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Graduate School of Engineering and Management, Air Force Institute of Technology

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THE GRADUATE SCHOOL OF ENGINEERING AND MANAGEMENT

AFIT ENGINEER

Air Force Institute of Technology

Student Research Selected as AFMC Spark Tank Semi-finalist

Patent-pending Technique Measures Light Emission from Nanomaterial Infused Paint

By Katie Scott
Air Force Institute of Technology

Two alumni and one current PhD student from the Air Force Institute of Technology's Graduate School of Engineering and Management were selected as one of the top-two finalists in the Air Force Materiel Command's 2020 MAJCOM Spark Tank competition. Their submission provides an easier and more cost effective technique to measure strain on parts using a nanomaterial based paint. The team's submission will compete for the chance to be selected as the final six ideas Air Force wide in December to move to the finals at the Air Force Association Aerospace Warfare Symposium in February.

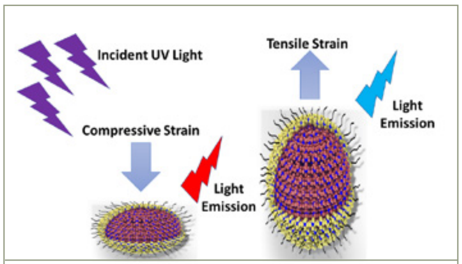
Spark Tank, a collaboration between AFWERX and the Deputy Under Secretary of the Air Force, Management, is an annual campaign designed to spur and empower innovative ideas from Airmen to further strengthen Air Force culture and capabilities.

The Spark Tank submission team includes 1st Lt. Michael Sherburne (M.S. Electrical Engineering, 2020), 1st Lt. Candice Roberts-Mueller (M.S. Aeronautical Engineering, 2020), and current AFIT PhD student Maj. John Brewer. Their submission is based on a patent-pending aircraft diagnostic technique using nanomaterial based paint. Colloidal quantum dots (CQDs), the nanomaterials used in this research, are infused as a polymer into paint and applied as a thin coating to an aircraft part. These quantum dots emit a specific wavelength of light when excited by a higher energy light, and when under strain, the dots emit a different wavelength of light. Using a camera that measures incoming light wavelengths, it is possible to measure the change in strain on the object. Using CDQs as an optical strain gauge could replace present testing techniques such as digital imaging correlation which can be challenging to setup.

"Maintenance technicians would only need to look at a screen that displays a 2D surface map of the strain, similar to how thermal cameras are used by firefighters to find people within a burning building," said Sherburne.

Testing the integrity and quality of aircraft structures is becoming more critical as the Air Force's fleet ages. However, applications for the patent-pending strain-sensing nanomaterial paint reach beyond aircraft and could be used in any industry requiring an optical strain gauge such as ships, ground vehicles, trains, bridges, and buildings.

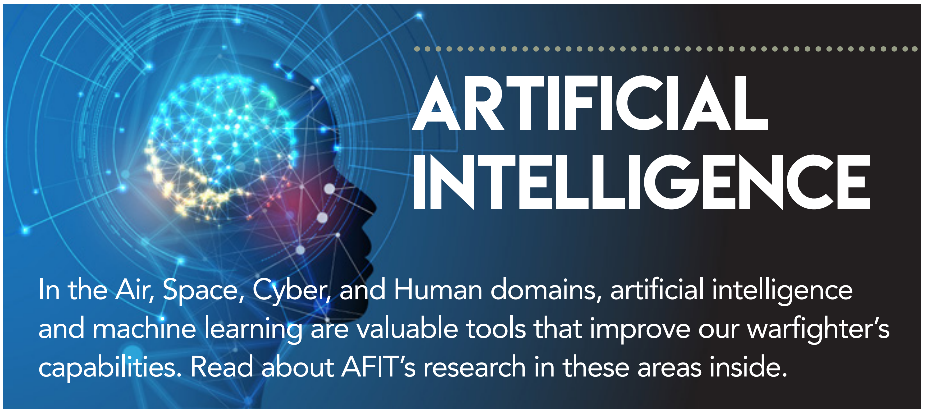
"The benefits for both the Department of the Defense and the civilian sector are many: reduce human error, fast scanning across any surface that the paint adheres to, and the ability to characterize strain on complex 3D printed parts," said Sherburne.



Contributed graphic

Research by the Air Force Institute of Technology and Los Alamos National Laboratory demonstrated that measuring the light emission from paint infused with nanomaterials can help identify strain on aircraft parts.

The Spark Tank submission is based on research completed at AFIT and Los Alamos National Laboratory published in the September 2020 American Chemical Society's Applied Materials & Interfaces journal. The article titled "Comprehensive Optical Strain Sensing Through the Use of Colloidal Quantum Dots" can be viewed at https://doi.org/10.1021/acsami.0c12110.



WHAT'S INSIDE

www.afit.edu/EN/afitengineer

AFIT is on the Right Path at Wright-Patt in Response to COVID-19 Pandemic

Dr. Adedeji Badiru

Welcome back to another edition of the AFIT ENgineer newsletter. This December 2020 issue (Volume 2 Issue 4) caps a tough year of unprecedented challenges in response to the COVID-19 pandemic. In spite of the operational impediments, we have continued to deliver our mission of teaching, research, and Air Force consultation, albeit using hybrid modes of operation. The pandemic has forced us to "grow up" faster than normal in the adoption of remote learning modes, online meeting tools, and conferencing in virtual space. Virtually-augmented reality became our calling card as we deliver education into uncharted landscapes. We quickly learned the arts of Zooming, PexlPing, MS-Teaming, Canvasing, Moodling, WebExing, Blackboarding, and so on. Our success in this endeavor is due to the resilience and adaptability of our faculty, staff, students, and administrators. We all banded together to keep our Air Force mission moving forward, unabated. Our uncompromised pursuit of the continuity of teaching, research, and consultation has led me to declare that:

AFIT is on the right path at Wright-Patt.

This declaration bears out our commitment to embrace and leverage the latest and emerging technologies that support the priority areas of the U.S. Air Force. This is confirmed by our emerging successes in Hypersonics, Artificial Intelligence, and the Digital Campaign. The creation of the U.S. Space Force (USSF) introduced a new dimension that our scholarly teams within the Graduate School of Engineering and Management have quickly embraced. The September issue of the AFIT ENgineer highlighted our contributions to space-related research and development. On the USSF workforce development, our school provided a good platform for harvesting well-groomed technical workforce for the Space Force. I am delighted by the continuing work of our Center for Space Research and Assurance (CSRA) in supporting USSF initiatives. We are in space and in step with USSF priorities in terms of educational programs, research studies, and consultation needs.

Through coordinated collaboration, our other research centers are also making contributions to USAF, USSF, and DoD organizations. The other research centers include Center for Cyberspace Research (CCR), Autonomy and Navigation Technology (ANT) Center, Center for Directed Energy (CDE), Nuclear Expertise for Advancing Technologies (NEAT) Center, Center for Technical Intelligence Studies and Research (CTISR), and Center for Operational Analysis (COA). Teamwork works well among our research centers.

In our continuing commitment to superior teaching, our TET (Teaching Evaluation Tool) is progressing well. I expect to have additional updates by the March 2021 issue of this newsletter. As always, we teach what we research and we research what we teach. We also practice what we teach and research.

In response to worldwide calls to combat the pandemic, please mask up and stay safe.

Respectfully,

Adedeji B. Badiru, Ph.D., PE, PMP, FIIE
Dean, Graduate School of Engineering and Management

EN OUTREACH

The AFIT ENGINEER is an official publication of the Air Force Institute of Technology, Graduate School of Engineering and Management.

Office of the Dean
2950 Hobson Way
Building 640, Room 302B
WPAFB, OH 45433

Patents Issued to AFIT Graduate School of Engineering & Management Faculty and Alumni

INVENTORS: Morgan Russell (M.S. Environmental Engineering & Science, 2017; now at AFLCMC); **Dr. John Stubbs** (Assistant Professor of Environmental Engineering & Science); **Lt Col David Kempisty** (M.S. Environmental Engineering & Science, 2006; former faculty member)

PATENT # 10,793,454 **DATE:** October 6, 2020

TITLE: Water Treatment System with Ultraviolet LEDs and Photo-catalysts

ABSTRACT: A reactor system for treating contaminated water is disclosed. The reactor system includes a reactor vessel having first and second end portions and an internal reactor volume defined by interior surfaces of the reactor vessel. A fluoropolymer coating is applied over at least a portion of the interior surfaces of the reactor vessel. The reactor system also includes a water inlet disposed in the first end portion and a water outlet disposed in the second end portion. At least one ultraviolet light-emitting diode (LED) is included and disposed so as to project ultraviolet light into the reactor vessel. A plurality of photo-catalyst substrates are also disposed within the internal reactor volume of the reactor vessel. Each of these substrates includes a coating of titanium dioxide applied to an outer surface of a substrate. A method for remediating contaminated water is also disclosed.

INVENTORS: Brian Cranston and **Dr. Anthony Palazotto** (Professor of Aerospace Engineering)

PATENT # 10,843,783 **DATE:** November 24, 2020

TITLE: Hexakis Icosahedron Frame-skin Vacuum Lighter Than Air Vehicle

ABSTRACT: A vacuum lighter than air vehicle (VLTAV) includes a rigid frame of rods connected together to form a hexakis icosahedron. A membrane skin covers the rigid frame and defines therewith a vessel configured to hold an internal vacuum that allows the vessel to float in the air. The plurality of rods and membrane skin have weights and dimensions that result in a neutral and/or positive buoyancy for the vessel while preventing geometric instability.

AFIT Academic Institutional Advancement

By Adedeji Badiru, Dean
Graduate School of Engineering and Management
Air Force Institute of Technology

> ***"The single biggest problem in communication is the illusion that it has taken place."***
> ***– George Bernard Shaw***

In academia, no aspiration is bigger than the goal of achieving, advancing, and sustaining institutional advancement. Unfortunately, institutional advancement does not happen by default. It must be pursued proactively through external communication to promote the accomplishments of the institution and sensitize all stakeholders to the prevailing priorities and needs of the institution. More often than not, academic institutions rest on their laurels under the assumption that everyone already knows what needs to be known about the institution. But as the opening quote above by George Bernard Shaw cautions us, "the single biggest problem in communication is the illusion that it has taken place." Therein lies the danger of becoming lackadaisical in an academic institution's communication strategies.

It helps when we have an internal team that is proactive in collating information and developing processes for strategic dissemination to all stakeholders, both internally and externally. This brings me to the direct observation of the teamwork of two of our AFIT colleagues, **Ms. Katie Scott** and **Ms. Stacy Burns**, who proactively take it upon themselves to constantly watch out for shareable nuggets of AFIT information to compile, vet, and disseminate through a variety of communication media. The dedication and consistency of their pursuit of AFIT's institutional advancement is worthy of being recognized and celebrated publicly. Hence, the motivation for me to write this brief article to thank them and encourage them to continue to do that which they already do so well. From a teamwork perspective, we all have a role to play in promoting our institution whether or not we have an official portfolio of functions to do so. In this respect, institutional advancement is the responsibility of everyone. I call upon all of us to operate accordingly.

Maslow's Hierarchy of Needs teaches us about respective needs of individuals along the rungs of the pyramid of needs, going from basic physiological needs, security needs, love and belonging needs, esteem needs, and ending at the self-actualization needs. In my seminars and presentations, I typically expand the 2-D triangle to a 3-D pyramid with one side added for "organizational needs." So, as we pursue our individual needs, so also must we concurrently recognize and appreciate the needs of the organization, within which we work. Institutional advancement is a critical need of our institution and we must recognize it as such. May we all band together to advance AFIT further, just as we are advancing our individual personal needs.

Second Annual GSEM Award Winners Announced

The value of an academic institution is a function of the accomplishments of its people (faculty, staff, students, and administrators) in both internal and external engagements pertaining to teaching, research, and professional service. The people of AFIT's Graduate School of Engineering and Management (GSEM) continue to excel along all the dimensions of scholarship and preeminence. Please join us in recognizing and congratulating our 2020 GSEM award winners.

2020 GSEM ADVISING & MENTORING AWARD

DR. SCOTT GRAHAM
DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING

AWARD CRITERIA: Recognizes faculty's efforts as an academic/research advisor and mentor to AFIT graduate students; recognizes creativity for advising in a way that promotes student learning, performance, achievement, progress/ success, engagement, growth and connectedness.

Dr. Scott Graham clearly demonstrates a long-term commitment to students. Since his return to faculty as a civilian professor in 2015, he has mentored over 56 students, either through direct advising or through active mentoring on committees. He advised and graduated 16 MS and 3 PhD students, and served on the committees of 17 graduated MS students. He is currently advising 4 MS and 5 PhD students, while serving on 8 committees for the 21M class, as well as 3 PhD committees. Dr. Graham is known for his skill, finesse and commitment to helping students succeed.

2020 GSEM EARLY CAREER ACHIEVEMENT AWARD

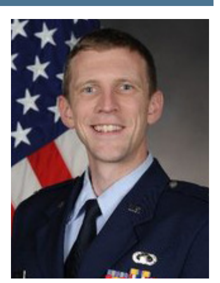
MAJ ROBERT BETTINGER
DEPARTMENT OF AERONAUTICS & ASTRONAUTICS

AWARD CRITERIA: Recognizes exemplary contributions to teaching, scholarship, and service following the formative years (the first 3 years) of a junior faculty member's initial appointment. While nominees may excel in 1 or 2 areas, they must be successful in all 3.

Maj Bettinger is among department (ENY) faculty with the highest scholarly performance and research productivity. In his first three years on faculty, Maj Bettinger made an indelible impression on AFIT by developing two new graduate-level courses as part of the Astronautical Engineering and Space Systems curriculum and created a new Graduate Certificate in Space Vehicle Design. Furthermore, he successfully served as Curriculum Chair, which is a position normally held by senior faculty. Maj Bettinger led the growth of a research relationship with the French Air Force Academy and serves as AFIT's Liaison with our French allies. His research output of 10 journal publications and over $1M in secured research funding in just 3 years is outstanding. A high-impact researcher, Maj Bettinger was awarded 2 provisional patents!

2020 GSEM TEACHING AWARD

MAJ JOSHUAH HESS
DEPARTMENT OF AERONAUTICS & ASTRONAUTICS



AWARD CRITERIA: Recognizes faculty who have contributed significantly to the intellectual life of GSEM through demonstrated excellence in classroom teaching; represents innovative curricular leadership over sustained period of time (tenure-track and tenured faculty).

Maj Hess has enthusiastically demonstrated the pedagogical practices inherent in a successful graduate educator. His record in and out of the classroom has been strong, as evidenced by his reputation among the student body and faculty. Maj Hess taught guidance, navigation, and control theory over the past four years, and has reinvigorated his courses with state-of-the-art technology (whether through software or incorporating new publications). He challenges students to push themselves intellectually, while making himself available at unprecedented times. Maj Hess led the 4-member plus Center for Space Research Assurance (CSRA) Orbital Warfare research team and has shaped his courses to support $500K in funding. He developed a new course in satellite rendezvous and proximity operations that has received top marks and has been offered both at AFIT and to members of the acquisition and intelligence communities.

2020 GSEM OUTSTANDING STAFF AWARD

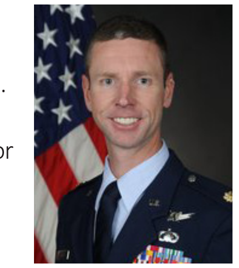
MS. ALICIA SPRINKLE
DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING

AWARD CRITERIA: Award recognizes exceptional service by administrative, support and technical staff employees in the GSEM.

Ms. Sprinkle clearly demonstrates a commitment to students, faculty and staff within the department (ENG) and the school. When she recognizes a challenge, problem, or issue, she immediately seizes an improvement opportunity for herself, the students, the department, and in many cases, the Graduate School of Engineering Management. Her positive attitude is a shining beacon – setting the example for others to follow. Since Oct. 2018, she has touched and improved the lives of many at AFIT – routinely exceeding her assigned duties as the graduate advisor to go above and beyond the call of duty. Acting as the interim advisor for the department's students upon their arrival, she engaged with 307 students, directly helping them clearly think about their strategy for completing the degree – she helps them form their education plans and assists them with enrollment and registration in one of the most stressful times of their program. With her careful, early mentorship, students develop their education plans efficiently and have been able to quickly focus on courses and research.

2020 GSEM RESEARCH AWARD

LT COL JAMES RUTLEDGE
DEPARTMENT OF AERONAUTICS & ASTRONAUTICS



AWARD CRITERIA: Recognizes outstanding scholars/researchers known externally in the academic community as leaders in their discipline. Recipient is singled out for distinction of his/her track record of scholarly research, and primarily for efforts while at AFIT.

Lt Col Rutledge's significant research contributions have resulted in the furtherance of national security. Lt Col Rutledge has pursued advancements in our understanding of heat transfer since he began specializing in gas turbine engines as an undergraduate student prior to entering the Air Force in 2002. A short summary of impressive metrics arising from his research accomplishments include 31 journal articles (and another two pending publication), 38 conference papers, two patents (with a third patent pending), and two American Society of Mechanical Engineers (ASME) Turbo Expo Best Paper awards. Additionally, he is an associate editor of the ASME Journal of Turbomachinery and was recently named a Fellow of ASME, both of which are exceptionally rare feats for a military member. Lt Col Rutledge has been recognized through various awards, including being named Outstanding Scientist/Engineer by the Air Education and Training Command in 2015 and 2019 and the Outstanding Science/Engineering Educator by Air Force Materiel Command (AFMC) in 2020. These awards recognize his contributions to turbine engines and highlight the application of his expertise to a number of other problems faced by the Department of Defense. Lt Col Rutledge was selected as the Graduate School's first-ever Senior Military Faculty where he will continue to advance the AFIT mission for years to come!

2020 GSEM FACULTY SERVICE AWARD

DR. MARC POLANKA
DEPARTMENT OF AERONAUTICS & ASTRONAUTICS

AWARD CRITERIA: Recognizes exceptional achievements in service to GSEM, AFIT, the profession, discipline, and/or to the public. Evidenced by activities beyond normal expectations, unique contributions or long-standing leadership and impact on GSEM and beyond.

Dr. Polanka's service to the profession is truly exemplary. He led the local American Institute of Aeronautics and Astronautics (AIAA) chapter in various capacities, even serving multiple terms as the section chair. Through his leadership, he ensured that the AIAA Dayton-Cincinnati Aerospace Sciences Symposium remains THE local conference for engineers and scientists to present work of interest to the local aerospace community. He currently leads the local AIAA section's honors and awards committee, recognizing excellence from high schoolers to university professors. Dr. Polanka serves as the AFIT AIAA student chapter advisor, providing opportunities for its 30 members within the AFIT community to hone their presentation skills and network with myriad aerospace professionals. Dr. Polanka is the chair of the National AIAA Associate Fellow committee and in this capacity, he supervised the selection of 134 new AIAA Associate Fellows from the seven regions of AIAA. Dr. Polanka has served as a faculty administrative fellow in the Graduate School since 2016. In that capacity, he contributed to faculty development opportunities and built upon AFIT's efforts to advance the faculty teaching assessment by implementing the development of the Teaching Evaluation Tool (TET) plan for the Graduate School.

AFIT Graduate School Dean Receives Taylor & Francis Lifetime Achievement Award

By Katie Scott
Air Force Institute of Technology

Dr. Adedeji Badiru, dean of the Air Force Institute of Technology's Graduate School of Engineering and Management, received the second annual Taylor & Francis Lifetime Achievement Award during a virtual ceremony on Oct. 30.

This award is in honor of Badiru's significant and pioneering contributions in the field of industrial and systems engineering and for his extensive publication record including books, book chapters, and also serving as the series editor or co-series editor of the Systems Innovation Book Series, the Environmental and Occupational Health Series, and the Analytics and Control Series. Badiru is dedicated to developing these series with important contributions from leaders in related disciplines, and from prominent young authors and scientists he's mentored as an accomplished Professor.

The Taylor & Francis Group is one of the world's leading publishers of scholarly journals, books, ebooks and reference works in Humanities, Social Sciences, Behavioral Sciences, Science, Technology and Medicine.

Contributed photo

Dr. Adedeji Badiru, dean of the Air Force Institute of Technology's Graduate School of Engineering and Management, accepted the second annual Taylor & Francis Lifetime Achievement Award during a virtual ceremony on Oct. 30.

"I am honored and delighted to be recognized with this rare award by Taylor & Francis Group," said Badiru. "The satisfaction I get from this award is not on the basis of what I have published myself, but the multiplier effect of mentoring new authors into the world of scholarly publishing."

Badiru joined the Graduate School of Engineering and Management in 2006 as the head of the Systems and Engineering Management department. He was promoted to the school's dean in 2013 where he is responsible for planning, directing, and controlling operations related to granting doctoral and master's degrees, professional continuing cyber education, and research and development programs.

A prolific author, Badiru has written with over 35 books, more than 30 book chapters, over 130 journal and magazine articles, and more than 200 conference presentations.

Badiru earned his doctoral degree from the University of Central Florida in Industrial Engineering. He is a registered professional engineer and a certified Project Management Professional. He is a Fellow of the Institute of Industrial & Systems Engineering and a Fellow of the Nigerian Academy of Engineering.

Dr. Badiru is also a member of several professional associations and scholastic honor societies including the Institute for Operations Research and the Management Sciences and the American Society for Engineering Education.

GRAD SCHOOL NEWS BRIEFS

CENTRAL STATE VISIT

Dr. Jack Thomas, President of Central State University, along with members of his senior staff, visited the Air Force Institute of Technology on Sept. 16, 2020. Thomas and his team met with AFIT leadership to discuss joint educational programs including an online technical MBA program and student intern programs for CSU research assistants. Opportunities for adjunct faculty appointments and use of research facilities were also discussed.

"We appreciated the opportunity to host Dr. Thomas and his colleagues on their first visit to Wright-Patterson AFB and AFIT," said Dr. Todd Stewart, AFIT Director and Chancellor. "The visit gave us the opportunity to highlight the potential for mutually-beneficial collaboration with other organizations at Wright-Patterson, like the Air Force Research Laboratory."

"The 1890 Land Grant designation of CSU brings unique opportunities for AFIT to leverage our technical capabilities in diverse STEM areas to partner with CSU in mutual pursuit of economic development programs fitting the ideals of a land grant institution," said Dr. Adedeji Badiru, Dean of AFIT's Graduate School of Engineering and Management.

AFIT ALUM RECEIVES U.S. SPACE FORCE ASSIGNMENT

Brig. Gen. Douglas A. Schiess (Master of Space Systems, 2004) will be assigned as director, space and cyber operations, Space Operations Command, U.S. Space Force, Peterson Air Force Base, Colorado. Schiess is currently serving as commander, 45th Space Wing; and director, Eastern Range, U.S. Space Force, Patrick Air Force Base, Florida.

AIRMEN TRANSITION TO SPACE PROFESSIONALS

In a virtual, world-wide event led by U.S. Space Force Chief of Space Operations Gen. John W. "Jay" Raymond, 15 Airmen from across Wright-Patterson Air Force Base ceremonially swore into the Space Force Sept. 15, 2020. More than 300 space professionals participated, including seven company grade officers and eight enlisted Airmen from the Air Force Institute of Technology and the National Air and Space Intelligence Center.

AFIT ALUM PROFILE: Major Solomon Sonya

By Katie Scott
Air Force Institute of Technology

Major Solomon Sonya

Major Solomon Sonya earned a master's of science degree in computer science from AFIT's Graduate School of Engineering and Management in 2014. He is an avid programmer and researcher focusing on the analysis of malware and computer memory management. "AFIT challenged me in many areas I did not know before and provided room for growth and devoted self-study that enriched my knowledge tremendously," said Sonya. "AFIT was a key part of strengthening my abilities to help me get to where I am today."

Sonya assumed command of the 39th Information Operations Squadron, Detachment 1 in June 2020. Located at Joint Base San Antonio-Lackland, Texas, the 150 person organization provides initial qualification training to Airmen destined for offensive cyber operations work roles. "We train all cyber attack Airmen who are outplaced to work at one of four squadrons within the 67th Cyberspace Operations Group and are expanding to train Airmen within the intelligence community and to our sister service branches as well," said Sonya.

Sonya's goal for his new role is to grow his organization to be a lethal offensive cyber operations training unit to best prepare individuals to defend the U.S. from cyber attacks. He is leaning on the education and experiences from his time at AFIT to be successful. "I remember the stress of completing my thesis at AFIT. I had a slightly elaborate thesis in which six or seven different laptops were used to run the project. I also remember the confidence created by completing such a large undertaking," recalls Sonya. "This gives me confidence to know that it will be possible to succeed in this new position and lead the Air Force's first offensive cyber operations formal training unit."

While a student at AFIT, Sonya's thesis research on a new secured distributed-access protection system received the 2014 Association of Old Crows Academic Research Excellence Award in Information Superiority. He credits the research process for expanding his knowledge and abilities. "Every project I have done since AFIT starts with an appropriate research hypotheses and then tests to prove or disprove the hypotheses," Sonya said. "I used that approach to interface with our mission partner and change the way the DoD selects and trains its interactive cyber attack operators."

Sonya has published several papers and received invitations to speak about his research from organizations all over the world. He believes his work with his advisor, Dr. Barry Mullins, was critical to that success and recalled one assignment in particular that changed his life. "Dr. Mullins taught our cyber attack course. There was an assignment to research a cyber tool and I asked Dr. Mullins if instead of researching other peoples' tools, can I create a tool and demonstrate it and to my surprise, Dr. Mullins said yes," Sonya said. "I developed a tool called Splinter the RAT (Remote Administration Tool) which allowed me to better recognize how tools like these could be detected across enterprise networks."

The research to develop the Splinter the RAT was presented by Sonya and his research partner Nick Kulesza at cyber conferences across the U.S. and to international audiences in Norway, France, Belgium, Luxembourg, Slovakia, Canada, and Sweden. "Dr. Mullins was a godsend for me getting to where I am today. He was an amazing advisor giving me flexibility to grow and explore," said Sonya.

Two Alumni Selected for AY21 Blue Horizons Fellowship

Major Benjamin Heruska (M.S. Computer Engineering, 2015) and Major Kassandra M. Miller (M.S. Operations Research 2011) were selected as AY21 Blue Horizons Fellows.

The Blue Horizons program is a 10-month professional developmental education program with the charter to explore issues of future geo-strategic and military-technological competition as they relate to building advantage for the United States.

Major Benjamin Heruska (M.S. Computer Engineering, 2015) commissioned in 2008 through the Air Force Reserve Officer Training Corps at Georgia Tech, and is a Computer Engineer, specializing in cyber and qualified as a cyber operations officer.

Major Kassandra M. Miller (M.S. Operations Research 2011) is an Operations Research Analyst specializing in Space Policy and Defense. She received her commission and BS in Operations Research in 2007 from the United States Air Force Academy.

AFIT Alumni Selected as AFRL Early Career Award Recipients

Dr. Nicholas Kovach (PhD Computer Science, 2016 and M.S. Cyber Operations, 2010) and Dr. Mark Spencer (PhD Optical Sciences & Engineering, 2014 and M.S. Optical Sciences & Engineering, 2011) are recipients of the 2020 Air Force Research Laboratory Science and Engineering Early Career Award.

Kovach is a research electronics engineer within AFRL's Sensors Directorate at Wright-Patterson AFB, Ohio. He is also the recipient of the 2019 AFIT Young Alumni Award.

Spencer is a senior research physicist within AFRL's Directed Energy Directorate at Kirtland AFB, N.M. where he leads research to understand deep atmospheric turbulence. He has two U.S. patents, including one with fellow AFIT alum Lt. Col. Casey Pellizzari (M.S. Electrical Engineering, 2010, DG), an assistant professor at the United States Air Force Academy.

Artificial Intelligence

AIR

Nearly since the beginning of flight, engineers have envisioned aircraft that fly autonomously. However, most current technology to automate aircraft flying have been tools to aid pilots such as autopilot systems that hold heading and altitude. AFIT has been developing these kinds of technologies for autonomous aircraft for many years in the forms of different controls technologies.

Recently AFIT has expanded research into AI technologies for aircraft. The most recent approaches have used deep learning to determine the algorithms required to pilot autonomous aircraft. These approaches aim to give users a push button capability to execute parts of missions that were typically done manually.

In this section there are three articles by current AFIT master's students using deep learning. The first two student articles showcase autonomy technologies for previously manual missions, air combat and aerial refueling. The final article introduces autonomy technology to fly a hypersonic glide vehicle to avoid obstacles and hit a ground target, a mission that is difficult and risky (since the vehicle is not intended to survive).

Automatic Jet Aircraft Control with Deep Reinforcement Learning Agent

By Capt Tyler Brown
MS Student, Department of Electrical and Computer Engineering
Air Force Institute of Technology

Technology is evolving at a rapid pace in the United States and the rest of the world, with computing power increasing one-trillion fold between 1956 and 2015. Artificial intelligence (AI) has exploded from an exponential gain in computing resources over the last century. A key component of defense is maintaining air superiority, which motivated this research to explore the emergent behavior of an AI agent pilot controlling a jet aircraft: Calspan's LJ-25D Learjet. A Variable Stability System (VSS) mod provides the capability to safely deploy an agent structured by a deep reinforcement learning, a cutting-edge AI algorithm. Automatic control of the Learjet is conducted by this agent through an action space that includes various commands down to the stick, rudder, and throttles. The agent is also supplied with an observation space that includes the current aircraft state trajectory and relative environmental states to make decisions. Finally, the agent "learns" through a reward and penalty function based on the error in achieving a desired goal, and adjusts weights in a neural network that approximates the flight environment and relative airspace. The dynamics model used as part of the environment was the Stitched Learjet Simulink model from USAF Test Pilot School, which was auto-coded to C++ to accelerate training time. The development and validation of this model led to an increase in run time speed 130x faster than the original. Part of this research explored an aerial rejoin task of a Learjet to an F-16 with 99% success rate after the agent was trained for one-billion time steps. To put that in perspective, that equates to ~32 years of flight experience for the AI agent, but with the super-computing resources available of 125 cores/250 threads, only took roughly 24 hours to train. The agent was tested first in simulation, and will be followed by real-world flight test experiments under USAFTPS project Have DEEPSKY.

AFIT Focuses on Improving AAR Position Estimation

By Lt Josh Larson
MS Student, Department of Electrical and Computer Engineering
Air Force Institute of Technology

The Air Force Institute of Technology is supporting the Air Mission of the USAF through Automated Aerial Refueling (AAR). AAR is the process of refueling a receiving aircraft without a pilot or boom operator in the tanker, and is a requirement for the aerial refueling of UAVs. The overall process can be broken down into two parts: knowing the type and position of the receiving aircraft and controlling the boom to refuel the receiver. The latter is a well-understood component of robotics, but the former is more complicated and is typically solved with the help of machine learning.

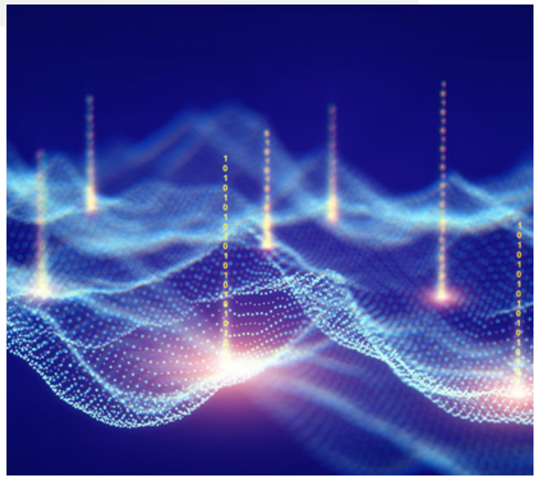
Since the primary challenge of AAR is the position estimation of the receiver, most of AFIT's focus is on improving that. There are two components of position estimation for AAR: 1) turning images into a 3D point cloud representing how far away each pixel of the image is from the tanker and 2) using this 3D point cloud to compute the relative position of the receiver from the tanker's perspective. As information propagates through each step of this system, most of the data requires a combination of filtering and analysis: both of which are machine learning's strengths.

One of the most important ways machine learning is used for AAR is to filter out areas of the input images that don't include the receiver. This dramatically increases the speed and accuracy of the system, because all subsequent algorithms are focused on the aircraft alone [1], [2]. Another important area where machine learning can be used is for receiver recognition: determining whether the tanker is refueling an F-15, F-16, or another aircraft. This allows the boom control algorithm to know where on the aircraft the refueling port is. Finally, current active research at AFIT for AAR is to use machine learning to improve the distance estimation for each pixel of the image—leading to increased position estimation accuracy.

[1] C. Parsons, Z. Paulson, S. Nykl, W. Dallman, B. G. Woolley, and J. Pecarina, "Analysis of Simulated Imagery for Real-Time Vision-Based Automated Aerial Refueling," *J. Aerosp. Inf. Syst.*, vol. 16, no. 3, pp. 77–93, Mar. 2019, doi: 10.2514/1.I010658.

[2] A. Lee, W. Dallmann, S. Nykl, C. Taylor, and B. Borghetti, "Long-Range Pose Estimation for Aerial Refueling Approaches Using Deep Neural Networks," *J. Aerosp. Inf. Syst.*, vol. 17, no. 11, pp. 634–646, Nov. 2020, doi: 10.2514/1.I010842.

"One of the most important ways machine learning is used for AAR is to filter out areas of the input images that don't include the receiver. This dramatically increases the speed and accuracy of the system."



Training ANNs to Fly Hypersonic Vehicles

By Lt Andrej Lysak
MS Student, Department of Aeronautics and Astronautics
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Hypersonic vehicles have the potential to revolutionize warfare. Traveling at speeds in excess of Mach 5, they have the potential to reach targets thousands of miles away in minutes. While ballistic missiles travel at similar speeds, they follow predictable trajectories allowing for a fast response by anti-ballistic missile batteries. Endo-atmospheric hypersonic vehicles on the other hand are able to maneuver during their entire trajectory, allowing them to mask their true target for nearly their entire flight. When their target is finally apparent, it might be too late for missile defense systems to engage the hypersonic vehicle before it impacts the target.

These hypersonic vehicles however, are exceedingly complex. They require unprecedented coordination between disciplines ranging from materials scientists to software engineers. Hypersonic vehicles have a number of constraints that traditional weapons systems do not. Traveling at hypersonic speeds within the atmosphere generates not only large structural stresses, but also significant heating loads. Exceeding any of the vehicle design parameters could lead to catastrophic failure. The vehicle must not only navigate towards its target, but also manage heating loads, g-forces, and dynamic pressure constraints. This makes trajectory generation for hypersonic vehicles extremely difficult. Optimizing such trajectories is highly computationally intensive, requiring the resources of massive computing clusters. Furthermore, such precomputed trajectories are static and cannot adjust to changing situations, limiting their operational usefulness.

"Traveling at hypersonic speeds within the atmosphere generates not only large structural stresses, but also significant heating loads. Exceeding any of the vehicle design parameters could lead to catastrophic failure."

One solution is to train an Artificial Neural Network (ANN) to fly the vehicle. The ANN, also referred to as an Artificial Intelligence (AI) or agent, receives information about the environment from virtual sensors, and then decides what actions to take with its virtual control surfaces. This research explores training such an ANN to fly a Hypersonic Glide Vehicle (HGV) from an insertion point to its target. An HGV is a vehicle that is accelerated to high altitude and hypersonic speeds with a booster rocket. The HGV is then released at an insertion point and from there flies to its target without any additional thrust.

The environment the agent trains in uses the OpenAI Gym library in Python. The Ray library is used to allow parallel training of multiple agents in separate simulations. Parallelization is important as it allows the agent to utilize multiple processing nodes available on High Powered Computing (HPC) clusters to train more quickly. Hundreds or even potentially thousands of agents can be trained simultaneously. The most successful agents can then be used in wargaming or could potentially be uploaded onto HGVs for operational employment.

The AI is trained through a series of increasing difficult challenges. The first step for any agent is to learn to reach the ground without violating any of its design parameters. Once the agent is capable of learning and is able to reach the ground, the next step is to train the AI to fly towards a target and hit the ground as close as possible. Once the agent is capable of impacting close to the target, the simulation increases in complexity. The start conditions begin to vary within a range to ensure that the ANN is robust enough to handle a wide array of insertion conditions. Once the agent can hit the target with varied start conditions, keep-out zones are added. Entering such a zone causes the agent to "die" in the same way as it would were it to violate any other constraint. The goal here is to train the agent to navigate towards the target while avoiding certain areas. The number of keep-out zones can be increased as the agent becomes capable of navigating an increasingly constrained airspace.

Once the AI is capable of hitting a target that is surrounded by several keep-out zones, the next step is to introduce hostile agents into the simulation. These agents themselves learn and are rewarded for stopping the HGV from reaching its target. The defending agents do not necessarily need to destroy the HGV. If they are able to force an HGV to turn away from its target then they will have won. The final challenge introduces additional agents into the simulation and allows the agents to explore small unit tactics. Agents are pitted against each other in 2v1, 2v2, 3v2, etc. engagements. This allows us to observe tactics developed by the AI and analyze their effectiveness in potential operational scenarios.

Artificial Intelligence
SPACE

Space operations were once characterized by a team of operators diligently monitoring a plethora of satellite subsystems via downlinked telemetry to ensure planned satellite maneuvers and onboard operations are accurate, fuel and power efficient, and lead to mission success. Gone are such luxuries of intense human-in-the-loop operations for modern satellite operations. The United States Space Force is faced with the challenge of operating ever more complex satellites at a faster cadence in an ever increasing contested and congested space environment. Addressing some of these challenges, the Center for Space Research and Assurance (CSRA) is conducting research on specific applications of Artificial Intelligence and Machine Learning to facilitate autonomous operations for the U.S. Space Force on its complex mission set, such as rendezvous, docking, refueling, and additional tasks associated with space warfighting. The following articles overview the need and provide examples of the use of AI for autonomous operations in the space domain.

Artificial Intelligence Applied to Pursuer-evader Multi-satellite Differential Games

By Lt Col Rachel M. Derbis, AIAA Member
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Space is an acknowledged warfighting domain. Developments in Space Domain Awareness are foundational in locating objects and identifying those that pose a threat. Once threats are identified, the ability to rapidly respond is required. For increasingly complex multi-satellite scenarios, the use of Artificial Intelligence can be used to search the state space for optimal solutions shortening the timeline for a response. Although proximity operations simulations have been developed, limited multi-satellite analysis has occurred. A three pursuer one evader satellite differential game was completed. The pursuer satellites use a simplified herding scenario that tries to intercept the evader satellite. Relative satellite motion is modeled with Hill Clohessy-Wiltshire equations. Using the pursuer satellite locations and their forecasted trajectories, the evading satellite seeks to calculate the optimal thrust angle to maximize the distance for the closest approach from any of the pursuers.

The few multi-agent pursuer-evader differential games that have been studied are planar with either two pursuers and one evader, or two evaders and one pursuer. Computational complexity increases exponentially for a differential game with greater numbers of pursuers / evaders in three-dimensions. In the scenario studied, each pursuer satellites completes a single maneuver, with one of them reaching the origin to prompt the evader satellite to move, in an attempt to herd it into the vicinity of the other pursuers.

The initial game state includes the starting and ending positions for the pursuer satellites, percentage of the orbital period for the pursuers to reach their destinations, and the maximum thrust magnitude for the evading satellite. The radial in-track cross track reference frame is used with the evader satellite located at the origin. From the initial conditions the required velocity components for the pursuers are calculated and subsequently based on impulsive burns, the positions are propogate throughout the duration of the scenario. The maneuver options for the evader corresponds to discrete angles for thrust within the orbital plane. The optimal escape trajectory corresponds to the maneuver with the greatest distance between the evader and pursuers. The angle and components of the thrust in each direction are the scenario solution output. Multiple game iterations were conducted varying the pursuers initial and final positions as well as using different percentage of the orbital period for the interceptors to complete their maneuver.

A pressing need exists to study space as a warfighting domain, specifically Rendezvous and Proximity Operations to respond to potential threats. The analysis developed an Artificial Intelligence optimal trajectory solver to rapidly identify the maneuver required for a satellite to maximize its distance from all pursuing vehicles.

Researching Applications of Artificial Intelligence to Spacecraft Attitude Control

By 1Lt Cecily Agu
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A spacecraft's attitude refers to its spatial orientation with respect to a reference frame, allowing for the accomplishment of various mission activities. Control allocation refers to the assignment of computed control to discrete onboard actuators. There are several machine learning (ML) methods currently being developed for spacecraft control allocation. Effective applications of such methods include those for spacecraft hovering in unknown dynamical environments of asteroids, finding low-thrust trajectories in cis-lunar space, and the learning and implementation of guidance strategies onboard spacecraft. ML has several approaches that are traditionally divided into the three broad categories of supervised, unsupervised, and reinforcement learning (RL). RL has recently shown promise in solving difficult numerical problems and spacecraft attitude control problems are an ideal candidate for the application of such methodologies.

1Lt Agu's research is investigating if RL techniques can be applied to traditional methods of spacecraft attitude control and control allocation to improve overall performance. Using a simulated spacecraft environment, her research seeks to utilize an RL controller for attitude control for a variety of spacecraft. Preliminary results demonstrate the ability of the RL agent to integrate with the attitude control system and to meet environmental constraints.

1Lt Agu will continue to innovate the algorithms for higher fidelity simulations to gain additional insights into attitude control performance enhancements enabled by RL.

Proximal Policy Optimization for Space Pursuer-evader Scenarios

By 2d Lt Mark Adams
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Leaps in computational power and algorithm development have led to an exponential increase in artificial intelligence research over the past decade. Meanwhile, the space domain has continued to become more contested and congested, with frequent maneuvers making an increased threat to satellite assets. This constantly changing space environment necessitates responsive and accurate maneuvering. Moreover, it requires mitigation strategies in situations involving hostile actors. As strategies must be enacted precisely and quickly, and the domain is dynamic and difficult to model, machine learning is well situated to handle the task. In the current research, the deep reinforcement learning framework is applied to generate optimal spacecraft movement.

Utilizing Hill Clohessy-Wiltshire dynamics, a decaying reward space, relative position observations, and limited-burn actions, Proximal Policy Optimization (PPO) is used in pursuer-evader scenarios to train two opposing satellite agents. During training, the agents are subjected to multiple adversarial strategies in order to induce more robust policies. While currently only achieving sub-human performance, this research demonstrates the merit of deep reinforcement learning, exploiter agents, and league learning in the space maneuver domain and presents a forward path for more agile and tactical satellites.

Future research will use league play like the AlphaStar agent by DeepMind to achieve human level performance by learning many different strategies for different opponents and situations.

Spacecraft Moment of Inertia Estimation via Recurrent Neural Networks

By 2d Lt Nate Enders
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Machine learning has seen a surge in popularity over the past few years, in part, for its ability to help make predictions. Making predictions or estimations can sometimes be difficult when there is a large amount of data. In situations where enough data is available, neural networks can be a powerful tool for gaining insight into certain aspects of the data. One of the main benefits of using neural networks over other machine learning techniques is the ability of neural networks to handle complex and highly nonlinear data.

One application of neural networks is the estimation of a spacecraft's moment of inertia (MOI), which is a measure of how the mass is distributed throughout the spacecraft. Normally, this would be calculated and determined before the spacecraft is launched, but there are scenarios where the MOI may be unknown. For example, if a spacecraft docks with a defunct satellite whose mass is unknown, then the new, combined mass of the two spacecraft will be unknown. Knowing the MOI is crucial for knowing how much torque to impart on the spacecraft to ensure it points where it should be pointing.

Put simply, a neural network takes a numerical input and gives a numerical output. In the case of spacecraft MOI estimation, the input is the angular velocity of the spacecraft, which is a measure of how fast the spacecraft is rotating about each of its axes. Another input could be a known torque acting on the spacecraft, such as a commanded torque or drag. In order for the neural network to learn, a truth label must be given, which corresponds to the input. In this case, the truth label is the spacecraft MOI. Given tens of thousands of inputs like the one just described, the neural network will learn the best way to map the inputs to the spacecraft MOI.

To learn effectively, the neural network requires a large amount of training data. Ideally, this training data contains samples that are representative of the conditions the spacecraft could potentially encounter. The data can either be taken from real-world instruments and sensors, or it can be simulated. As this project is in the early stages of research, all of the training data is simulated. This requires a method to randomly sample spacecraft MOI and initial conditions.

> “The ability to make accurate predictions for unseen data is what makes neural networks so powerful.”

Once the neural network learns to predict the MOI given angular velocity and known torques, it can then estimate the MOI for scenarios that it has not yet seen. The ability to make accurate predictions for unseen data is what makes neural networks so powerful. It is important to note that although neural networks are great at interpolating, or determining some value within a range of previous data, they are not so great at extrapolating, or determining a value for a sample far away from previous samples. This is an important distinction, and in the case of MOI estimation, if the neural network only trained on spacecraft with MOI up to 100 kg m^2, then there is no guarantee that it would work on a spacecraft with MOI of 1,000 kg m^2. For this reason, it is important to train the neural network on a wide range of samples.

The research completed for this project so far has shown that the neural network is able to estimate the MOI when there is a known torque acting on the spacecraft. This torque could be a commanded torque, or a well-modeled disturbance torque. When the spacecraft is operating in a torque-free environment, the best the neural network can do is to estimate the relative MOI, which is a measure of how large the MOI values are relative to each other.

The ability to quickly predict the MOI of a spacecraft, or even just the relative MOI, could make controlling a spacecraft after docking much easier. It could allow for a control solution to be implemented much sooner than if using conventional techniques. Making use of neural networks and AI in general can make solving certain problems much easier. As innovations such as AI emerge, it is prudent to investigate the unique capabilities they offer.

AIRMEN AND ARTIFICIAL INTELLIGENCE:

THE WINNING COMBINATION

By Dr. Michael Miller
Professor of Systems Engineering & Human Systems Lead
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Air Force Institute of Technology

"Airmen powered by innovation" illustrates the importance of leading-edge technology, including artificial intelligence, to the Air Force of the past and future. Today's AI systems can perform tasks that we, as humans, find difficult or even impossible to perform. However, AI systems lack some abilities that are common to humans, including the ability to reason inductively and to adapt to unexpected circumstances. It is this ability to adapt that permits us, as humans, to find surprising solutions to difficult problems and to alter strategies and tactics in response to adversarial action. This need is encapsulated in the well-known military adage "no plan survives first contact with the enemy."

This ability to adapt is among the reasons AI must be designed to interact robustly with airmen, permitting us to harness the best of both human and artificial intelligence. This is not a new concept. J.C.R. Licklider, who was director of ARPA's Information Processing Techniques Office from 1962 to 1964, funded significant human-centered advances such as the precursor to the internet, the computer mouse, and the graphical user interface. In his seminal paper Man-Computer Symbiosis, he clearly discussed the need for AI to be designed to collaborate with humans. However, 60 years later, we primarily imagine AI as replacing, rather than partnering, with humans.

How do we overcome this narrative that AI will, or should always be considered as, a replacement to human operators? In our human-agent interaction research at AFIT we believe there are three primary barriers that we must overcome. First, we need better system design and analysis tools which permit us to design reliable human-agent teams to permit robust process integration. Second, we must design AI to work as a true teammate. Third, we must design AI to adapt its behavior in real time within the framework of a human-agent team.

IMPROVING SYSTEM DESIGN TOOLS TO INCLUDE HUMAN-AGENT TEAMING

At the request of the Air Force Research Laboratory (AFRL), AFIT designed a course in human-machine teaming in 2014. At the time, no civilian institute offered the desired course. Development of this course led to a few realizations. The current wave of AI is different than previous waves as it is supported by low cost sensors and actuators to augment advances in computation. Therefore, we focused on human-agent interaction where the agents must have the ability to sense information about their environment, make decisions based upon this information and be able to take some action to affect the world. These sensors and actuators do not have to be embodied in a single system, like a robot, but they must exist to permit the AI to adapt to world circumstances and to team with the human. We found this concept, when combined with literature from the field of cognitive systems engineering (CSE), to be an effective framework for improving student's understanding of AI systems.

We also needed design tools. We began with tools from model-based systems engineering (MBSE), software agent design, and intelligent information system. We adopted the concept of shared human-agent goals from the CSE and intelligent information system design literature. Understanding responsibilities of the team and allocating portions of these responsibilities to subsets of the humans and AI in the team were adopted from combinations of the CSE and software agent design literature. Tools to understand interdependent behavior were adopted from CSE. Finally, Use Case, Requirements, and Activity diagrams and concepts were borrowed from MBSE. With these tools in hand, class project teams describe and model the systems they envisioned throughout the course. Through iteration we have developed extensions to the systems modeling language which lets us describe these systems in MBSE tools. The tools remain under development, but our students are applying them to facilitate conceptual design of human-agent teaming systems and gaining early insights into how we can reconfigure human teams to include AI agents as teammates.

This has led students, including Major Chris Henry, to redirect their research towards aiding team-oriented behavior instead of individual behavior. Major Henry's dissertation, advised by Dr. Gilbert Peterson, evolved from a visualization tool to a tool which supports collaboration among a team of reverse engineers. This tool is described in the dissertation entitled "Analytic Provenance for Software Reverse Engineers" and has received accolades from the user community as it supports a previously unrecognized need.

INCREASING KNOWLEDGE SHARING

An important concept from the cognitive systems engineering literature is the need for teammates to be able to observe, predict, and direct each other depending upon the authority and knowledge that each cognitive entity has at any moment in time. Our research focuses on how to design agents which can robustly observe and predict human behavior. This is particularly difficult when our systems are comprised of multiple, narrowly-focused, functional agents. For instance, a UAV routinely has individual functional agents to aid navigation, serve as autopilot, track ground targets, among others. These functional agents do not only interact with one human but with a team of humans who may have different behaviors.

A recent dissertation by Dr. Michael Schneider, who attended AFIT through the STEM+M program from the Life Cycle Management Center, focused on the development of a specialized intent agent. This dissertation, advised by Dr. Michael Miller and entitled "Operationalized Intent for Improving Coordination in Human-Agent Teams" discusses an intent agent that observes the world, the state of the aircraft, communications among the humans in the system, and human behavior to understand human priorities. For example, does the UAV pilot currently value minimizing fuel use or maximizing maneuverability when approaching a target area? Understanding the pilot's priorities helps the various agents select exact courses of action, such as how the autopilot should adjust airspeed or how direct a path the navigation agent should plot given potential threats or other limitations. In this research, an intent agent was defined, a system prototype was configured, and UAV pilots from the Michigan Air National Guard flew the prototype, providing ground truth information. AI-based Intent agents were then constructed to learn and predict changes in operator intent as they flew a few simulated missions. The vision is for future intent agents, such as the one demonstrated in this research, to publish the pilot's intent so that all of the functional agents in the system can understand the pilot's priorities and adjust their behavior appropriately. At the same time, this intent is made available to the human crew so that they also understand and modify these priorities if necessary.

U.S. Air Force Courtesy Photo

Capt Anthony Castello views the Vigilant Spirit Control Station. This software, developed by the 711th Human Performance Wing's Supervisory Control & Cognition Branch, allows operators to control UAVs in complex, simulated environments. Dr. Schneider's dissertation research applied this software to understand how members of the Michigan Air National Guard fly challenging missions. His research provided insight into how operator intent changes as missions evolve and the development of AI to understand these changes.

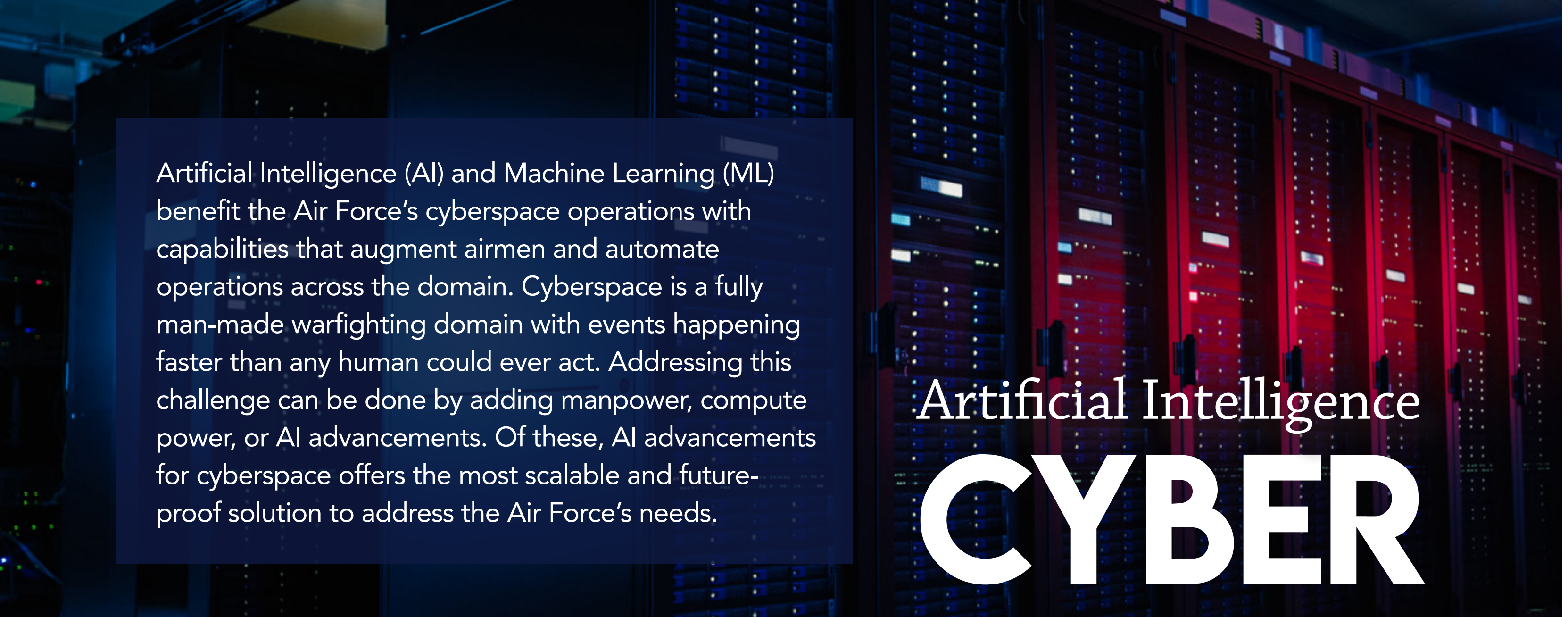
Besides operator intent, this intermediate agent might make other important judgements about the human in the system. Another line of research relies on measures of human physiology and brain activity to attempt to understand whether the operator is experiencing excessively high workload or stress, understand when the human might be losing vigilance, or is dissatisfied with the performance of the agents. Similarly, this information could be made available to the functional agents in the system, allowing them to adjust their behavior in response. For example, Major Ryan Hefron's dissertation advised by Dr. Brett Borghetti and entitled "Breaking Down the Barriers To Operator Workload Estimation," developed algorithms to assess human workload from EEG analysis. This dissertation advances the ability of AI agents to understand when the operator is becoming overloaded so that it can target assistance and actively participate in crew resource management.

Yet another example is provided by Lt Nick Forrest's thesis, advised by Dr. Ray Hill, Dr. Phil Jenkins, and Dr. Jason Anderson. This research supported the Air Force's Pilot Training Next (PTN) program, which seeks a more efficient pilot training environment emphasizing the use of virtual reality flight simulators alongside periodic real aircraft experience. The objective of the PTN program is to accelerate the training pace and progress in undergraduate pilot training. Lt Forrest's thesis applied advanced machine learning techniques to auto-generate the planning of in-flight events using hybrid filtering and deep learning techniques. The resulting approach captured temporal trends of user-specific and program-wide student performance to recommend a feasible set of graded flight events to guide a student's next training exercise and improve their progress toward fully qualified status. The prototype system achieved over 90% accuracy compared to the schedules produced via the time-intensive manual method and was transitioned to the PTN program for implementation.

BUILDING AGENTS TO INCLUDE TEAMING KNOWLEDGE

A final area of research is to understand how agents might be constructed which understand how to share work with team members. The primary focus of this work is to construct flexibility into the actions that the AI can take such that the human can aid the AI when it is unable to perform part or all of a task that it might commonly perform. For instance, an agent may have difficulty classifying a target on the battlefield. In many of today's systems, the human's only course of action under this circumstance is to turn the automation off and perform the entire task by her or himself. The desire is to build flexibility into the system so that the human can help the agent with the classification of a target and then, armed with this knowledge, the agent can continue with the tasks that it would normally perform. Similarly, an agent might observe that the human is struggling to perform a task and volunteer assistance if it has useful knowledge to contribute. These types of backup behaviors enable human teams to perform feats that no individual could preform and will be important for the success of future human-agent teams.

It is our belief that these areas of research have the potential to change the conversation. We should not be asking "when will AI replace humans." Instead, we must be looking to unleash the power of our human-agent teams to perform superhuman feats while empowering our Airmen to innovate.



Artificial Intelligence (AI) and Machine Learning (ML) benefit the Air Force's cyberspace operations with capabilities that augment airmen and automate operations across the domain. Cyberspace is a fully man-made warfighting domain with events happening faster than any human could ever act. Addressing this challenge can be done by adding manpower, compute power, or AI advancements. Of these, AI advancements for cyberspace offers the most scalable and future-proof solution to address the Air Force's needs.

Artificial Intelligence

CYBER

Intelligent Cyberspace Agents

By Dr. Gilbert Peterson
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Department of Electrical and Computer Engineering
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AFIT has been leading research and education at the juncture of AI and cyberspace for over two decades. AFIT research examines the gamut of cyberspace and includes advancements in operations, defense, and attack.

Operations

AFIT has advanced capabilities to answer common operational questions such as 'What is on my network?', 'Can I get ahead of a failure?', and 'How long can we expect to wait for a resolution?'

LEVERAGING ANNs TO IDENTIFY DEVICES ON NETWORK

As the proliferation of small low-cost wireless devices continues in home, building, and industrial automation applications, the ability to establish the identity of devices accessing the network remains a critical task for securing networks. Presently, digital credentials such as media access control (MAC) addresses, electronic serial numbers, pre-shared-keys, and similar are the basis for establishing a device's identity and granting/denying network access. These digital credentials are universally vulnerable to be compromised through either sophisticated surveillance, "hacking" or theft by individuals with appropriate access. Individual wireless devices, through minor variations in the manufacturing process, have unique signatures, or distinctive native attributes (DNA) imprinted on their signals. By extracting these unique signatures from device emissions in various operating domains (time, frequency, joint time-frequency, constellation, etc.), the individual devices can be reliably identified down to identical devices differing only in serial number. Recent advancements by Lt Col James Dean and Dr. Michael Temple leverage a Deep Artificial Neural Networks (ANNs) to learn DNA features. The application of machine learning provides a significant advantage in exploiting systems that utilize novel waveforms, for which subject matter expertise is limited. Additional benefits are to be able to identify devices that utilize more than one communication need and dramatically speed up the ability to identify new devices without subject matter expertise.

PREDICTING SERVICE AND SERVER FAILURES

Although being able to predict network and service outages caused by an axe-wielding worker is not realistic, we do need the capability to predict when there will be a hardware or software failure in a service. Redundancy and fault tolerance mitigate this need, but cases exist in which redundancy is not available or still fails.

Statistical machine learning to predict failure provides a solution. However, since failure is still a relatively rare event, obtaining labelled training data to train these models is not trivial. Capt Paul Jordan's work presented an automated framework that includes fault induction mechanisms with a complementary machine learning to learn a per-service fault prediction model. The automated framework simulated fault inducing by applying stresses associated with software errors and hardware loads for the Microsoft enterprise authentication service and Apache web server. These fault loads were successful in creating realistic failure conditions that were then accurately identified by statistical learning models.

PREDICTING WHEN OUTAGES WILL BE RESOLVED

Organizations use a Plan of Action and Milestones (POA&M) process when a service does go down. A core component of this process is tracking—often conducted via a trouble ticket tracking system. A trouble ticket is an electronic record which technicians use to store outage data, document all actions taken, and control the flow of work as it is completed. A common concern for users is that during the outage they are unable to use their equipment, and often there is no way to know ahead of time how long the problem will take to resolve. This resolution-time uncertainty can lead to poor decisions such as wasting resources on a work-around for a problem easily and quickly resolvable, or underestimating the duration of their outage and failing to take actions to accomplish their work another way.

Capt Kenneth Sample and Lt Col Jason Bindewald's research developed a machine learning system that (using past resolution time data for a ticket) could make a prediction on when an outage will be resolved. Classification and regression models developed used boosted regression trees and artificial neural networks (ANNs). Evaluating on 12,303 trouble tickets from the Air Force Network (AFNet), which contains 88 standardized fields

> "AFIT has been leading research and education at the juncture of AI and cyberspace for over two decades."

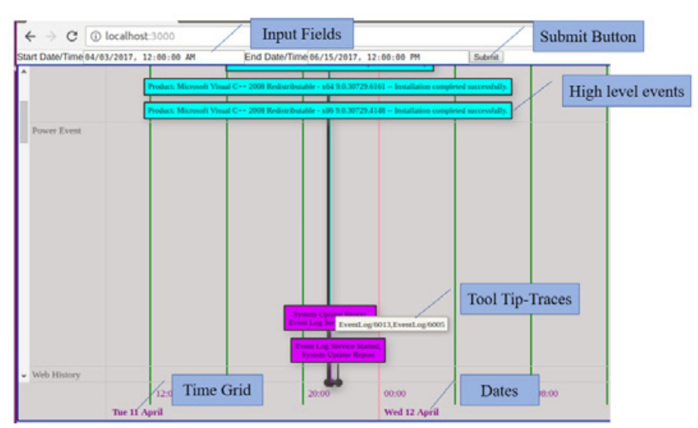
and free text. Their machine learning model had a 74.5% accuracy, and a regression mean absolute error (MAE) of 24.8 hours, where hours is actual clock hours. This means that predicted error for time of resolution was on the order of one working day.

Defense

Beyond developing systems that attempt to prevent an attack from occurring, a large need in enterprise network defense is in assessing what has happened or is happening across an enterprise. A goal for this is a narrative, who did what, when, where, why, and how. Unfortunately, building this narrative is a very manually intensive task. Confounding this is that the details for every incident are slightly different—if they were mostly similar, detection would be straightforward. AFIT has been developing AI systems for this problem from assisting in detecting what all the way through capabilities to automate a fully explainable and factually grounded narrative.

USING SEQUENCE PATTERN MINING TO ANALYZE DATA

Network defenders, in particular incident responders and digital forensics examiners, are being overwhelmed by the increased demand on their services. The volume of raw data is scaling faster than it can be reviewed. While there are many tools to capture and extract data, there are fewer to analyze it, and there are none that automatically summarize raw data into a human understandable narrative. Dr. James Okolica and Dr. Gilbert Peterson created the Temporal Event Abstraction and Reconstruction (TEAR) tool to address this problem. TEAR uses sequence pattern mining (SPM) techniques as a first step to creating such a narrative. The goal of Sequence Pattern Mining (SPM) is to take a list of transactions organized by the time they occurred and discover the sequential patterns that occurred frequently enough to be meaningful. To produce the effects that we use every day, computers perform thousands of transactions. However, as humans we'd like to have those transactions summarized in one or two sentences, e.g., "John copied the files from folder A to the removable USB drive" or "Mary logged into her web email and emailed file C to Jane." TEAR begins that process.



An example Temporal Event Abstraction and Reconstruction timeline.

The two SPM algorithms created to make TEAR work on cyber data are Single Object and Sequence Loop Abstraction and Sequence Mining of Temporal Clusters. These algorithms extend SPM by attaching attributes to items in the sequences and handling the interleaving of multiple sequences in the list of transactions. These are both unique traits of cyber data, while you work on your computer tens of other processes are reading and writing data and sending network traffic. What TEAR does is from a limited number of samples of a narrative process "User opens a .docx file via MS Word, edits and saves it" it identifies the correlating data items found on the media to create a rule that can then be used to fill in the details of who the user was, when they did these actions, what the full filename was, etc. The full automation of the rule creation means that a network defender does not have to manually check all of the data artifacts and correlate them. It also means that each time there is a new application, we do not have to rely on an expert to create an automated rule to build the narrative.

These auto-generated rules are also extremely accurate. Testing showed a 96% reduction in transactions to review and a worst case 0.03% detection of false positives. These rules fit into a larger automation capability that performs a full analysis of media, extracts all temporally related artifacts and leverages the rules with a constant time lookup for queries. All of this to drive the ability to provide examiners the abstract narrative and a full linking to all of the individual artifacts in an interactive exploratory GUI. Results from a pilot study with experienced Air Force examiners was overwhelmingly positive, with comments such as "extremely beneficial" and that it made observations of system activity "easy and fast." They want to see future tighter integration into their existing tool chains, which we are currently working toward.

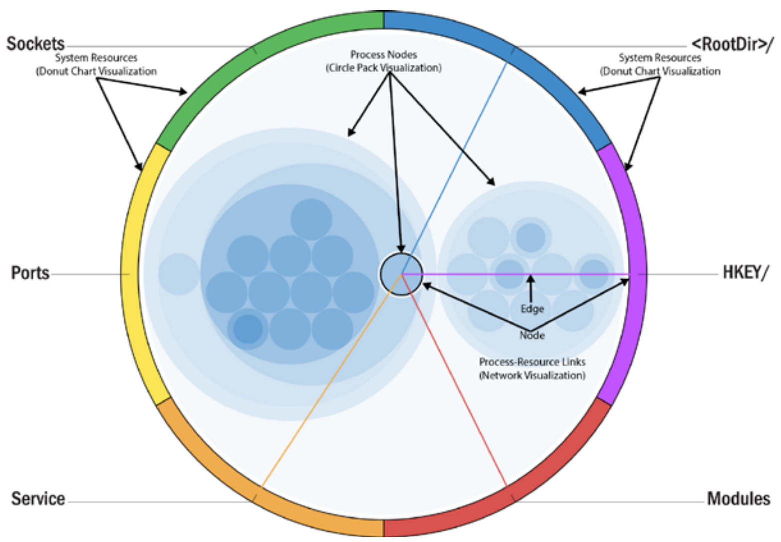
EXTRACTING ACTIVITY ACROSS AND ENTERPRISE

Enterprises leverage network monitoring tool suites to ensure that the network is properly configured, in compliance, and critical missions are functioning. These same enterprises often leverage host-based security solutions to ensure the hosts themselves are secure and compliant. The data these tools capture, which includes the current operating state of a computer, can provide additional conclusionary information to extend the network defense capabilities. Most of the tools available treat the data being collected as a flat record, like a row in a spreadsheet. The problem with this is that the data being captured is very hierarchical and associative. There a number of parent-child relationships as well as neighbor connections that are not being evaluated by treating the data as a row rather than in a tree or graph-like structure.

Led by Dr. Gilbert Peterson, Lt Kevin Cooper developed a tree edit distance metric that when applied to the processes available on an enterprise network demonstrates novel security, compliance, and critical mission monitoring opportunities. In particular, by using the tree edit distance with unsupervised learning, the learning algorithm is able to identify out-of-date configurations, highlight unique executables, and collect resource identification and usage. The unsupervised learning approach is able to build clusters of common and normal computer and user behavior and leverage these models to highlight when things are no longer consistent. The difficulty with any network hunting-like capability is the sheer variety of compute devices, programs and user behaviors that take place at any given time. This type of capability is best used to augment the human analysts.

SPEEDING MEMORY AND INCIDENT RESPONSE ANALYSIS

Maj Joshua Lapso demonstrated this with his research on a visualization tool that improves analysis methods through simultaneous representation of the hierarchical and associative relationships and local detailed data within a single page application. A novel whitelisting feature further improves analysis by eliminating items of less interest from view. Study results demonstrate that the visualization tool can assist examiners to more accurately and quickly identify artifacts of interest. This visualization capability is currently being licensed for integration into a full-blown capability.



Interactive Memory Visualization and Behavioral Clustering

Attack

Cyber is somewhat different from other domains in that a number of the tools used for attacking are similar to those used during operations and defense. The most clearly differentiating of these are during battle damage assessment, which is a question like in operations and defense of what is running on a given system. However, it does have unique elements such as reverse engineering and attack automation requirements.

REVERSE ENGINEERING M2M DATALINK

Gaining insight into an adversary's threat systems and associated machine-to-machine (M2M) communications provides warfighters and commanders with timely and actionable intelligence. Reverse engineering an M2M datalink has many complex steps that have to be performed without error. The process is highly specialized and labor extensive requiring skilled and experienced analysts. The massive increase in volume and complexity of adversary M2M data has exceeded the capacity of traditional analysis process flows. Today's mission requires automation to empower analysts by optimizing the human-machine teaming needed to maintain technological advantage over adversary threats.

AUTOMATIONS TO ASSIST ANALYSIS

To support this trend, Dr. Jon Knapp developed a series of automations that assist in the analysis of M2M communications as part of his dissertation at AFIT. His work can be used for the object ID field identification, field boundary identification, field data format analysis, and field data type identification. A data link is often defined by one of more fields, which represent specific pieces of information, such as airspeed, altitude, and engine RPM. His work provided a technique that reliably finds like objects within datalinks and identifies the field boundaries for this field. He also explored algorithms to identify the individual field boundaries within the datalink, the data format for the field, including byte and bit directions, and finally the specific type of information being represented, the data type. These algorithms were integrated within mainstream Intelligence Community analysis tools, providing a familiar and trusted environment while enhancing analysis capabilities and automation needed to discover, characterize, and gain intelligence on threat systems.

VIABILITY OF AUTOMATION

Even with the intelligence, the attack process still tends toward a cyclical process of probing, evaluating results and then an attack that is repeated to increase access or get closer to the target. This is what vulnerability assessment/penetration testing (VA/PT) teams do. Because of the number of steps, performing a VA/PT takes time. Capt Graeme Roberts' work demonstrates the viability of automating this process with an alternative method for network simulation and decision making.

Leveraging Bayesian decision networks allows for a scalable and lightweight representation of the systems current state, enabling automated decisions to be made accounting for currently known information as well as probabilities of unknown variables. Observing the outcomes of chosen actions, updating current belief states and repeating this process allows the system to iteratively traverse unknown networks towards a defined goal. This method of action selection followed by outcome observation mimics the techniques of expert human VA/PT actors.

It has been discussed for years how AI and ML can impact cyber-security. Even with the encouragement, there are few commercial tools available that include a significant AI component. However, as shown above, research does exist that can apply AI to the cyber domain with positive effects in helping airmen do what they do best and remove some of the redundant work from their processes.

Artificial Intelligence

AUTOMATING DATA ANALYSIS DECISION-MAKING

In the Air, Space, Cyber, and Human domains, artificial intelligence and machine learning are valuable tools that improve our warfighter's capabilities. AFIT also contributes to a wide range of other aspects of military interest, from our intelligence communities needs for remote sensing… to the nuclear non-proliferation and treaty monitoring community missions… to controlling contract costs and improving manpower retention… all with machine learning.

MACHINE LEARNING IMPROVES MANY AIR FORCE MISSIONS

IMPROVING REMOTE SENSING

Atmospheric Compensation with Physics-aware Deep Learning

By Dr. Brett Borghetti
Associate Professor of Computer Science
Department of Electrical and Computer Engineering
Air Force Institute of Technology
Co-author Maj Nicholas Westing, PhD, AFIT Graduate

One of AFIT's most recent doctoral graduates, Maj Nicholas Westing, pioneered a method for efficiently processing infrared hyperspectral imagery. This imagery is similar to a picture – it has a height and width. Unlike a picture, it captures many individual bands of infrared light not visible to the human eye. The intensity of light in each wavelength is measured at each pixel. This results in one picture at each wavelength, which forms a three-dimensional data cube: height by width by wavelength. Hyperspectral imagery measures material reflection across hundreds of wavelengths. The detailed wavelength information reveals material characteristics and allows for the discrimination of materials and objects on the ground- supporting domains such as target detection and search and rescue operations.

Hyperspectral imagery requires careful estimation of the atmospheric conditions to distinguish surface materials and objects accurately. This atmospheric compensation step can be time-consuming as atmospheric constituents such as water vapor, carbon dioxide and ozone must be carefully estimated. Maj Westing developed a fast and accurate deep learning technique to estimate atmospheric constituents using a hyperspectral data cube. One cutting-edge machine learning technique that Maj Westing employed controlled the way the network learned by using a known physics law which governs how light travels through the atmosphere and reflects off a material. By incorporating this physics-based radiance transfer function, he enabled the network to learn a better model than would be possible without it. The trained model allows computing the atmospheric compensation directly from a hyperspectral data cube – on the order of 10 times faster than the current state of the art method, while maintaining the needed accuracy to perform target detection. This speedup means the AF can process data much faster – potentially accelerating the entire target detection pipeline.

SOURCE: Westing, Nicholas M., Gross, Kevin C., Borghetti, Brett, J., Schubert Kabban, C. M., "Multimodal Representation Learning and Set Attention for LWIR In-Scene Atmospheric Compensation" *IEEE Journal of Selected Topics In Applied Earth Observations and Remote Sensing*, (IEEE Early Access, 28 Oct 2020).

DOI: 10.1109/JSTARS.2020.3034421.

URL: https://ieeexplore.ieee.org/abstract/document/9242299

Monitoring Nuclear Treaties One Particle at a Time

By Dr. Abigail Bickley, Assistant Professor of Nuclear Engineering and Maj James Bevins, Assistant Professor of Nuclear Engineering
Department of Engineering Physics
Air Force Institute of Technology

Understanding other countries' pursuit of nuclear technologies has been a national security objective since before the United States embarked on its own efforts to develop nuclear weapons. However, US efforts to understand nuclear proliferation and the movement of nuclear material is not a secret, and countries often go to great lengths to obscure their nuclear weapons programs and related activities. Efforts to improve the minimum detectable limits, standoff, and characterization of activities have largely hit a hardware limit, necessitating the development of advanced data analysis techniques. In this space, machine learning has shown great promise when applied to technical signatures such as particulate matter, electromagnetic (EM) signals, and radiation detection to provide an enhanced understanding of the activities that generate these signatures.

Particulate matter morphology and elemental composition can be indicative of the creation environment providing insight into proliferant activities, specific synthtic processes, and geographic origin. With the advent of automated scanning electron microscopy (SEM), the sheer volume of collected imagery has increased exponentially. Current research by Capt Daniel Gum and Capt Jason Siek has demonstrated the feasibility of automated ML-based classification to enhance the ability of analysts to identify the needle in the haystack. Future research aims to use a particle classification database to identify statistically meaningful correlations between the particulate and proliferant activities thereby enhancing the value obtained from the collection of particulate samples.

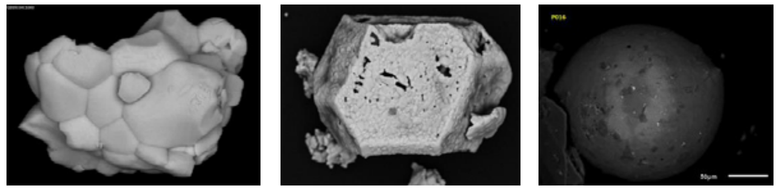
Obtaining particulate matter requires some form of facility access, whereas technical signatures such as seismic, acoustic, magnetic, and radio-frequency enable remote sensing. Traditional signals analysis is limited in terms of the standoff distance and characterization of the operational characteristics. For example, traditional analysis of magnetometer data can often distinguish if a reactor is on or off, but it cannot necessarily distinguish the reactor power level because of the many confounding factors. Current research is aimed at adding in this multi-modal classification of facility operational characteristics. Additionally, initial research by 2Lt Marcus Brinker and collaborators at the University of California, Berkeley led by Dr. Bethany Goldblum has shown that the feed-forward neural network models developed for this task do not generalize well to similar facilities (i.e. one reactor to another) due to differences in reactor types and operation characteristics. Ongoing research is developing methods to perform incremental learning on target facilities to improve overall generalizability and classification accuracy.

While tracking fuel cycle production activities are important for emerging proliferation risks, locating and characterizing nuclear material ensures that previously produced special nuclear material doesn't fall into the wrong hands. One powerful tool in the search for nuclear material are radiation imagers that can pinpoint the direction and shape of a radiation source in a field-of-view (FOV). However, these devices are often very large, expensive, and/or have a limited FOV. Portable single detector systems, such as the AFIT-developed rotating scatter mask (RSM), overcome these limitations but sacrifice information used in traditional image reconstruction. Using convolutional neural networks, Capt Robert Olesen showed that the RSM can image radiation sources with much higher accuracy than traditional techniques. However, the current approaches are highly-dependent on the training set data, making further improvements in generalizability a must for future real-world implementation.

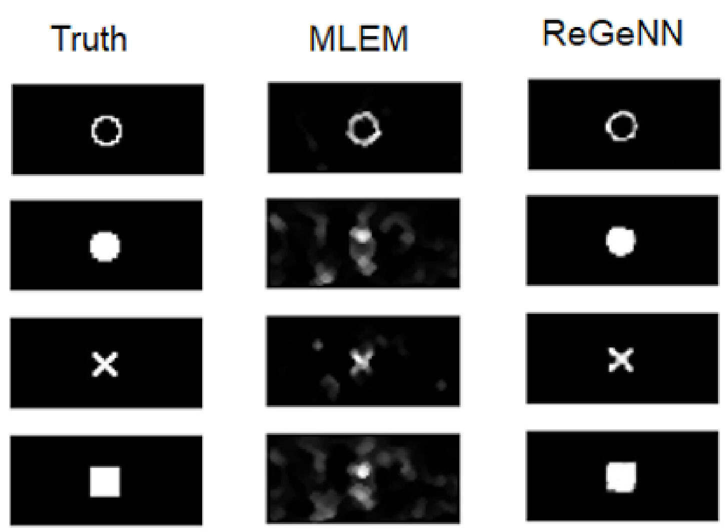
AFIT STUDENT RESEARCHERS: Capt Daniel Gum, Capt Robert Olesen, Capt Jason Siek, and 2Lt Marcus Brinker.

SOURCE: D. Gum*, G. Varshney, A. Holland, J.W. McClory, A.A. Bickley, "A Machine Learning Approach to Characterizing Particle Morphology in Nuclear Forensics", vol 39 (2021), in press.

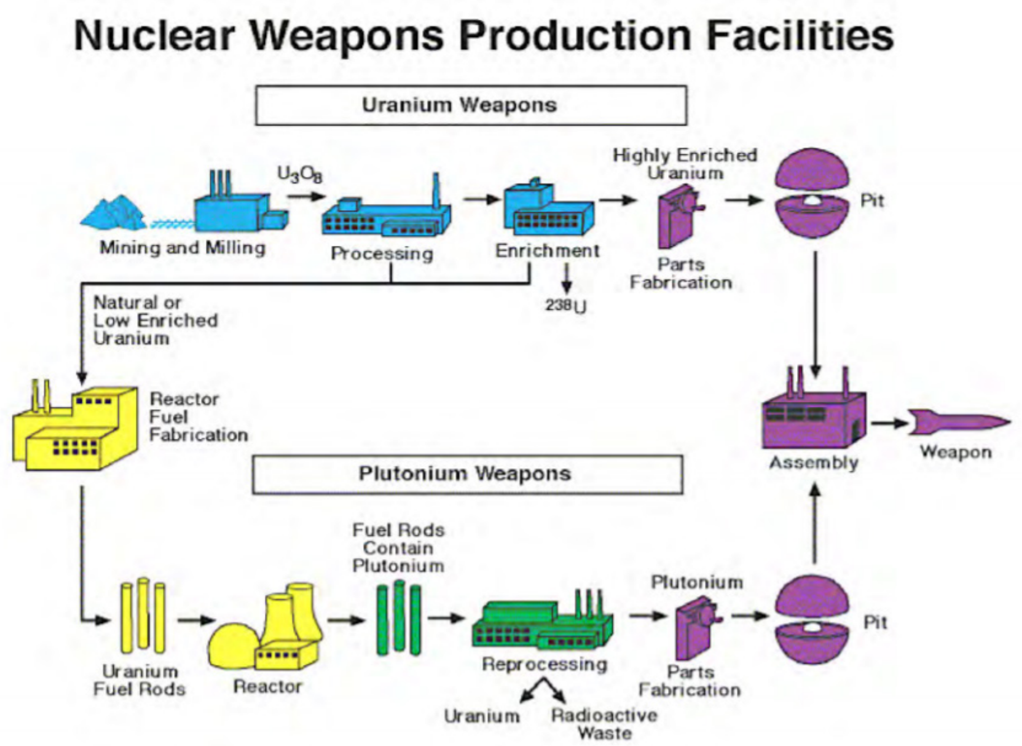
DISSERTATION: Low-information Radiation Imaging using Rotating Scatter Mask Systems and Neural Network Algorithms – Robert J. Olesen, September 2020.



SEM images of particles created under different creation environments highlighting the presence of unique features that image-based machine learning can use to classify the particle's origins.



Example 2-D radiation projections relating to useful real-world nuclear sources of interest (left) were developed to demonstrate the limitations of traditional algorithms (Maximum Likelihood-Expectation Maximization (MLEM), middle) and highlight the improvements made with a ML-based approach (ReGenerative Neural Network (ReGeNN), right).



The goal of the particle matter morphology and technical signatures work is to develop techniques that push proliferation detection to the left – earlier in the nuclear fuel cycle and further from nuclear weapon development.

Nuclear Treaty Monitoring: Seismic Situation Awareness with Deep Learning

By Dr. Brett Borghetti
Associate Professor of Computer Science
Dept. of Electrical and Computer Engineering
Air Force Institute of Technology
Co-author Dr. Joshua Dickey, AFIT Graduate

Earlier this year, Dr. Joshua Dickey, an Air Force Technical Applications Center (AFTAC) employee, completed his doctoral degree at AFIT, making important research contributions in seismic data analysis – an area vital for our country's role in the nuclear treaty monitoring. Dr. Dickey's work focused in three areas – event detection, association, and localization – using a single deep learning architecture.

One of the needs of the treaty monitoring community is association: determining whether or not two seismic signals, recorded at different geographic locations are actually from the same event. One of the difficulties with association is that the path from the source to each of the sensors is different, and seismic signals are greatly affected by the geological attributes of the path they travel through. This causes the signals recorded at one sensor to appear different from those recorded at another, even though they came from the same event.

Dr. Dickey's goal was to create a method for assigning a seismic signal to its originating source event (e.g. a specific earthquake).Unfortunately, traditional machine learning methods, like classification, were out of the question... with millions of events each year, there were simply too many classes to use a standard machine learning tool known as classification. Instead, he took advantage of a cutting-edge deep learning concept from the field of facial recognition—the Siamese neural network.

While traditional classification algorithms look at a single observation and predict from a fixed set of classes, Siamese networks are different. Siamese networks look at a pair of observations and predict if the pair is a match – where the definition of match is defined during training. By training the network on source-matched pairs, regardless of which seismic sensor they were recorded at, Dr. Dickey's network learned to capture the source-specific path-invariant attributes of a seismic signal in the heart of the network – in what machine learning researchers call "latent space." Essentially the network distills the essence of the original event from the measured signal, allowing it to accurately predict whether measured signals recorded at two different geographic locations were actually from the same event. This powerful new technique created an automated path-invariant source association process for the seismic analysis pipeline – something previously deemed impossible by experts in the field.

SOURCE: Dickey, Joshua, T., Borghetti, Brett, J., Junek, William, and Martin, Richard "Beyond Correlation: A Path-invariant Measure for Seismogram Similarity" *Seismological Research Letters*, 6 Nov 2019, Vol 91, pp 356-369.

DOI: 10.1785/0220190090

URL: https://pubs.geoscienceworld.org/ssa/srl/article-abstract/91/1/356/574774/Beyond-Correlation-A-Path-Invariant-Measure-for?redirectedFrom=PDF

DISSERTATION: Neural Network Models for Nuclear Treaty Monitoring: Enhancing the Seismic Signal Pipeline with Deep Temporal Convolution – Joshua T. Dickey, June 2020: At AFIT Scholar: https://scholar.afit.edu/etd/3630/

Estimating Contract and Employee Costs and Hiring the Right People

By Lt Col George Noel
Assistant Professor of Computer Science
Department of Electrical and Computer Engineering
Air Force Institute of Technology

Natural Language Processing (NLP) leverages artificial intelligence to improve computer "understanding" of the written and spoken word. Our team uses NLP techniques to assist the Air Force in two primary areas. First, we are helping the Air Force Research Laboratory (AFRL) to automate contract bid assessment. Specifically, the Air Force would like a way of determining if manpower salary levels contained within the bid are commensurate with average civilian salaries for that job. Job labels are not consistent across bids, let alone the industry, creating a challenge when comparing. This research leverages words in the job description and statistical machine learning techniques to match the job's equivalent industry counterpart. Unlike existing research, this approach uses word relationships defined in a semantic network called ConceptNet. These word relationships (e.g., 'drive' is related to 'car') help the classifier utilize words that did not appear in the training set to improve accuracy.

Second, our team is assisting AFRL and the Air Force Personnel Center (AFPC) in automating parts of the civilian hiring process. One of the first steps in the process is evaluating applicants against minimum qualifications. This currently involves a team of technicians assessing résumés against job requirements, and often these personnel lack domain knowledge. If a job requires experience in satellite communications, these technicians may reject someone with experience repairing and maintaining High Power Amplifiers (HPA). An AI leveraging domain knowledge would recognize HPAs are components found in satellite landing sites. Once again, Semantic networks provide robust domain knowledge that algorithms can leverage to improve and automate this process.

> "Leveraging methods from reliability theory and machine learning, we utilize survivability functions constructed from historical retention data to develop and demonstrate a statistically defensible methodology for creating the sustainment lines at the core of the Air Force personnel management system."

Improving Workforce Retention

By Dr. Raymond Hill, Professor of Operations Research
and Dr. Matthew J. Robbins, Associate Professor of Operations Research
Department of Operational Sciences
Air Force Institute of Technology

The United States Air Force organizes its workforce around rank structure and work specialty codes (Air Force Specialty Codes (AFSCs)). Unlike civilian organizations, all active duty Air Force personnel start at the entry level ranks. The challenge is to develop and manage personnel to fill a variety of skill sets at a variety of ranks over a 20 to 30 year planning horizon. The Air Force uses sustainment lines to accomplish many of its manpower management goals. However, the current methodology for developing these sustainment lines is not statistically defensible based on the actual retention data and does not provide management a means to identify specialty codes of concern. Leveraging methods from reliability theory and machine learning, we utilize survivability functions constructed from historical retention data to develop and demonstrate a statistically defensible methodology for creating the sustainment lines at the core of the Air Force personnel management system and provide a tool for managers to focus attention on potential workforce problem areas. Related ongoing research efforts directly examine large-scale, Air Force specific manpower planning problems. We formulate Markov decision process models of the problems and solve them by applying an approximate dynamic programming (i.e., model-based reinforcement learning) approach. Various statistical machine learning techniques provide high-quality value function approximations within our customized stochastic optimization solution procedures. Recent efforts to characterize retention outcomes using machine learning inform development of realistic sub-models driving stochastic evolution of the modeled Air Force manpower system. The work on officer attrition by Maj Jill Schofield and Maj Christine Zens, along with advisors Dr. Ray Hill and Dr. Matthew (JD) Robbins, was published in Computers and Industrial Engineering. Work focused on enlisted retention was performed by Maj Jaime Zimmerman, work on pilot retention by Capt Courtney Franzen, work on economic impacts on retention by Lt Jake Elliott and Lt Trey Pujats, and work on manpower planning by Maj Joey Hoecherl. All work was sponsored by HAF/A1.

AI | MACHINE LEARNING

DETERMINING HOW WELL MACHINE LEARNING IS DOING

Statistical Inference in Machine Learning

By Dr. Christine Schubert Kabban
Professor of Statistics
Department of Mathematics & Statistics
Air Force Institute of Technology
Co-authors Dr. Fairul Mohd-Zaid (AFRL/RHWAI) and Ms. Elizabeth Zink (OSU Grad Student)

Machine learning (ML) methods have been applied successfully in a myriad number of applications with an exceptionally high level of accuracy as measured by mean squared error (MSE) computed from training, validation and test datasets. The assumption, then, is that any prediction made by the ML method would then be subject to the same level of (small) error that was observed when using data collected to build the ML based model. However, the error associated with the predicted response is often unknown, as the intricacies of many ML models cause issues with tracking the error through the complex ML model.

Methods have been proposed to estimate the error associated with the predicted response, most notably asymptotic methods and methods which assume aspects of normality for the predicted response. Indeed, when ML models mimic traditional statistical methods (logistic regression, for example), parametric assumptions track through the model and exact confidence intervals for the predicted response can be constructed. However, it is in the complex ML models, such as those fit by neural network approaches, where standard error is harder to track and valid inference via a confidence interval on the response is hard to construct.

The validity of a confidence interval is measured through its coverage and width. Of these two properties, coverage is often the most critical. Having a very tight, minimum width, confidence bound on a predicted value is of no use if the confidence coefficient is not maintained, that is, a 95% confidence interval on the predicted response should have 100(1-α)% coverage of the true predicted value.

A team consisting of Dr Schubert Kabban (AFIT/ENC), Dr. Mohd-Zaid (AFRL/RHWAI) and Ms. Zink (OSU graduate student) are working to theoretically derive exact confidence intervals for the predicted response from a neural network as well as developing appropriate nonparametric techniques for this inference. In their examination of current asymptotic methods and nonparametric methods such as the bootstrap, they have found inconsistent results in confidence interval coverage (intervals not meeting coverage and intervals being too conservative on coverage). Further, they have found some studies which improperly compute coverage. Instead of relying on the true underlying models to evaluate coverage, these studies simulated coverage results from a simulated "truth" model. Such methods almost always lead to confidence interval coverage much higher than that designed. Currently, Dr Schubert Kabban and her team is focused on the proper way to bootstrap a neural network that will provide 100(1-α)% coverage at a minimum width. These methods rely on appropriately estimating and using the covariance that exists both within and between the features used to create the ML model.

IMPORTANT DATES

JANUARY 2021

AFIT Graduate School Winter Quarter Classes Begin
AFIT Campus, WPAFB, OH I 04 Jan 2021

FEBRUARY 2021

AFIT Graduate School Spring Quarter Registration Begins
AFIT Campus, WPAFB, OH I 08 Feb 2021

Graduation Applications Due to Registrar's Office
AFIT Campus, WPAFB, OH I 19 Feb 2021

MARCH 2021

AFIT Graduate School Winter Quarter Classes End
AFIT Campus, WPAFB, OH I 12 Mar 2021

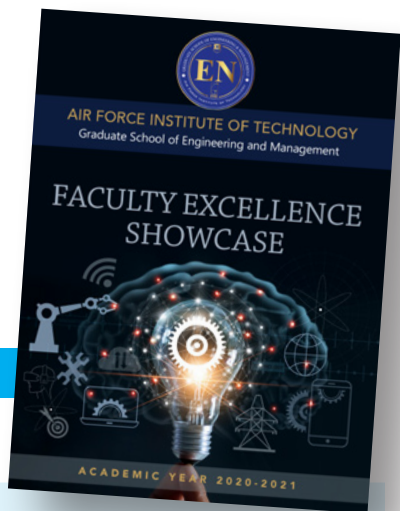
AFIT Graduate School Awards and Commencement Ceremonies
AFIT Campus, WPAFB, OH & Online I 25 Mar 2021

AFIT Graduate School Spring Quarter Classes Begin
AFIT Campus, WPAFB, OH I 29 Mar 2021

Academic Year 2020-2021 Faculty Excellence Showcase Available Online

To learn more about Graduate School faculty members and their research, view the academic year 2020-2021 AFIT Graduate School of Engineering and Management Faculty Excellence Showcase publication online at:

www.afit.edu/EN/facultyexcellence



2020-2022 Faculty Handbook Available Online

Find the 2020-2022 AFIT Graduate School of Engineering and Management Faculty Handbook online by visiting www.afit.edu/EN and clicking on the Faculty Resources tab.

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