-023-29182-y.

BACTERIOPHAGE-BASED NANO-BIOSENSORS FOR THE FAST IMPEDIMETRIC DETERMINATION OF PATHOGENS IN FOOD SAMPLES

Summary of research:

The research demonstrates that a newly developed electrochemical impedimetric biosensor, utilizing a nanocomposite made from gold nanoparticles, multi-walled carbon nanotubes, and tungsten oxide, can achieve rapid and highly selective detection of the target pathogen in food samples. The methodology involved optimizing the electrochemical performance of disposable screen-printed electrodes with the nanocomposite and immobilizing a specific bacteriophage onto the sensor surface for enhanced sensitivity. The results indicate that the biosensor achieved a limit of detection of 3.0 colony-forming units per milliliter, with a recovery rate of 90-100% in various food matrices. This research underscores the potential of using phage-based biosensors for real-time monitoring of food safety, particularly in combating the health risks posed by pathogenic bacteria.

Why it matters to CWMD:

The ability to detect pathogenic microorganisms rapidly and accurately can enhance health responses to biological attacks or outbreaks caused by engineered pathogens. By providing a reliable method for monitoring food safety, the technology developed in this study not only addresses foodborne illnesses but also contributes to broader biosecurity efforts. The rapid detection capabilities of the bacteriophage-based biosensor can be crucial in emergency scenarios, enabling swift action to contain and mitigate the spread of harmful agents. Furthermore, the low-cost and disposable nature of the biosensors allows for widespread deployment in various settings, enhancing readiness against potential biological threats and ensuring food safety in vulnerable populations.

REFERENCE:

Nader Abdelhamied, Fatma Abdelrahman, Ayman El-Shibiny, and Rabeay YA Hassan, "Bacteriophage-based nano-biosensors for the fast impedimetric determination of pathogens in food samples," *Scientific Reports* 13, no. 1 (2023): 3498, https://doi.org/10.1038/s41598-023-30520-3.

SEMANTIC SEGMENTATION OF METHANE PLUMES WITH HYPERSPECTRAL MACHINE LEARNING MODELS

Summary of research:

This research addresses the significant challenge of detecting methane plumes in remote sensing data, specifically aiming to improve the accuracy and efficiency of automated detection methods. The main hypothesis revolves around the development of machine learning models that can accurately identify methane emissions while reducing false positive rates. The proposed models, HyperSTARCOP and MultiSTARCOP, demonstrate significantly improved performance over existing methods, with the HyperSTARCOP model achieving better semantic segmentation of methane plumes in hyperspectral data. The study utilized a robust dataset of verified methane plume images and background samples, employing a lightweight U-Net architecture for model training. The results underscore the potential of these models to operate effectively across different sensor types, showcasing their sensor agnosticism. This research contributes valuable insights and tools for enhancing methane detection methodologies, which are crucial for environmental monitoring and climate change mitigation.

Why it matters to CWMD:

Understanding and detecting methane emissions is vital not only for environmental reasons but also for national security, particularly in countering weapons of mass destruction. Methane is often associated with industrial activities, including oil and gas extraction, which can be linked to the proliferation of certain technologies and materials that could be misused. By enhancing the capabilities for real-time detection of methane leaks, this research offers a framework for monitoring industrial sites more effectively, which could serve as a deterrent against illicit activities associated with weapons production. The automated detection systems proposed in this study could help authorities quickly identify and respond to abnormal emissions that may indicate unauthorized activities. Furthermore, with the advancement of remote sensing technology and machine learning, this research promotes the development of monitoring systems that could provide actionable intelligence for national security agencies, thereby strengthening efforts to counteract the risks posed by weapons of mass destruction.

REFERENCE:

Vít Růžička, Gonzalo Mateo-Garcia, Luis Gómez-Chova, Anna Vaughan, Luis Guanter, and Andrew Markham, “Semantic segmentation of methane plumes with hyperspectral machine learning models,” *Scientific Reports* 13, no. 1 (2023): 19999, https://doi.org/10.1038/s41598-023-30310-x.

ACCURATE PREDICTION BY ALPHAFOLD2 FOR LIGAND BINDING IN A REDUCTIVE DEHALOGENASE AND IMPLICATIONS FOR PFAS (PER- AND POLYFLUOROALKYL SUBSTANCE) BIODEGRADATION

Summary of research:

The protein T7RdhA, derived from the bacterium Acidimicrobiaceae TMED77, can effectively bind ligands necessary for the biodegradation of per- and polyfluoroalkyl substances (PFASs) like perfluorooctanoic acid (PFOA). The key findings reveal that T7RdhA acts as a corrinoid iron-sulfur protein, utilizing a norpseudo-cobalamin cofactor and two iron-sulfur clusters for its catalytic function. Molecular dynamics simulations and ligand docking confirmed the protein's capability to bind PFOA, supporting its potential role in PFAS degradation. The methodology involved employing AlphaFold2 for structural predictions combined with experimental validation to assess ligand binding capabilities. This research highlights how AF2 can predict the dynamic interactions between proteins and their substrates, providing insights into enzyme functions relevant to environmental remediation efforts.

Why it matters to CWMD:

PFAS, known for their persistence and potential adverse health effects, pose significant risks in various contexts, including military and industrial applications. By understanding how specific enzymes, such as T7RdhA, can effectively degrade these substances, we can develop bioremediation strategies that mitigate the harmful effects of chemical pollutants. This contributes to national and global security by reducing the environmental footprint of hazardous materials. The advancement in bioremediation techniques enhances our ability to manage chemical threats and ensures a cleaner environment, which is vital for preventing the proliferation of harmful chemical agents associated with WMD.

REFERENCE:

Hao-Bo Guo, Vanessa A. Varaljay, Gary Kedziora, Kimberly Taylor, Sanaz Farajollahi, Nina Lombardo, Eric Harper et al., "Accurate prediction by AlphaFold2 for ligand binding in a reductive dehalogenase and implications for PFAS (per-and polyfluoroalkyl substance) biodegradation," *Scientific Reports* 13, no. 1 (2023): 4082, https://doi.org/10.1038/s41598-023-30310-x.

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