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 CQDs 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.

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.

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.

In the Air, Space, Cyber, and Human domains, artificial intelligence and machine learning are valuable tools that improve our warfighter’s capabilities. Read about AFIT’s research in these areas inside.
AFIT is on the Right Path at Wright-Patt in Response to COVID-19 Pandemic

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, PexIPing, 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: AFFIRMATION: The AFIT Engineer highlighted our contributions to space-related research and development. On the USAF 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 USAF initiatives. We are in space and in step with USAF priorities in terms of educational programs, research studies, and consultation needs.

Through coordinated collaboration, our other research centers are also making contributions to USAF, USAF, 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 Financing Technologies (NEFT), 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 to teach and research.

Respectfully,

Adedeji B. Badiru, Ph.D., Pe, PMP, FIE
Dean, Graduate School of Engineering and Management

AFIT Academic Institutional Advancement

By Adedeji Badru, 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 bend 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 ADEVISING & 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 16 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 & AEROSCINPTICS

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 Bettiger is among department (ENY) faculty with the highest scholarly performance and research productivity. In his first three years on faculty, Maj Bettiger 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 Bettiger 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 astounding. A high-impact researcher, Maj Bettiger was awarded 2 provisional patents!

2020 GSEM TEACHING AWARD
MAJ JOSHUA HEISS
DEPARTMENT OF AERONAUTICS & AEROSCINPTICS

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 (CSR/A) 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 (ENY) 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 FACULTY SERVICE AWARD
DR. MARC POLANKA
DEPARTMENT OF AERONAUTICS & AEROSCINPTICS

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.

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. This term 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 Badiri, 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.

This award is in honor of Badiri’s significant and pioneering contributions in the fields 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. Badiri 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.

“Taylor & Francis is delighted to honor Dr. Adedeji Badiri for his significant contributions in the areas of industrial and systems engineering,” said John Marshall, President of the Taylor & Francis Group. “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.”

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

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

AFIT ALUM PROFILE: Major Solomon Sonya

By Katie Scott
Air Force Institute of Technology

Major Solomon Sonya earned a master’s of science degree in computer science from AFIT’s Graduate School of Engineering and Management in 2016. 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 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 elected to demonstrate specific cyber roles. “We train all cyber attack Airmen who are outposted 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,” recalled 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 Crow’s Academic Research Excellence Award in Information Superiority. He credits the research organization for expanding his knowledge and abilities. “Every project I have done since AFIT starts with an appropriate research hypothesis and then tests to prove or disprove the hypothesis,” 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, I could create a tool and demonstrate it 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 Kuleza at cyber conferences across the U.S. and to international audiences in Norway, France, Belgium, Luxembourg, Slovakia, Canada, and Sweden. “Dr. Mullins was a good mentor and he taught me a lot,” Sonya said. “He was an amazing advisor giving me flexibility to grow and explore,” said Sonya.
Artificial Intelligence

Nearly since the beginning of flight, engineers have envisioned aircraft that fly autonomously. However, most current technology to automate aircraft 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.

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 maintain heading and altitude. AFIT has been developing these kinds of technologies for autonomous aircraft for many years in the forms of different controls technologies.

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 UH-60. 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]. 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—to increase position estimation accuracy.

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References:


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

By Lt Col Rachel M. Darby, AIAA Member
PhD Student, Department of Aeronautics & Astronautics
Air Force Institute of Technology

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 the application 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.

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 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 reaching a target 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 that 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 violate any other constraint. The goal here is to train the agent to navigate towards the target without violating any constraints. 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 Applied to Pursuer-evader Multi-satellite Differential Games

By Lt Andrej Lysak
MS Student, Department of Aeronautics and Astronautics
Air Force Institute of Technology

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.

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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 Performance Computing (HPC) clusters to train more quickly. Hundred 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 reaching a target 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 that 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 violate any other constraint. The goal here is to train the agent to navigate towards the target without violating any constraints. The number of keep-out zones can be increased as the agent becomes capable of navigating an increasingly constrained airspace.

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Training ANNs to Fly Hypersonic Vehicles

By Lt Andrej Lysak
MS Student, Department of Aeronautics and Astronautics
Air Force Institute of Technology

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Proximal Policy Optimization for Space Pursuer-evader Scenarios

By 2d Lt Mark Adams
MS Student, Department of Electrical and Computer Engineering
Air Force Institute of Technology

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 the need to find novel ways to accomplish the mission at hand. 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
MS Student, Department of Aeronautics and Astronautics
Air Force Institute of Technology

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 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 then be either 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.

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 m², then there is no guarantee that it would work on a spacecraft with MOI of 1,000 kg m². 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.

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

Researching Applications of Artificial Intelligence to Spacecraft Attitude Control

By 1Lt Cecily Agu
MS Student, Department of Aeronautics and Astronautics
Air Force Institute of Technology

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 on-board 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.

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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 then be either 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.
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 responsible human behavior and the systems supporting 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 teams. We find that these tools and methods support the development of automations that permit us, as humans, to co-design the human-agent system.

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 community as it supports a previously unrecognized need.

INCREASING KNOWLEDGE SHARING
An important concept from the cognitive systems engineering literature is the need for teamware 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 ST3H-M program from the Life Cycle Management Center, focused on the development of cognitive systems engineering (CSE) for human-agent teams. 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. An AI-supported 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.

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 herself. 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 perform 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 unlock the potential 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 aim to and automate operations across the domain. Cyberspace is a fully man-made warfare 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.

**Operations**

AI 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 attributes (DNA) imprinted on their signals. By extracting these unique signatures from device emissions in various operating domains (time, space, usage, or AI advancements), network defenders can be reliably identified down to identical devices differing only in serial number.

Statistical machine learning to predict failure provides a solution. However, since failure is still a relatively rare event, obtaining labeled 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 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 case exists where redundancy is not available or still falls.

**Artificial Intelligence**

By Dr. Gilbert Peterson

Professor of Computer Science

Air Force Institute of Technology

AFIT has been leading research and education at the juncture of AI and cyber for over two decades. AFIT research examines the gamut of cyberspace and includes advancements in operations, defense, and attack.

**Intelligent Cyberspace Agents**

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 lists 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 and saves it,” it identifies the corresponding data items found on the media to create a rule that can be used to fill in the details of who the user was, when they did 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.

**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. Confusing this is that the details for every event are not in the forefront—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 Ololotia 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 the sequence patterns that occurred frequently enough to be representative of the effects that we use every day. Computers perform thousands of transactions. However, as humans we’ll like to have those transactions summarized in one or two sentences, e.g., “John copied the files from Kilder A to the removable USB drive” or “Mary logged into her web email and emailed file C to Jane.” TEAR begins that process.

**EXTRACTING ACTIVITY ACROSS AND ENTERPRISE**

Enterprises leverage network monitoring tools to ensure that the network is properly configured, in compliance, and critical resources 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 conclusive 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 are 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

**Example Temporal Event Abstraction and Reconstruction Timeline**

An example temporal event abstraction and reconstruction timeline.
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 computer devices, programs and user behaviors that take place at any given time. This type of capability is best used to augment the human analysts.

**SPREADING 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.

**AUTOMATIONS TO ASSIST ANALYSIS**

To support the 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 airspace, 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 data, including bytes 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 network 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 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 analysts do what they do best and remove some of the redundant work from their processes.

**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. This 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.

**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—in area, length, 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 radiation 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 speed-up means the AI can process data much faster—potentially accelerating the entire target detection pipeline.


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Monitoring Nuclear Treaties One Particle at a Time

By Dr. Abigail Bickley, Assistant Professor of Nuclear Engineering and Maj James Bovin, 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 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 synthetic 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 signal analysis is limited in terms of the standoff 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 Lt Marcus Brinker and collaborators at the University of California, Berkeley led by Dr. Kathryne Rutland has shown that the feed-forward neural network models developed for this task do not generally work as 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 technical signatures such as particulate matter, electromagnetic (EM) signals, and radio-frequency enable remote sensing. Traditional signals analysis is limited in terms of the standoff 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 Lt Marcus Brinker and collaborators at the University of California, Berkeley led by Dr. Kathryne Rutland has shown that the feed-forward neural network models developed for this task do not generally work as 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 traditional classification algorithms look at a single observation and predict from a fixed set of classes, it can be challenging to learn an 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 known as Siamese recognition—the Siamese network.

Dr. Bickley’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 known as Siamese recognition—the Siamese network.

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Estimating Contract and Employee Costs and Hiring the Right People
By Lt Col George Noof
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 classify invisible 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 resumes against job requirements, and often those 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.

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 rank. The challenge is to develop and manage personnel to fill a variety of skill sets at entry level 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 Jili Scheffeld and Maj Christine Zeh, along with advisors Dr. Ray Hill and Dr. Matthew (Matt) Robbins, was published in Computers and Industrial Engineering. Work focused on enlisted retention by Capt Courtney Fransen, 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.

Determining How Well Machine Learning Is Doing
Statistical Inference in Machine Learning
By Dr. Christine Schubert Kabbani
Professor of Statistics
Department of Mathematics & Statistics
Air Force Institute of Technology
Co-authors: Dr. Faisal Mohd Zaidi (AFRL/RH/WAI) 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 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 Kabbani (AFIT/ ENC), Dr. Mohd Zaidi (AFRL/RH/WAI) and Ms. Zink (OSU graduate student) are working to theoretically derive exact confidence intervals for the 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 “true” model. Such methods almost always lead to confidence interval coverage much higher than that designed. Currently, Dr Schubert Kabbani 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  |  04 Jan 2021

FEBRUARY 2021
AFIT Graduate School Spring Quarter Registration Begins
AFIT Campus, WPAFB, OH  |  08 Feb 2021
Graduation Applications Due to Registrar’s Office
AFIT Campus, WPAFB, OH  |  19 Feb 2021

MARCH 2021
AFIT Graduate School Winter Quarter Classes End
AFIT Campus, WPAFB, OH  |  12 Mar 2021
AFIT Graduate School Awards and Commencement Ceremonies
AFIT Campus, WPAFB, OH & Online  |  25 Mar 2021
AFIT Graduate School Spring Quarter Classes Begin
AFIT Campus, WPAFB, OH  |  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.