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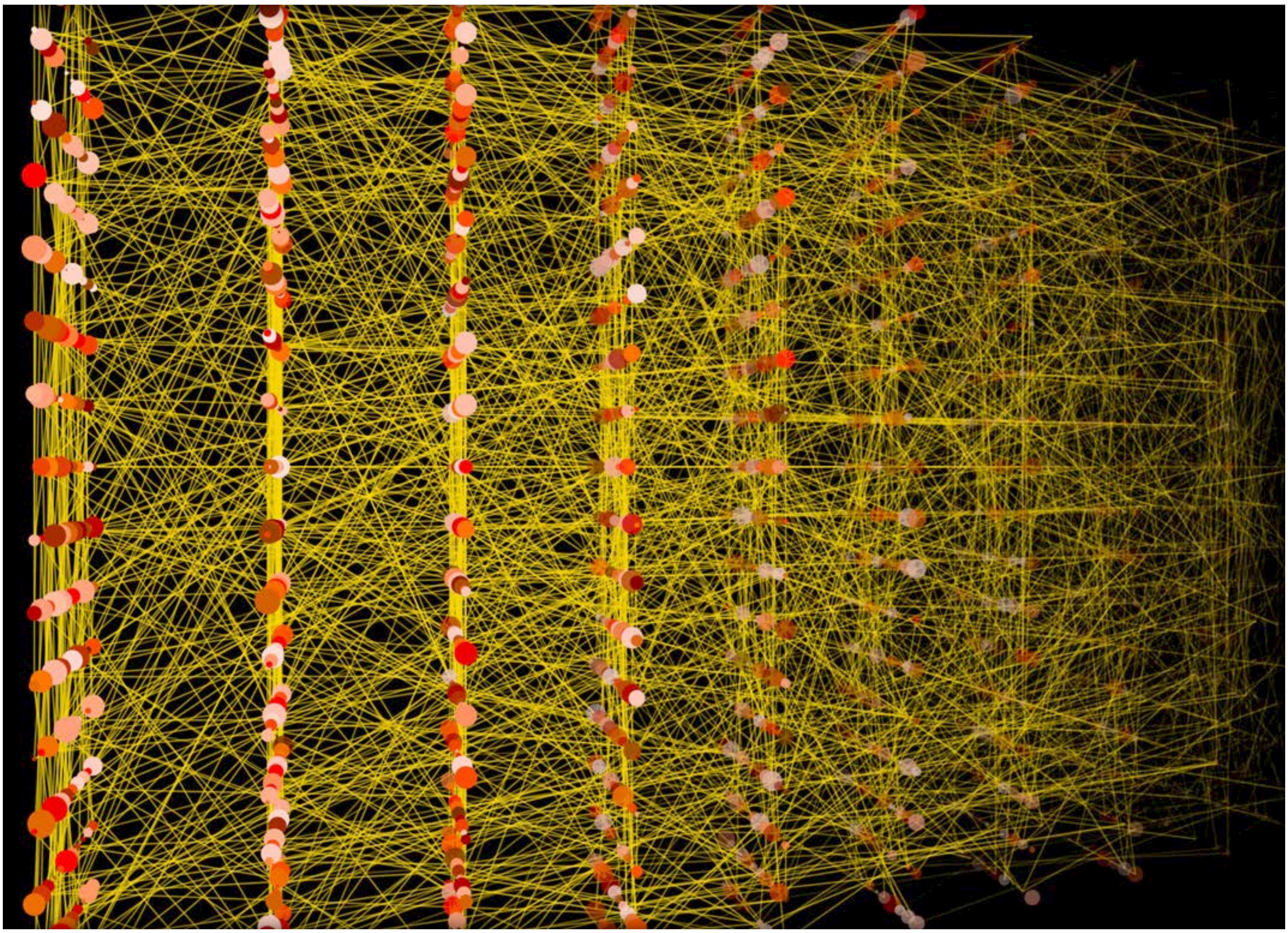
TECHNOLOGY TODAY

Highlighting Raytheon's Engineering & Technology Innovations



SPOTLIGHT

ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING AT RAYTHEON

EYE ON TECHNOLOGY

MECHANICAL MODULAR OPEN SYSTEMS ARCHITECTURES

Discussing industry shifts toward open standards designs

SPECIAL INTEREST

THE INVENTION ENGINE

Raytheon receives the 10 millionth U.S. Patent in history

Raytheon

TECHNOLOGY TODAY

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ON THE COVER
Artist's depiction of a deep neural network

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A MESSAGE FROM MARK E. RUSSELL

VICE PRESIDENT OF ENGINEERING, TECHNOLOGY AND MISSION ASSURANCE

This document does not contain technology or technical data controlled under either the U.S. International Traffic in Arms Regulations or the U.S. Export Administration Regulations.

Welcome to the newly formatted *Technology Today* magazine. While the layout has been updated, the content remains focused on critical Raytheon engineering and technology developments. This edition features Raytheon's advances in Artificial Intelligence and Machine Learning.

Commercial applications of AI and ML — including facial recognition technology for mobile phones and social applications, virtual personal assistants, and mapping service applications that predict traffic congestion — are becoming ubiquitous in today's society. Furthermore, ML design tools provide developers the ability to create and test their own ML-based applications without requiring expertise in the underlying complex mathematics and computer science. Additionally, in its 2018 National Defense Strategy, the United States Department of Defense has recognized the importance of AI and ML as an enabler for maintaining competitive military advantage.

Raytheon understands the importance of these technologies and is applying AI and ML to solutions where they provide benefit to our customers, such as in areas of predictive equipment maintenance, language classification of handwriting, and automatic target recognition. Not only does ML improve Raytheon products, it also can enhance our business operations and manufacturing efficiencies by identifying complex patterns in historical data that result in process improvements. This issue of *Technology Today* highlights some of Raytheon's innovative developments and applications of AI and ML.

In our Leaders Corner, Raytheon Missile Systems' Technical Director Dr. Jeff Vollin answers questions about his role, and what excites him about technology development at Raytheon. Our Eye on Technology section highlights our Mechanical, Materials, and Structures technology network and how the industry shift toward open standards designs exerts influence on this technology area.

The Special Interest section highlights Raytheon's White House visit to celebrate the 10 millionth U.S. Patent, granted to Raytheon engineer Joe Marron. Finally, the People section spotlights Raytheon women engineers encouraging and mentoring young women in high school on Science, Technology, Engineering and Math careers during a FIRST® Robotics Competition in California.

Mark E. Russell

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AI AND MACHINE LEARNING

AI AND MACHINE LEARNING

The 2018 National Defense Strategy has listed the military application of AI and ML as a key element of the U.S. military modernization strategy.[1] Artificial Intelligence (AI) and Machine Learning (ML) will serve as an enabling technology of next generation battle networks; human-machine collaboration & combat teaming; human-assisted operations; and network-enabled autonomous weaponry. Raytheon continues to strategically invest in AI and ML technology development as a key contributor in delivering and operationalizing cognified capabilities to achieve technological overmatch for the United States and its allies.

AI and ML technologies are reshaping the commercial world as well as the military. In fact, commercial industry and academia are leading much of the basic AI and ML technology developments. In his book, *The Inevitable,* futurist and internet pioneer, Kevin Kelly, describes the forces and inherent biases that direct the course of technology. Inexorable momentum drives these shifts in technology, making them "inevitable." Kelly describes these forces not as nouns but as verbs due to the relentless change inherent in modern technology; technology that is in a continuous state of "becoming," rapidly evolving in ways outside the realm of human control. Among the most impactful of these forces is "Cognify," the tendency for technology to get smarter.[2] Over time, objects tend to evolve an embedded intelligence that makes them exponentially more effective. Indeed, cognified things are transformative. Like Gutenberg's printing press and electrification, intelligent machines are transforming economics, government, healthcare, social interactions, as well as warfare.

"SUCCESS NO LONGER GOES TO THE COUNTRY THAT DEVELOPS A NEW TECHNOLOGY FIRST, BUT RATHER TO THE ONE THAT BETTER INTEGRATES IT AND ADAPTS ITS WAY OF FIGHTING."[1] — JAMES MATTIS
26TH UNITED STATES SECRETARY OF DEFENSE

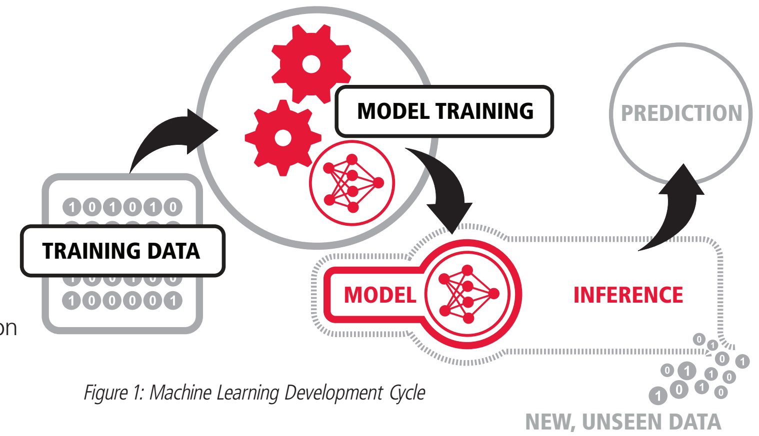

Figure 1: Machine Learning Development Cycle

Technological cognification has accelerated in recent years through the potent combination of ever more cost effective, accessible and powerful computing hardware; massive volume and availability of data; virtually unlimited scalability of software platforms and architectures; and AI and ML algorithms and software. ML is often considered an enabler for the broader notion of AI that includes man-machine teaming and autonomous operations. Unlike traditional rules-based analytics that are explicitly programmed, ML is programmed through learning; automating the creation of rules through "training" on sample datasets. The result of this training is a "model" which knows enough about the dataset to make an inference or "prediction" about statistically similar unseen datum *(Figure 1).* ML is important because it avoids the bottleneck of traditional analytics, the cataloging and implementation of rules. Traditional approaches do not scale well for scenarios in which all the rules or situations are not known ahead of time. For example, consider object recognition in an image. An engineer, or even a team of engineers, could take years to program all the rules required to identify an object (e.g. a cat) in an image.

Despite its proven utility, ML also has some idiosyncrasies. Although the fundamental algorithms can be generalized, its performance is typically context and data specific, tightly coupled to a single solution-space and to attributes of a particular data domain. For instance, an ML object detection algorithm for automatic target recognition (ATR) trained to identify tanks in a desert environment will likely not correctly recognize tanks in a dense forest. The implications are that the technology does not yet provide the human-like, general intelligence AI (or "Strong AI") that one might see depicted in movies.

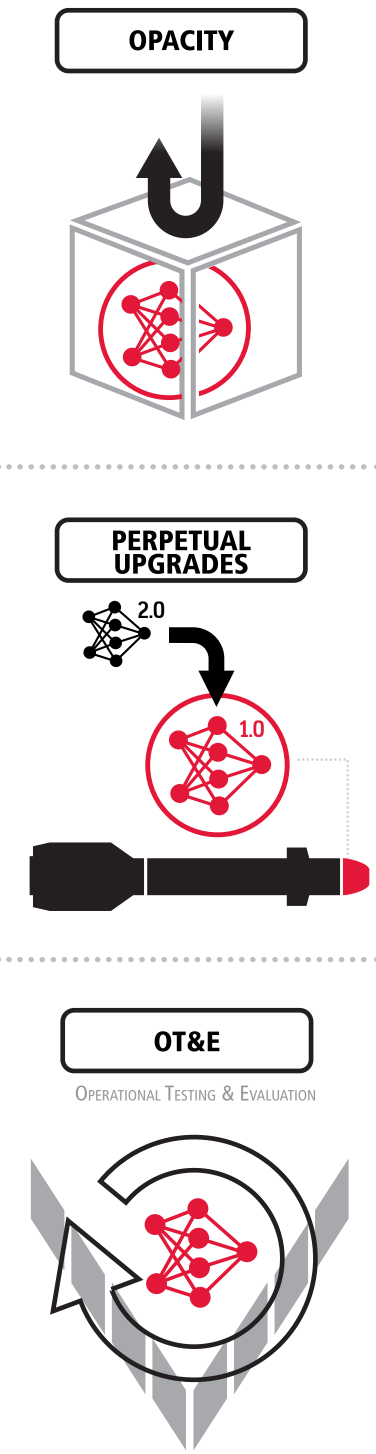

Figure 2: Challenges of Machine Learning

As AI and ML is introduced into systems, especially those that perform missions of high consequence, developers and users will have to deal with a range of challenges, including opacity, perpetual upgrades, and Operational Testing and Evaluation (OT&E); *Figure 2.*

Opacity. AI and ML aligns with a common trend across many of today's advanced technologies, the danger of overwhelming complexity. Humans now build machines that we cannot fully comprehend and AI and ML exacerbates the issue many times over.[3] A compounding factor in ML systems is opacity where the inner mechanisms operate as a black box ("algorithmic mystery").[4] This is particularly the case with Deep Learning where many layers of thousands of simulated neurons embody the network reasoning for functions like computer vision. Effective solutions for explaining why ML algorithms arrived at a particular answer will be a key contributor in cultivating trust, the primary roadblock to operationally effective human-intelligent machine interactions.[5]

Perpetual Upgrades. All analytics models, particularly ML models, have a lifecycle and eventually grow stale due to change. Things like evolving mission requirements, dynamic environments and enemy counter-measures mean the effective life of an analytic model can vary from years to days, or in extreme cases, perhaps even seconds. Similarly, AI technology is becoming ever more widely accessible, causing the cycle of model obsolescence to further accelerate. The average model lifespan will likely grow ever shorter as the AI/ML space matures and becomes ubiquitous across the battlefield. Beginning with one set of algorithms, once the battle is underway, combatants will introduce new algorithms while evolving and deprecating the old. The cycle of this "AI arms race" will ultimately collapse into second-by-second contests of updating and evolving algorithmic models as each side attempts to counter, nullify and obfuscate each other's capabilities. The key discriminator in this environment will be automation: automated model development, testing and deployment. Combat-effective AI capabilities of the future will have the ability to continuously update through automated mechanisms to out-sense, out-think and ultimately overmatch the intelligent machines of an adversary.[6] Perpetual upgrades are the future of AI and the most effective practitioners will embrace it.

Operational Testing and Evaluation (OT&E). Conventional OT&E methods and techniques are wholly inadequate for AI/ML systems. Beyond the opacity challenge, intelligent machines, especially AI system of systems, are inherently complex, non-deterministic systems.[7] Unanticipated emergent behavior, indeterminate test results, dynamic behavior adaptation and Black Swan events (i.e. a rare, unexpected, high-consequence event) all impact AI OT&E. Future operationally effective capabilities will demand a re-imagined, novel approach to OT&E — fertile ground for innovative solutions.

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Tod Newman
Raytheon Missile Systems

With over 21 years of experience, Tod Newman is currently the leader for Raytheon's Machine Learning (ML) and Artificial Intelligence (AI) Center of Excellence (CoE). In this role, he works to align technologies and processes to enable faster adoption and maturation of ML and AI at Raytheon. As Chair of Raytheon's Information Systems and Computing Technology Network, he leads Raytheon Missile Systems' research in advanced processing architectures. "This research complements my AI and ML role," Newman explains. "The significant challenge of bringing AI and ML into our culture revolves around our ability to integrate inference into embedded processing systems."

With regard to his current work with AI and ML, "Our customers have been very interested in machine intelligence for a number of years," Newman states. "I have been tracking this closely since 2010 and have seen the Contract Research and Development (CRAD) opportunities in this area increase significantly in that time. The AI and ML CoE will play a key role in helping the technologies developed under Independent Research and Development (IRAD) and CRAD migrate successfully to product and business applications."

Previously, Newman served as the Raytheon Corporate Technology Area Director for Information Systems and Computing (ISaC), and he led the Raytheon Missile Systems Test Systems Department for four years. He is a 1992 graduate from the U.S. Coast Guard Academy, and he served for six years as an officer in the Coast Guard. "A lot of the work we did in the Coast Guard was very hard," Newman relates, "but clearly, it was critical for the lives and safety of others. The key skills the Coast Guard and other military branches teach their officers and enlisted personnel is how to recognize and prioritize the most critical activities, and also, how to adapt and overcome when your best plan is thrown into disarray by events. This has had a lasting impression on me and is reflected in the way I approach my responsibilities at Raytheon."

Newman is a Raytheon Certified Architect and a member of various Science Advisory Boards, primarily focusing on cognitive processing technology research.

ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING AT RAYTHEON

Raytheon has performed significant Research and Development (R&D) in machine learning over the last decade, much of it at Raytheon BBN Technologies.[8] Spanning theoretical to field-deployed applications, this activity has bridged multiple problems, from natural language processing to network flows and cybersecurity. As examples, Raytheon BBN's MultiMedia Monitoring System (M3S) is a deployed application utilizing numerous machine learning solutions to provide analysts a unified interface for direct access to diversified media, including television, web and social media *(Figure 3)*, and the Strategy Optimizer that uses machine learning to adaptively reconfigure radio and network stacks to maintain consistent communications on mobile ad hoc networks (MANETs).

Figure 3: Multimedia Monitoring System (M3S) Display of Entity Network Analysis

In addition to Raytheon innovation in AI and ML, a primary driver of innovation in the field is the commercial sector. In the U.S. alone, the number of AI startups has increased by a factor of 14 since the year 2000, while the amount of annual venture capital investment into AI has increased six-fold during the same time period.[9] The result has been a flourishing and rapidly evolving ecosystem of machine intelligence innovation that would be difficult to match in the defense industry alone. Commercial AI/ML technology as well as academic research cannot be viewed as competition but rather as an important opportunity for partnership, integration and collaboration. A key Raytheon role in the intelligent machine era will be as the integrator of cutting edge AI/ML capabilities, increasingly sourced and adapted from the commercial market. The insertion of AI capabilities into the Department of Defense (DoD) and Intelligence Community (IC) requires proven domain expertise to make them operationally effective. Raytheon's role will not only include fundamental research into core technologies but also the integration and operationalization of AI/ML for overall mission effectiveness.

OUR FEATURE ARTICLES

Today, ML is automating what was once a costly and time-consuming analysis of artifacts and data to generate new intelligence. One example of this is hand written notes or "pocket litter." Because it is potentially more secure and immune to electronic surveillance, handwriting is increasingly becoming a preferred communication method, oftentimes placed over existing written or typewritten pages *(Figure 4)*. Using a variety of ML classification techniques, Dr. Darrell Young's "Detection, Extraction, and Language Classification of Handwriting" article describes his approach to obtain good results on simulated handwriting of 16 languages including Chinese, Cyrillic and Arabic.

Another automation example is Christine Nezda's article "Machine Learning to Determine Patterns of Life" that describes an approach to model the state of an entity, such as an aircraft or maritime vessel based on historical observations, including location, speed, maintenance cycle and other attributes. These Patterns of Life (PoL) are widely applicable to many domains and can be used for route prediction, anomaly detection and targeted event characterization. Also discussed in this article is the underlying software framework, a horizontally scalable approach adapted for true big data analytics.

Raytheon is continually innovating with AI/ML for product improvement and reliability. Dr. Kim Kukurba's DREAMachine concept analyzes factory data to predict future defects, highlights leading factors of defects, and identifies redundant testing. Dr. Kukurba's article, "Machine Learning in the Factory," describes both supervised and unsupervised ML approaches for automated defect reduction, a key enabler to increase operational effectiveness and cost containment. These same goals are shared by Michael Salpukas in his article "Raytheon Predictive Maintenance (RPM)," which discusses methods for predicting hardware failures to increase system availability and reduce costs associated with current preventive and reactive maintenance approaches. Using discrete machine learning and parameter tuning methods, RPM provides real-time anomaly detection on multiple radar and other system datasets.

Detecting emergent threat behaviors is the subject of Dr. Shubha Kadambe's article, "PRoactiVE emergiNg Threat detection (PREVENT)." PREVENT is based on a dynamic stochastic network which consists of sparse super nodes and dense local nodes. It detects emergent group threat behaviors by computing and evaluating the instability metric of the stochastic network. PREVENT provides early warning to operators based on this detection to conduct further analysis on the identified participants (or actors) involved in the activity. This approach has been tested and evaluated under multiple use cases, including several littoral scenarios and oil rig activities.

A key enabler of many Raytheon capabilities is Automatic Target Recognition. Mark Berlin and Matt Young's article, "Automatic Target Recognition (ATR) Systems," provides an overview of a core technology that interprets data far faster than human analysts. The article discusses the challenges of ATR, research in academia and the commercial industry, and emerging advanced approaches including deep learning. ATR algorithms are often applied to use cases where limited sample data requires new training techniques like Generative Adversarial Networks (GANs) to teach the ML algorithms. GANs are also one of the main topics of the article, "Strategies for Rapid Prototyping

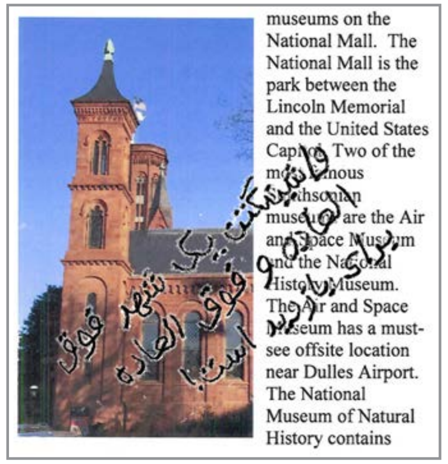


Figure 4: Sample handwriting over text and picture

Machine Learning" by Steve Israel, Philip Sallee, Franklin Tanner, Jon Goldstein and Shane Zabel. Supervised training on large, labeled datasets has enabled most of the recent advances in AI and ML. However, a lack of sufficient data has excluded the use of ML in many defense applications. GANs are a method of training with sparse datasets, allowing ML applications to be used in previously unsuitable customer mission environments.

We are at the beginning of the intelligent machine era which promises widespread evolution and exponential boosts in defense capabilities. Raytheon will continue to partner with its DoD and IC customers in the further development and integration of operationally effective AI/ML applications to ensure mission success.

Darryl Nelson

[8] See for instance, Ilana Heintz, "Machine Learning Applications," Technology Today, 2017 Issue 1.

[9] Shoham, Y., Perrault, R., Brynjolfsson, E., Clark, J., Manyika, J., & LeGassick, C. (n.d.). 2017 AI Index Report. Retrieved from Artificial Intelligence Index: http://cdn.aiindex.org/2017-report.pdf

Darryl Nelson
Raytheon Intelligence, Information and Services

Darryl Nelson is lead for IIS' Analytics & Sensing Capability Center, where he directs Independent Research and Development (IRAD) and Contract Research and Development (CRAD) projects, and he develops technology roadmaps for distributed computing and scalable architectures in the areas of analytics, machine learning, and systems and software architecture. Nelson has spent more than 20 years in software engineering, the recent 14 of which at Raytheon. "My work is fundamentally about data manipulation," Nelson says. "I work with brilliant teams on next generation advanced analytics, manipulating massive volumes of data to extract actionable insights. Ultimately, we provide cognitive augmentation and amplification to help our customers become hyper-productive and make better decisions, faster."

Prior to his current role, Nelson served as the Information Systems and Computing Technical Area Director in corporate Technology & Research where he focused on analytic model productivity, cloud computing and big data analytics for cyber applications. He also co-chaired the Big Data Analytics, Cloud Computing and Mobile Computing Technology Interest Group. Nelson has presented at multiple Raytheon symposia and external technical conferences.

Nelson had previously worked with Special Operations Command, the U.S. Army and the Intelligence Community in various roles, including the IIS Big Data Analytics Lead, the Ubiquitous Computing Technology Center Chief Scientist, and the Distributed Common Ground System-Army Intelligence, Surveillance and Reconnaissance Surge Lead & Chief Architect. He deployed to Baghdad, Iraq in 2005 and 2007 in support of the Raytheon Persistent Surveillance and Dissemination System of Systems program.

Nelson received his Master of Engineering from Texas Tech University, and he is a veteran of the U.S. Army. "Of the many events in my lifetime, one in particular stands out that shaped my approach to engineering. During Desert Storm, when I served as a U.S Army soldier as an M1A1 Abrams tank crew member, I vividly experienced the decisive advantage that technology can play on the battlefield. The confidence we had in our equipment (such as the Raytheon TOW missile) greatly contributed to our mission success. That experience continues to drive me to develop capabilities that will instill the same confidence in future generations of warfighters, analysts and all those who serve our country."

AUTOMATIC TARGET RECOGNITION SYSTEMS

In today's battlefield, there are a large number and variety of platforms and systems, many having multiple sensors that create a picture of the battlespace from all angles and across the electromagnetic spectrum *(Figure 1)*. But while the U.S. and allied militaries have made significant investment in providing this vast quantity of data, the data alone is useless unless *interpreted* to extract relevant details and actionable items.

Traditionally, human beings have been employed to interpret this data; for example, a shipboard operator monitoring one or more radar screens, a pilot viewing his head-up display (HUD), or even a soldier looking through a gun sight. And although humans excel at analyzing and interpreting data, our faculties are limited in that operators can become fatigued, pilots may be unable to respond to many alerts and notifications, and soldiers can be distracted by activity in their surrounding environment.

In today's world, data is created much faster than available human resources can effectively use it. Automatic Target Recognition (ATR) is a technology designed to enhance the utility of military systems by interpreting data faster and more accurately than human analysis alone.

Intelligence, Surveillance & Reconnaissance (ISR) platforms produce a constant stream of data. The rate at which platforms and sensors are being deployed in this domain outpaces the rate at which human analysts can be trained and mobilized. Moreover, since each analyst can only review a small subset of data, it is possible to miss the big picture provided by all platforms surveilling an area.

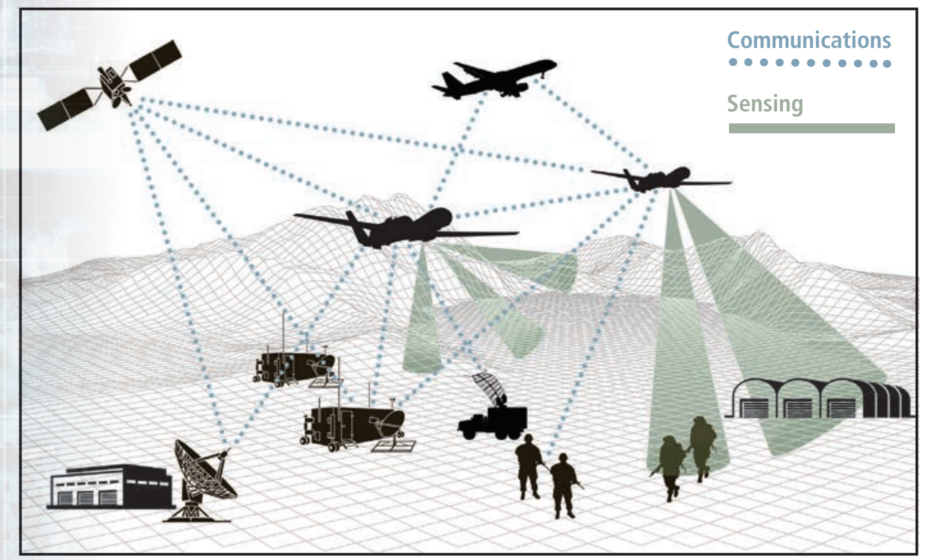


Figure 1: Sensors gather and share data across the battlespace

As the capabilities of threats to engage and destroy aircraft increase, maintaining air dominance in the battlespace becomes more challenging. Oftentimes, an aircraft's survival and mission success depend on mere seconds in a pilot's decision making process. While early detection and early warning systems help, as enemy capabilities proliferate so do the technologies to defend against them. As a result, HUDs and cockpit control systems are becoming increasingly complex and data intensive, making it difficult for pilots to execute within the critical short timeframes required.

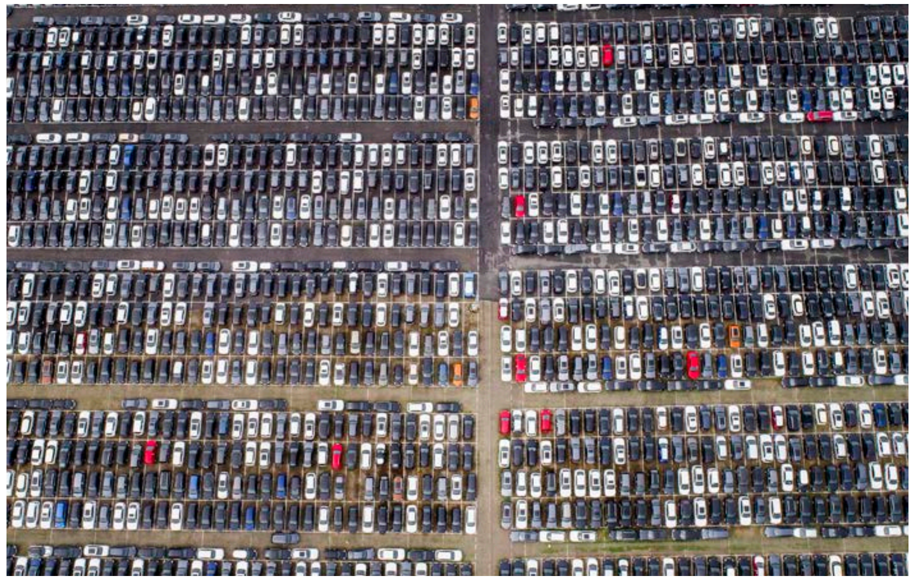


Figure 2: Identifying the correct object amidst many very similar objects can be a challenge

Today's weapons must fly faster, farther, and hit more precise aimpoints than ever before. Asymmetric and urban warfare require precision guidance while Anti-Access/Area Denial capabilities demand weapons be launched from farther away, with less opportunity for pilot guidance. Capabilities beyond fire-and-forget are required, and often missiles must be launched *before* a target's location has been clearly identified.

ATR systems specifically address these challenges, helping to meet warfighter needs and maximizing utility of Raytheon-built sensors, platforms, weapons, and ground based systems.

THE CHALLENGE IS REAL

Humans can readily interpret an outdoor scene or photograph, and may easily take for granted or underestimate the complexities and challenge of the underlying problem. To interpret an image, you must identify and differentiate spatially varying intensity patterns resulting from a highly complex transformation of sensor specific phenomenology, viewing geometry, surface materials, and environmental conditions. One may think of image interpretation as "natural," but the quantity and quality of training data required to develop this capability is significant. For example, babies are presented with a nearly continuous stream of labeled training data from their parents, siblings, and even TV shows all designed to teach letters, animals, vehicles and other images. A young child will see photographs of dogs, drawings of dogs, cartoons of dogs, and likely interact with a dog in the process of learning and understanding "dog." Even with this amount of training input, it takes years of trial and error for children to become skilled at identifying objects in a complex scene with many distractors, for example, finding a specific vehicle in the parking lot depicted in *Figure 2*.

Conversely, ATR algorithms are expected to reach the same level of recognition performance with only a small number of samples collected over a limited set of conditions. This is why classical ATR approaches typically behave well only when the operating conditions are very similar to the training data. When objects of interest are embedded in complex environments, such as an urban landscape, or when techniques are applied to disguise signatures or deceive the system, classical algorithms often fall apart quickly. In these situations, templates may no longer match; characteristics extracted from principal component analysis or other decomposition methods may no longer be present or might have been altered; and hand crafted features, while robust, are limited by the imagination of the designer and frequently cannot distinguish similar objects.

EMERGING ADVANCED APPROACHES

A number of different approaches exist for building ATR systems. One method relies on the creation of a database containing three dimensional (3D) computer aided design (CAD) models of targets to be identified by the ATR algorithms. These models are rendered into two dimensions (2D), taking into account sensor specific phenomenological effects and viewing geometry to produce synthetic 2D signatures that are scanned across an image to find the best match. Although this is a purely physics based approach and theoretically requires no measured data for training, the 3D models require CAD modeling expertise and are expensive to build. Additionally, some amount of measured data is needed for calibration purposes.

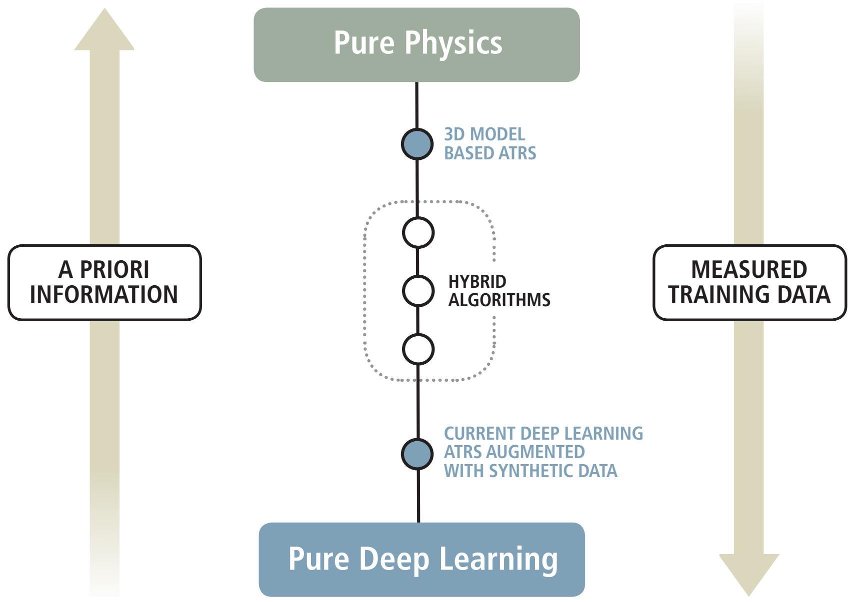


Figure 3: Emerging Automatic Target Recognition (ATR) approaches incorporate rapid 3D target modeling and Deep Learning

Recently, deep learning algorithms have been applied to ATR systems. These algorithms are automatically trained, using large amounts of data, to learn differences between target signatures of interest — eliminating the need for human phenomenological or 3D modeling expertise.

There is rarely enough measured training data available for deep learning ATRs to adequately cover all possible imaging conditions of interest. One approach for generating large amounts of synthetic data, sufficiently similar to measured data for deep learning algorithms to be effectively trained, makes use of Generative Adversarial Networks (GANs). GANs are an unsupervised machine learning approach utilizing two competing network models, one discriminative and the other generative.[1] A topic of active interest across the entire deep learning community, GANs are actively being investigated and adapted across Raytheon under ongoing Independent Research and Development (IR&D) efforts.

Pure model based ATRs and Deep Learning based approaches are two extremes of the continua shown in *Figure 3*. The model based approach maximizes encoding of a priori target information by humans whereas a pure deep learning approach requires no a priori information but requires significant measured training data. Between these two approaches, we believe there are hybrid algorithms that pay some cost in providing limited a priori information but with the important benefit of reducing the amount of training data needed.

Increasingly, the distinguishing capability for military success is knowledge of the battlespace, and ATR provides real-time knowledge across a broader swath of data than previously possible by human operators alone. Raytheon's investment in ATR technology is building a foundation for the future of military combat. We are developing advanced machine learning algorithms capable of being trained with limited data and deployed on computationally limited platforms. Integrated into Raytheon's product offerings, they will be trusted to provide the right answers even in challenging environments of complexity and adversarial action.

Mark Berlin
Matt Young

[1] Generative Adversarial Nets, Ian J. Goodfellow, Jean Pouget-Abadie, Mehdi Mirza, Bing Xu, David Warde-Farley, Sherjil Ozairy, Aaron Courville, Yoshua Bengioz, Département d'informatique et de recherche opérationnelle Université de Montréal, Montréal, QC H3C 3J7.

FEATURE

PROACTIVE EMERGING THREAT DETECTION (PREVENT)

In today's world, terrorist and other hostile threats to both domestic and international peace can appear almost anywhere. When acts of aggression or harmful events occur, post forensic analyses are conducted to determine cause, methods and associated patterns, which are then used to avoid similar events in the future.

The adversaries are creative however, improvising and creating new tactics every day. Consequently, there is a need for a proactive and predictive capability to detect threat activities before harmful events occur. In many cases, anomalous behaviors can be indicators or predictors of hostile activities, and if detected, they can generate alerts in real time, helping to thwart an action before it occurs and provide an opportunity to save lives. Raytheon has developed such a capability in an analytical tool, PRoactiVE emergiNg Threat detection (PREVENT), based on a dynamic stochastic network, to assess unusual patterns or behaviors as they happen.

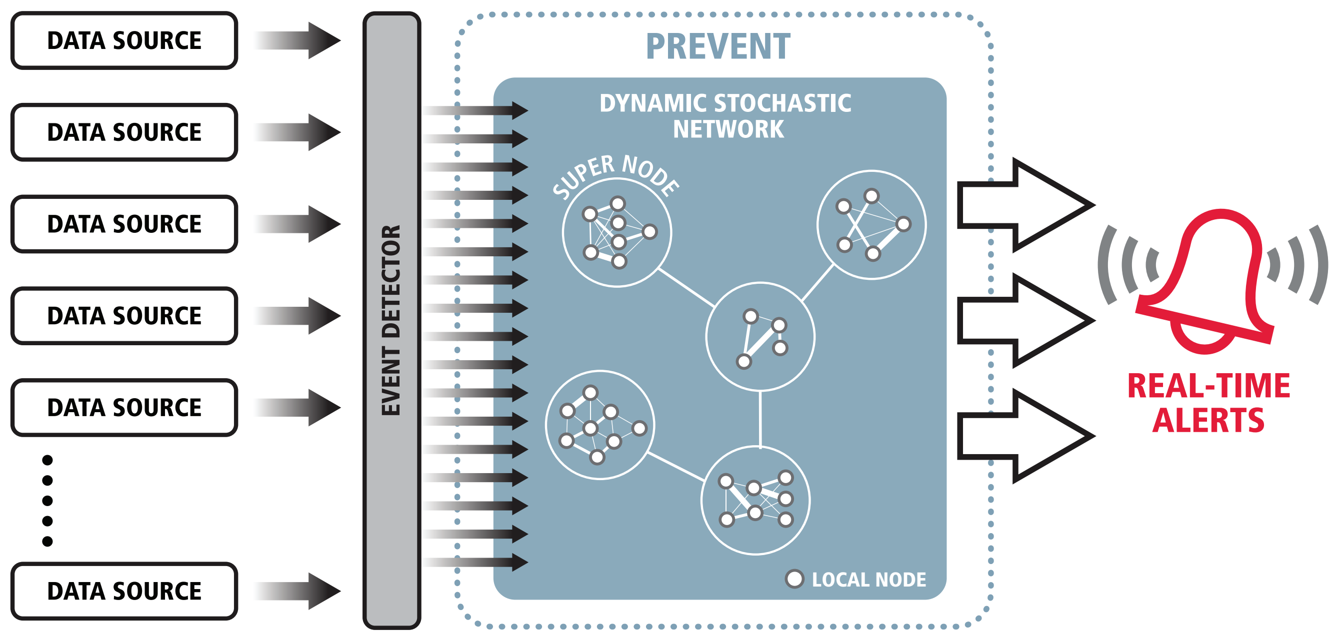


Figure 1: PREVENT functional block diagram

PREVENT detects an emergent threat behavior in real time by computing an instability metric of the stochastic network. It provides early warning to operators based on this detection, who then conduct further analysis on the identified participants in the anomalous behavior. PREVENT is a general behavior analysis capability and has been applied to detect emerging threats in many environments, such as cyber/computer networks, oil rig operations, air traffic and littoral activities. This article presents an overview of the tool's functionality along with its performance in example cases.

A functional block diagram of PREVENT is shown in *Figure 1*. It operates by the collection, correlation and categorization of events, forming a dynamic stochastic network depicted in the figure as a network graph diagram. Events are collected from multiple data sources, each corresponding to an agent ("who"), event type ("what") and event time ("when"). As they are received and processed, the network is formed, or learned, consisting of sparse super nodes shown as large ellipses with dense local nodes contained therein. Events in the network are represented by lines or connections (called edges) between the nodes. The nodes are represented by the agents associated with the events. As agents interact over time, connections are made or broken. These connections increase or decrease in strength with the number of events the agents have in common, shown by the thickness (or weight) of the edges between the two nodes. Sets of densely connected nodes in the network are modeled as a super node, which represents events and agents associated with one type of data source. The sparse connectivity between super nodes reflects the relationship of events/agents between the different data sources.

For example, if one data source provides computer network activities and another telephone network activities, then one super node corresponds to computer network events and the other to telephone network events. The nodes within each super node correspond to agents (people) using the computer and telephone network, respectively. When several computers are exchanging data, the IP address (and associated user) of each computer is represented by a node within that super node, and connections (edges) are made between them reflecting the specific data exchanges. Similarly, in the telephone network super node, each phone device (and associated person) is a node, and any calls among these phones are reflected in the edges between them. If a node in the computer network calls a phone in the telephone network, a voice over IP (VOIP) call or text message for example, then a connection between these two super nodes is made.

In this fashion, PREVENT learns the network structure as different data sources and events are available. Periodically, PREVENT estimates the stability of the network's current state. For this, it summarizes key statistics about each active agent such as configuration (the number and type of events in which it is participating), duration of events and its connections both within the super node and to other super nodes. The difference between current and previous empirical distributions of network activity is computed, and if the magnitude of this difference is above a specified threshold, PREVENT generates associated alert(s) to the operator or analyst. With this information, further specific monitoring can be started; additional data sources or sensors activated; or an appropriate course of action initiated to stop further threats or harmful activity. The period for network stability calculation and alert thresholds are configured based on the specific environment and events being monitored.

A SWARMING BOAT USE CASE

The capabilities of PREVENT are readily demonstrated in the swarming boats scenario shown in *Figure 2*. The scene involves a strait with both fishing areas and shipping lanes populated by different types of vessels such as cargo ships, fishing boats, pleasure craft and military vessels. As shown in the figure, activities include cargo ships navigating through the strait via one of two shipping lanes; fishing by four groups of fishing boats (green circular formations); military vessels in the shipping lane moving faster than the cargo ships; and twelve small fast boats disguised as pleasure craft, manned by persons (agents) ultimately planning to take aggressive action against the military vessels. As the scenario plays out, groups of the fast boats enter each fishing area and stop among the fishing boats. Then after some time, they set an intercept course for the military vessel(s).

The data source for PREVENT in this scenario was events created from vehicle tracks received from multiple radar sensors. Raytheon's Intersect Sentry^{TM} product generated events from the tracks using different analytics, such as proximity, heading changes, speeds above and below limits, acceleration and deceleration. PREVENT then processed the events and the agents (vessels) associated with the events to dynamically form the stochastic network used to detect anomalous behavior. *Figure 3* is a plot of the network stability metric computed by PREVENT throughout the scenario. The instability can be seen to rise above the threshold whenever there is anomalous behavior of fast moving craft, such as traveling

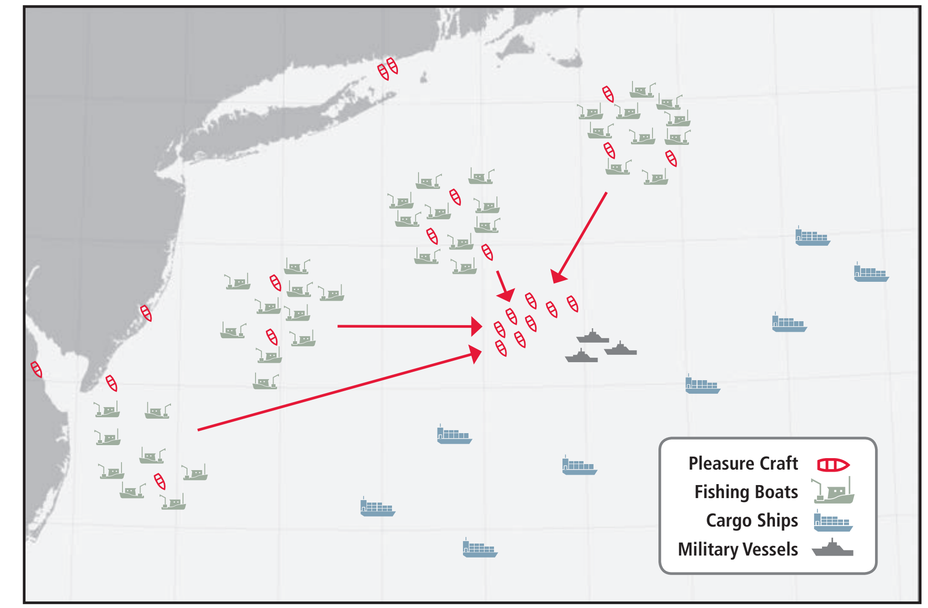


Figure 2: Swarming boat scenario

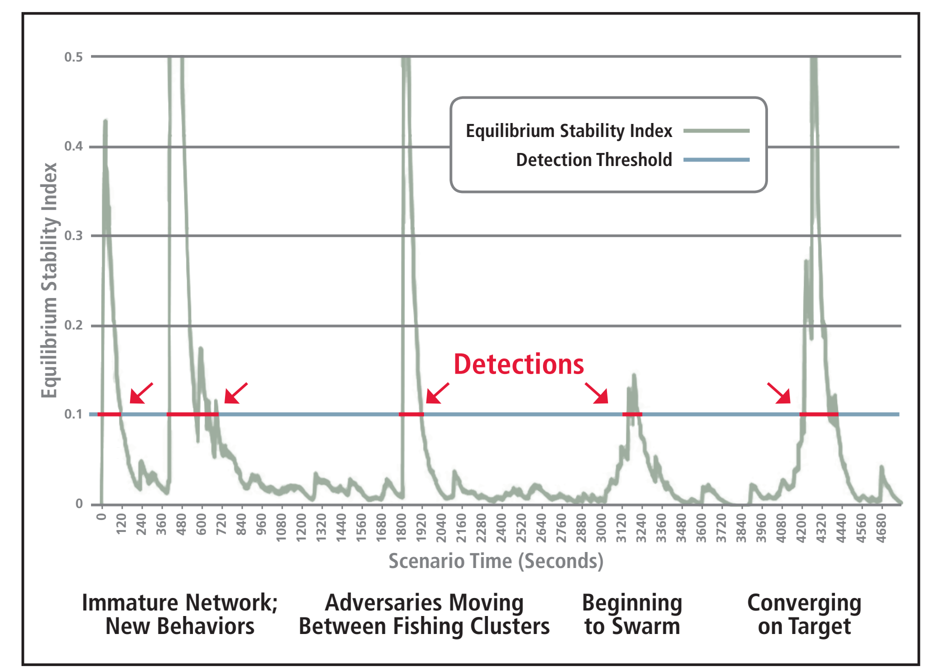


Figure 3: Anomalous behavior detection in the case of swarming boats

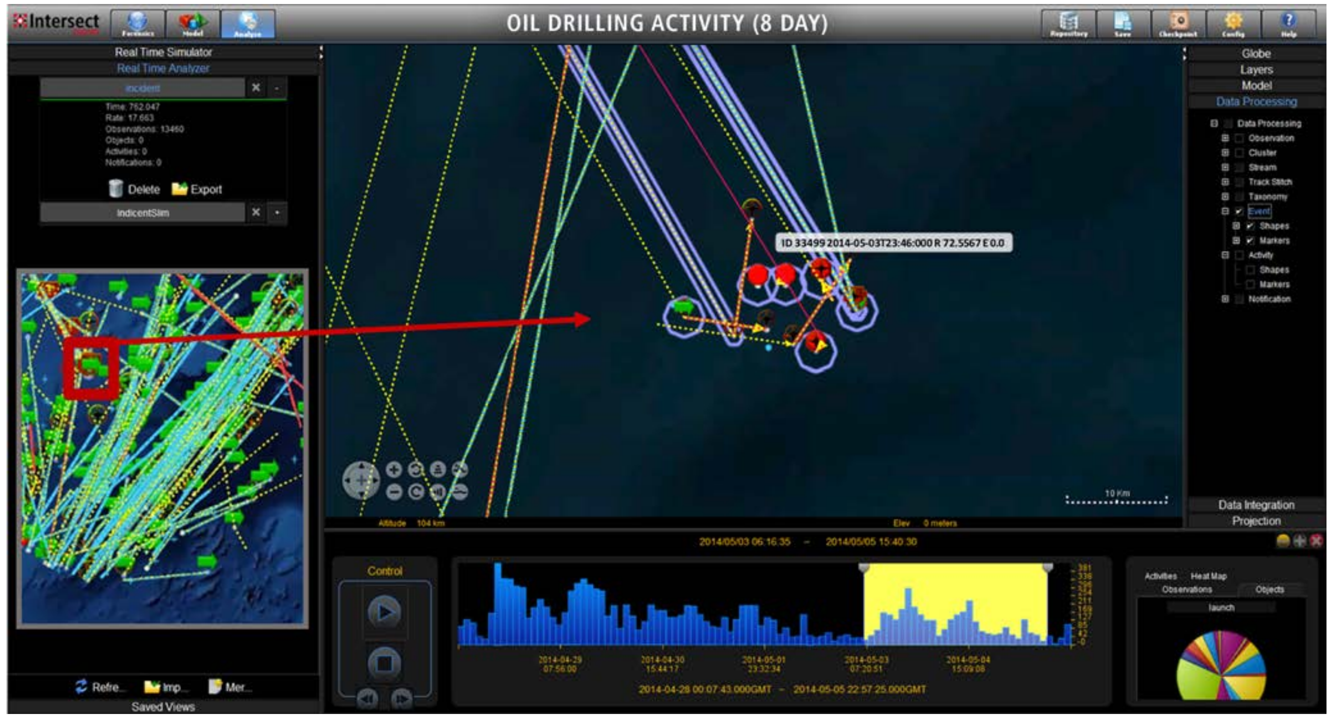


Figure 4: Intersect Sentry operator screen monitoring activities near area of interest. Center screen is the zoomed area of anomalous ship activity.

between fishing clusters, an initial swarming toward the shipping lane and finally, converging on a target. Although the instability is above the threshold early in the scenario (before 1000 seconds have elapsed), PREVENT ignores the detections as the network is still being formed. After the network matures, PREVENT acts on all detections by generating alerts to the operator.

OIL DRILLING USE CASE

PREVENT has been demonstrated to work on real-world data associated with oil drilling activities. *Figure 4* shows an Intersect Sentry operator screen monitoring an offshore area of interest with ongoing oil drilling operations. Similar to the previous swarming boats case above, Intersect Sentry extracts events analytics from the real-time track data such as loitering, immediate proximity and immediate proximity exit. In this longer scenario, PREVENT uses the events and the associated agents (or actors) to learn the network and then computes the instability metric over a period of days, detecting and reporting anomalous behavior(s). The number of alerts per day reported by PREVENT is shown in *Figure 5*. The typical activities correspond to oil drilling and the associated craft's movement. The anomalous behavior corresponds to an adversary's craft steaming to join the drilling activity. The increase in reported alerts shown in *Figure 5* is associated with the Identified ship (ID 33499), a driver of network instability as it steamed to join drilling activity over five separate alerts. This matches the truth for that time period, shown in the zoomed scenario area in the center of the operators screen in *Figure 4*.

PREVENT's architecture is designed to scale. PREVENT has been integrated with Docker™[1] and Raytheon Space and Airborne Systems' (SAS) Adaptive Technique Manager (ATM), which enables distribution of PREVENT across multiple systems and computational parallelization of events and stochastic network learning. SAS ATM is an event-driven workflow manager for performing both man-in-the-loop and fully automated missions. It consists of a web interface, sensor adapters, event processors and technique manager. Sensor adapters receive data from different sensors or data sources and convert the data into streaming events. The event processor receives these events from the sensor adapter and generates events analytics which are used by PREVENT to learn the stochastic model previously described. Docker is a lightweight, open, scalable and secure commercial tool. It can accelerate software development, eliminate environmental inconsistencies and easily distribute the sharing of content or application to many platforms. By integrating PREVENT with ATM and Docker, it can be scaled to environments with millions of events and tens of thousands of actors.

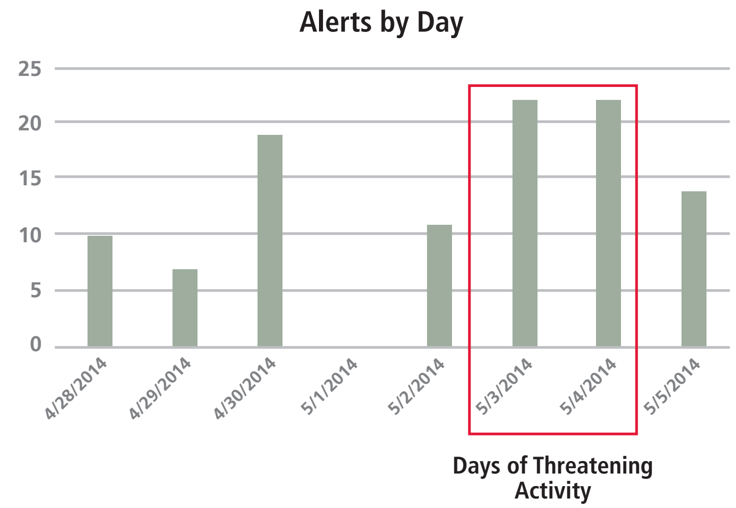


Figure 5: Alerts per day reported by PREVENT

In addition to scalability, PREVENT is architected to be a real-time proactive analytics tool. For example, in the oil drilling scenario depicted in *Figure 4* with 840 actors and 60,000 events, PREVENT was able to process the data and arrive at the anomalous event in less than a minute on a laptop computer. PREVENT can ingest data from multiple disparate sources simultaneously and can learn relationships among those sources and actors. Future work includes integrating PREVENT as part of Raytheon SAS's Cyber Electro Magnetic Battle Management (CEMBM) product for predictive analytics and to detect anomalous spectrum behaviors of adversaries. Based on how the spectrum is denied and used by the adversaries, Electronic Warfare Officers can maneuver and counter adversarial attempts to deny spectrum to U.S. military forces.

In summary, PREVENT is a novel approach for detecting emergent threat behavior through the modeling of events and actors as a dynamic stochastic network. It utilizes an unsupervised learning approach for real-time proactive analytics and can easily model new domains simply by defining a new set of associated actors and events. PREVENT's forensic capability allows learned configurations to be stored as a sequence with associated time stamps and then later analyzed to determine associations between actors, events and activities. PREVENT is an important analytic tool for Raytheon and its customers — providing a capability to thwart harmful events and save lives.

Dr. Shubha Kadambe

Shubha Kadambe, Ph.D.
Raytheon Space and Airborne Systems

Dr. Shubha Kadambe is a senior engineering fellow at the System Engineering, Integration and Test (SEIT) Center for Raytheon Space and Airborne Systems (SAS). She has in-depth experience in the development of advanced and innovative machine learning (ML) and artificial intelligence (AI) algorithms for applications such as electronic warfare (EW), radar, sonar, speech and communications. Dr. Kadambe uses this background to lead engineers in the research and development of AI/ML capabilities for cognitive EW; activity based intelligence (ABI); smart sensors; human-machine teaming; and efficient decision-making tools to reduce warfighter workloads and improve their ability to make quick decisions.

Prior to joining Raytheon in February of 2013, Dr. Kadambe worked for Rockwell Collins™, Inc. where she led a team of engineers to develop, from concepts to prototype, a cognitive EW architecture and system to be part of a larger communication system. Dr. Kadambe was a program officer at the Office of Naval Research (ONR) prior to joining Rockwell Collins. At ONR, she managed signal/image processing and understanding, a multi-university research initiative, and Small Business Innovation Research (SBIR) programs. Additionally, Dr. Kadambe has held various research positions at HRL Laboratories™, Atlantic Aerospace Electronics Corporation and AT&T Bell Laboratories, where she successfully completed several Defense Advanced Research Projects Agency (DARPA™) projects and other Department of Defense (DoD) funded projects.

When asked for advice for up-and-coming engineers at Raytheon, Kadambe said to "be passionate, have conviction and understand the underlying physics of the problem that you are working. When facing a problem, have the bigger picture in mind, and once you've come to a conclusion, analyze your results to be sure they support that conclusion."

Dr. Kadambe obtained her Ph.D. in Electrical Engineering from the University of Rhode Island. "My interest in science and math in high school led me to engineering," she reflects fondly. "And the hands-on training I had during my undergraduate work in engineering led me to a career in research." Dr. Kadambe's technical credits include more than eighty referenced journal and conference papers, seven invited chapters, an IEEE® video tutorial on Wavelets and its applications, 26 U.S. patents and four trade secrets.

[1] An open-source container-based platform for effective application development and deployment (https://opensource.com/resources/what-docker)

MACHINE LEARNING IN THE FACTORY

Raytheon develops, matures and exploits machine learning to improve designs, enhance performance and raise the quality of its solutions in support of customer missions. Raytheon also utilizes these advanced cognitive and analytical methods to continually enhance its business operations. Machine learning powered approaches are now emergent across the company in all disciplines, including Engineering, Operations, Information Technology, Supply Chain and Business Development, helping to improve decision-making and maintain a competitive advantage.

APPLYING MACHINE LEARNING IN THE FACTORY

Raytheon generates a vast amount of data throughout the design, production and deployment of its complex defense systems. At each step, data is generated and retained, capturing details, decisions, measurements and transaction logs associated with products, processes and people. Some examples of data types include design simulations, supplier purchase orders, assembly steps, component tests, final quality assessments and field testing. One area that is particularly data-rich and filled with opportunity to apply analytics and machine learning is the factory floor, where the production, integration and test validation of products are completed.

Machine learning can provide predictive power and actionable insight to nearly all aspects of manufacturing on the factory floor. Unlike descriptive or diagnostic analytics, predictive analytics enabled by machine learning provide future predictions based on patterns discovered in historical data *(Figure 1)*. Insight into the future, as opposed to statistics of the past and present (descriptive and diagnostic analytics), enables a business to be less reactive and more proactive in its decision-making. For example, a probabilistic estimation of when a product will fail permits proactive planning before the failure ever occurs. This technical approach can be applied within manufacturing across multiple areas to improve product yields, decrease cycle time, and eliminate redundant testing and processes. It also helps improve product quality through lower probability of defects, reduced scrap and decreased costs due to rework. All of these benefits increase competitive advantage and ensure high-quality products are delivered quickly and efficiently to customers.

Machine learning tasks can be categorized into three broad categories: supervised, unsupervised and reinforcement. Supervised learning is applied to understand the relationship across various inputs to predict specific outputs. For example, supervised learning can be used to evaluate attribute data about a component (input) to predict the probability of a future defect (output), and ultimately use that information to reduce the likelihood of occurrence or eliminate it totally. Unsupervised learning is applied to discover patterns or a hidden structure from input data where the output is unknown; for instance, it can be used to cluster or detect anomalies within product quality. Lastly, reinforcement learning is applied to find the ideal behavior within a given situation in order to maximize a reward; for example, it can be utilized to maximize physical space within a factory layout. Supervised and unsupervised learning have the most direct applicability to the manufacturing environment, although reinforcement learning may have utility for certain applications. Both unsupervised and supervised machine learning use iterative algorithms designed to learn continually and seek optimized outcomes as more data is incorporated. These algorithms can detect patterns across intricate datasets in seconds, thereby identifying optimized outcomes in seconds, where an analyst may require weeks to make the same determination. Further, the specific algorithms employed are chosen based on their higher interpretability (or explainability — the understanding of why an algorithm makes a specific prediction), *Figure 2*. This understanding provides more actionable insights for daily operations.

Figure 1: Analytics capability trade-space

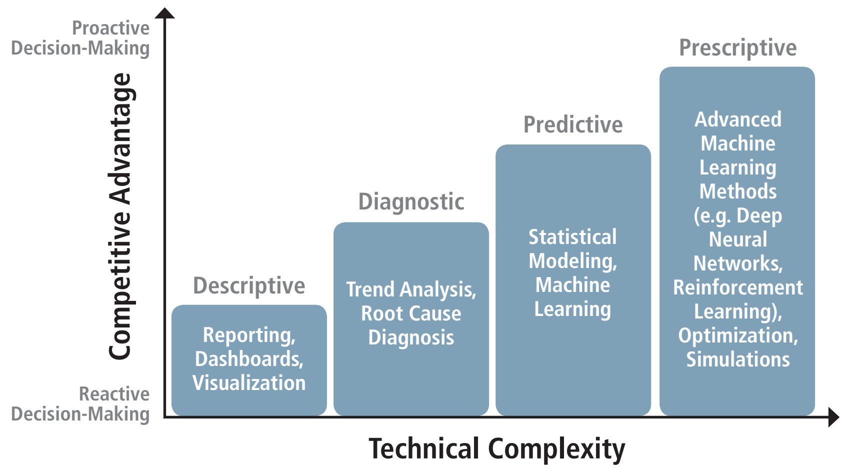
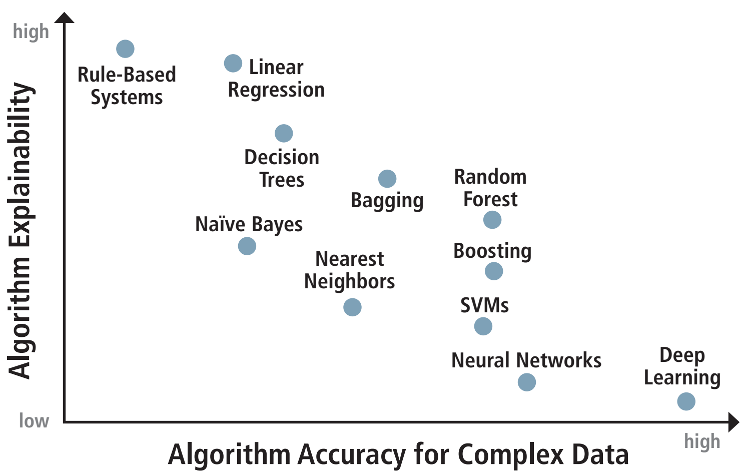


Figure 2: Tradeoffs between accuracy and explainability of techniques



AN APPLICATION OF MACHINE LEARNING WITHIN THE FACTORY: DREAMACHINE PROJECT

Introduction

At Raytheon, as each part is manufactured or purchased, component assembled, subsystem integrated, and tested on the factory floor, data is generated and stored to business and enterprise information systems. On a high-rate production program with multiple domestic and international customers, slices of the data are regularly used to construct reports and metrics, ensuring that the manufactured products met their quality and on-time delivery requirements. Large-scale data integration and analysis of this data is typically difficult due to historically siloed information systems, expensive storage costs, and discipline-specific nomenclature across data sources. However, with the application of machine learning in projects such as DREAMachine (Defect/Test Reduction Empowered by Analytics and Machine Learning), the cost-benefit tradeoff is shifted due to the ease of applying machine learning techniques and the broader insight they provide. Machine learning makes it possible to quickly sift through vast amounts of information, recognize complex patterns and predict future outcomes to support data-driven decision making.

Overview of the Technology

DREAMachine applies machine learning to traditionally siloed data sources to achieve a whole-systems view focused on reducing testing and predicting future defects *(Figure 3)*. The execution of testing and rework of defects account for a large portion of the cost of manufacturing products; therefore, any opportunity to reduce these costs can have a sizable impact to a business. DREAMachine extracts data from business warehouses and enterprise systems, automates the data integration across sources, and builds upon open-source analytics and machine learning software libraries. It employs a modular architecture, where additional data sources are easily integrated as new information emerges, to achieve greater predictive accuracy and deeper systems-level understanding.

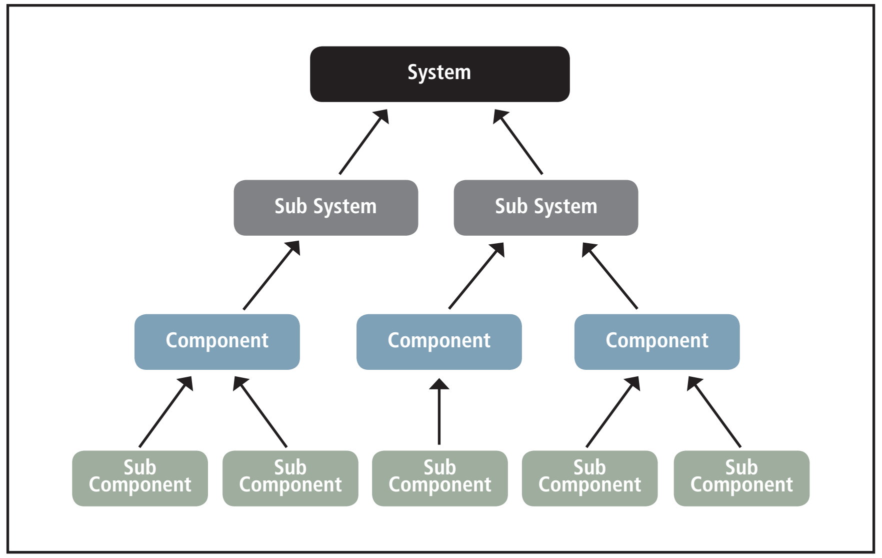


Figure 3: Whole system view versus traditional single component view

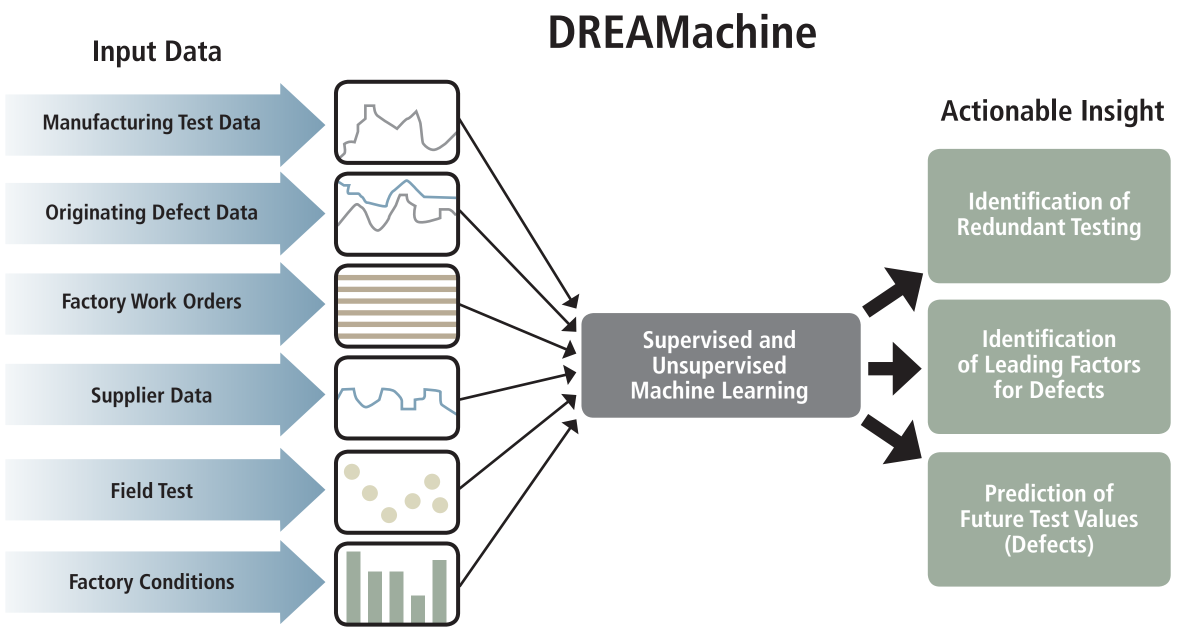


Figure 4: Overview of RIC DREAMachine generalizable framework

First, DREAMachine imports production process data from multiple information systems, such as enterprise resource planning (ERP) systems, databases and servers. This data can represent parametric test data from components, quality fault codes, work operation orders, supplier data and other production related information. Next, the data is filtered and joined to relate information across disciplines and through all levels of components and systems in the product structure. Finally, exploratory data analyses, including unsupervised machine learning approaches (e.g. k-means and hierarchical clustering, principal components analysis, linear discriminant analysis) are performed. It is these methods and algorithms which identify meaningful new groupings that point to potential opportunities to improve testing procedures and operational processes.

For example, k-means clustering can be applied to the component and system test values to identify clusters of similar values and highlight areas of redundancy. Then, supervised machine learning methods (e.g. decision trees, gradient boosting, random forests, support vector machines, naïve Bayes) are applied to predict future defects at both the component and system levels *(Figure 4).* Specifically, parameters such as test values, time of day the operation occurred, location of the test chamber and quality attributes are utilized to probabilistically predict if and when a failure will occur. In other words, historical data about the tests and operations are used as input into a model, an ensemble model like gradient boosting for example, to learn and discover patterns across the data from which future pass/fail predictions can be made.

Results

In the initial stage of DREAMachine development, the project team's analysts partnered with a production program to create the use case and ensure that the implementation added value to key decision makers on the shop floor. The supervised learning methods applied to predict failures at the component and system levels achieved accuracies of up to 99% in predicting failures. More significantly, the unsupervised learning methods identified areas of redundancy in the test flow, highlighting opportunities for process optimization.

Early on, test and reliability engineers suspected that the elimination of certain testing operations could speed up the production line while maintaining strong quality standards. DREAMachine integrated traditionally siloed historical data and analyzed the dataset, validating that a lengthy series of test operations provided redundant information without additional benefit or insight, and could possibly be reduced or eliminated. Further, it was determined that suggested process optimizations could increase production capacity by as much as 40%, potentially saving millions of dollars once enacted on the production line.

Next Steps

In close collaboration with a Raytheon program, DREAMachine developed and applied machine learning methods to reduce redundant testing and predict future defects that could enhance critical production metrics. The next steps include continued testing and validating across other programs. The reusable DREAMachine framework will be applied to accommodate lower-volume production programs, as well as programs with markedly different product features. Further evolution of DREAMachine will improve the algorithms and fine-tune overall application performance. Feature enhancements and additional program data will improve prediction accuracies and provide greater insight into the testing and quality of Raytheon's products. Aside from simply adding more historical records, the ability to combine data across multiple programs is a powerful advantage. For instance, patterns related to a particular component may be undetectable on a single program, but with data from the same or similar component combined across multiple programs patterns become stronger and more readily detected, enabling formulation of more accurate predictions. The ultimate integration and analysis of data across all Raytheon programs and businesses will provide new and actionable insight at the enterprise level for enhancing the production of complex defense systems.

INDUSTRY 4.0 AND ADDITIONAL MACHINE LEARNING APPLICATIONS IN THE FACTORY

As the manufacturing space continues to experience an unprecedented increase in available data, the opportunities for applying and attaining value from machine learning will grow. Known as "Industry 4.0" or "Smart Manufacturing," the current industrial movement aims to include more automation and data generation within manufacturing systems by exploiting the Internet of Things (IoT), cyber-physical systems, cloud infrastructure, and cognitive analytics. This data encompasses a variety of different formats, semantics, quality levels, and sources. For example, it could include sensor data from a robotics line, environmental data of the factory building, tooling calibration and maintenance, operation timing or assembler training history. This increase in data provides machine learning analysis opportunities to gain efficiencies throughout the factory.

Some machine learning applications that are already under development across Raytheon manufacturing include production schedule optimization, factory floor layout planning via reinforcement learning, predictive maintenance of machines, and automated quality inspections using image processing empowered by convolutional neural networks. In conjunction with additional data sources, supervised machine learning models can be used to analyze and improve key business metrics, such as on-time delivery performance (probability of delivering products on-time across specific scenarios), cost forecasting (probability that the budget will be met given new constraints), and contract wins (probability of winning a specific contract and the associated risks).

In conclusion, machine learning-powered approaches have the potential to improve all aspects of the factory and business. As a leader in the defense industry, Raytheon continues to apply advanced analysis methods to understand the past, present, and future state of its factories, products, and businesses — making optimal, data-driven decisions and improving competitive advantage.

Kimberly Kukurba, Ph.D.

MACHINE LEARNING FOR PATTERNS OF LIFE

With the rapid expansion in variety and accessibility of military, commercial and open/free data sources, Raytheon's customers are challenged to effectively leverage this information for detection, tracking and averting adversarial activity as part of daily Activity Based Intelligence (ABI) missions.

ABI is "…an analysis methodology which rapidly integrates data from multiple intelligence sources and sources around the interactions of people, events and activities, in order to discover relevant patterns, determine and identify change, and characterize those patterns to drive collection and create decision advantage."[1] Detecting, characterizing and monitoring Patterns of Life (PoL) is a critical ABI input. A PoL is best understood as a model, created through the analysis of entity, event and activity data which describes patterns in repeated activities, ongoing interactions or periodic changes in state. In military applications, patterns of life are useful for detecting anomalies, predicting future actions and helping to improve situational awareness from air, land, sea and space operating pictures. Today, practices within the Department of Defense (DoD) and Intelligence Community (IC) commonly include doctrine tuned to work on a single intelligence source, and are unable to process high volumes of data quickly enough to impact real-time decision making.

Raytheon's Intersect Sentry™ capability is meeting the volume and velocity challenges of today's data sources with services to detect, characterize and exploit patterns of life, at scale, in near real time. Leveraging big data machine learning for source fusion, target feature discovery and PoL modeling, it is able to make predictions about future target state. In order to form a complete common operating picture, Intersect Sentry combines customer data with open-source news data such as GDELT (Global Data on Events, Location and Tone); satellite imagery; video feeds of vehicle traffic flow; vessel track information from AIS (Automatic Identification System); air tracks from ADS-B (Automatic Dependent Surveillance - Broadcast); vehicle tracks from OpenStreetMap™; public utility patterns (e.g. electricity, water); and weather station reports from NOAA® (National Oceanic and Atmospheric Administration). Together, these sources provide a nuanced story for how a target behaves in space-time, how targets behave at the aggregate level or how the activity at a location changes over time.

Intersect Sentry's big data architecture gives the warfighter a decision advantage with real-time patterns of life, confidence metrics, and downstream exploitation for alerting and tipping. For example, today's Air Force warfighter must manage thousands of potential threats to space assets per day, and the timeline for input into Space Situational Awareness systems is on the order of minutes across all of the orbital regimes. Currently, there are more than 4000 maneuverable objects, but with the rapidly growing constellation of SmallSats (Small Satellites), this number is projected to nearly double by 2022, making real-time patterns of life and predictive machine learning models critical decision aids for timely mission inputs.

Marines are responsible for conducting such missions as enemy engagement, embassy protection, non-combatant evacuation and disaster relief. Mission planning for these efforts requires establishing and continuously updating normal baselines to quickly recognize, understand and, if necessary, mitigate anomalies in real time.

The Navy and Coast Guard are concerned with maritime domain awareness, including detection and interdiction of smuggling, illegal fishing and other nefarious activities. These challenges require the collection and fusion of open-source track and satellite information with Department of Defense (DoD) and Intelligence Community (IC) sources. Pattern of Life analysis of multi-source data is required to identify, track, characterize intent and predict future location or actions that would not be evident from single source analysis alone.

Through recent data partnerships, data acquisitions and existing proprietary sensor collection, Raytheon has unprecedented access to multi-INT (multiple intelligence) geo-temporal data sources, where the nature of the data is such that the read and update rate is beyond human comprehension and sensemaking abilities. For example: Twitter data has up to 330 million users and produces more than 500 million tweets/day; the Automatic Identification System (AIS) monitors more than 500 thousand vessels with roughly 150 million reports/month; and the Global Database of Events, Language and Tone (GDELT) generated a nearly 2.5 trillion node graph of new events in 2017 alone.

[1] Atwood, Chandler P., Activity-Based Intelligence: Revolutionizing Military Intelligence Analysis, Joint Force Quarterly 77 (2nd Quarter, April 2015), National Defense University Press.

As evidenced by recent broad agency announcements (BAA), requests for information (RFI) and requests for proposal (RFP), customers are seeking full exploitation of both commercial and military data assets for near real-time forecasts of target maneuvers, anomaly detection and activity assessments. Across military branches and the intelligence community, the new reality is that digital footprints and the resulting patterns reveal adversarial intent when leveraged in a timely and comprehensive way. Raytheon has made a significant investment in developing the necessary machine learning algorithms, products and systems to automate the creation and use of Patterns of Life at a scale to meet demands of both the IC and DoD. These real-time patterns provide Raytheon customers with the actionable intelligence they need to monitor adversaries, coordinate direct action forces and provide mission planning or collection tasking inputs in an increasingly complex and dynamic environment.

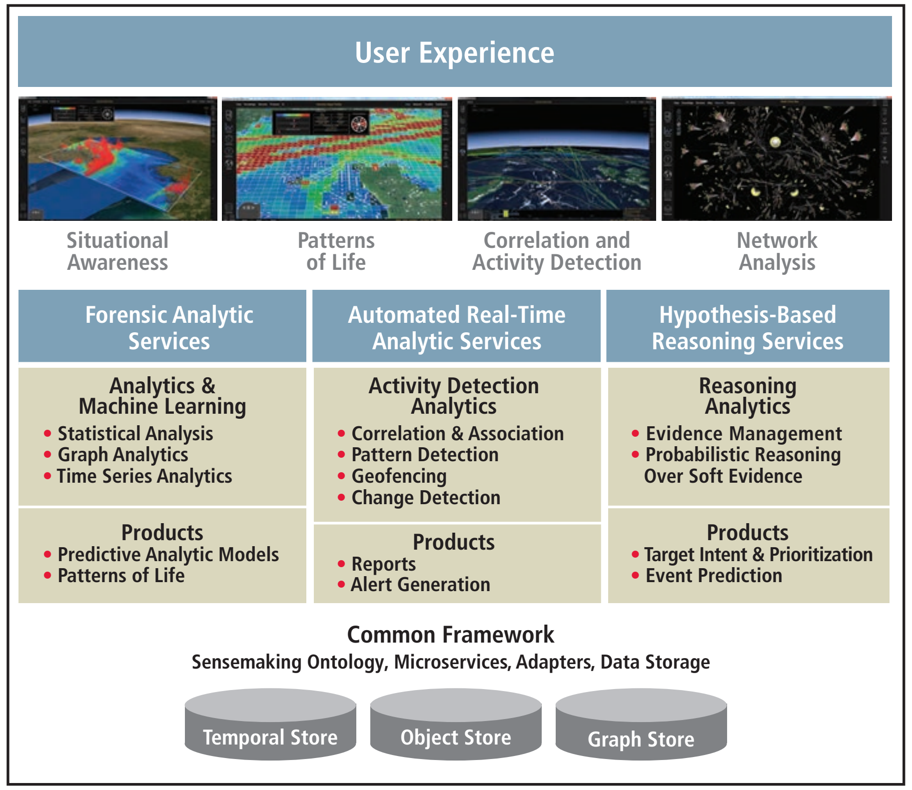


Figure 1: Intersect Sentry: Real-time multi-INT big data analytics ecosystem

BIG DATA PATTERNS OF LIFE ON APACHE SPARK®

Intersect Sentry's Pattern of Life capabilities are part of a real-time multi-INT big data analytics ecosystem illustrated in *Figure 1*. The Pattern of Life models are built forensically from multi-INT time series observation data processed by Apache Spark[2] to extract patterns and generate predictive machine learning models. The resulting analytic products are pushed to a distributed Object Store and then queried by automated analytic agents to detect activity in near real time, assess potential anomalous conditions and make predictions about future activity.

With the volume and velocity of data coming from multi-INT sources, big data solutions are needed that scale appropriately based on the system load. Parallelizing updates to machine learning models and statistical summary data becomes increasingly important as the number of target entities grow beyond human operator capacity. Further incremental updates to global and local analytic products triggered by data source updates can quickly exceed the boundaries of performance for big server systems. Three specific big data capable machine learning products from Intersect Sentry's Analytic Suite are presented in the remaining paragraphs along with their application across the air, sea, ground and space domains.

[2] Apache Spark is a unified analytics engine for large-scale data processing (https://spark.apache.org)

GEOSTAT: BIG DATA, NEAR REAL-TIME SITUATIONAL AWARENESS

Intersect Sentry's GEOSTAT forensic analytic service continuously processes geospatial observation data to learn and statistically characterize global and regional patterns of life. These patterns are useful to define the historic norms of an area of interest for real-time anomaly detection and event prediction.

In the maritime, domain observations include vessel position data reported from the Automatic Identification System (AIS), a rich source of information about the speed, location and direction of travel for more than 500,000 vessels around the world. At a global scale, the GEOSTAT service has processed up to a year of maritime data to perform statistical analysis across all oceans and waterways at varying geospatial and temporal scales. Global, regional, and local patterns are characterized with associated probabilities enabling deduction of entity class, activity, and destination. Deviations and temporal changes to patterns of life are also analyzed.

In *Figure 2,* the observation frequency and density of vessels observed from AIS are visualized as a fluctuating heat map for the English Channel. To create the heat map, the area of interest is first divided into small cells, then the frequency is determined by the number of unique vessels in each cell, and the density is calculated as the number of vessels per unit area for the cell. In addition, probability distributions are calculated to determine the direction of travel and speed observed in each cell revealing patterns of activity such as routes and shipping lanes *(Figure 3)*. This same area of interest can also be overlaid with flags *(Figure 4),* showing which country's ships are predominant in the various routes and regions.

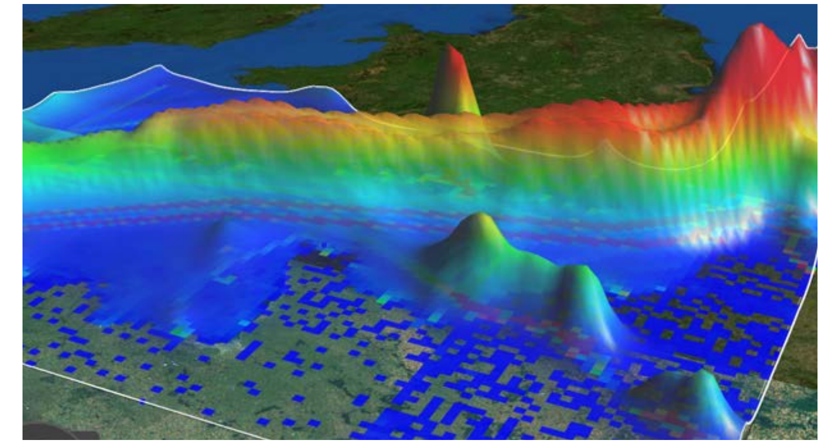


Figure 2: Intersect Sentry displays a fluctuating heat map of vessel frequency and density in the English Channel

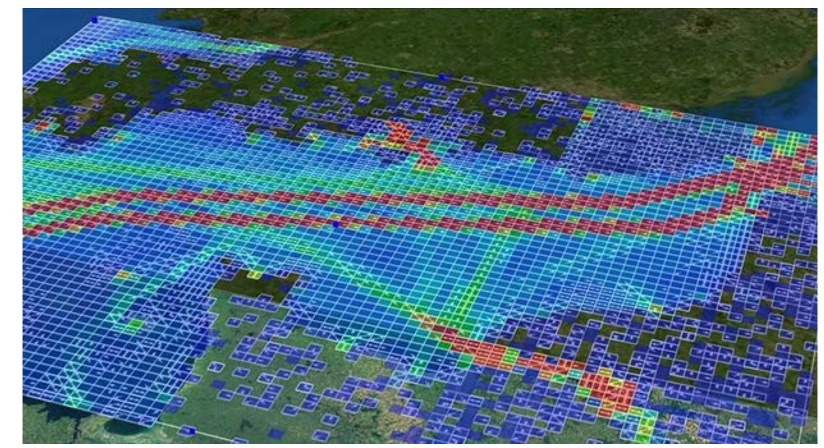


Figure 3: Intersect Sentry displays discovered routes and shipping lanes

Figure 4: Intersect Sentry displays a distribution of vessel country of origin for the region

BIG DATA, ENTITY PATTERNS OF LIFE SERVICE

To complement the aggregate patterns of activity, the PoL service analyzes observations at the entity level to generate Patterns of Life for individual actors. The goal of this analytic is to learn a probabilistic function to capture and quantify any recurring behavior in each entity state needed for downstream predictions and anomaly detection.

The PoL service processed AIS data to generate profiles for each entity based on their position and speed reports. A profile includes the most likely locations (hangouts) for an entity, the revisit rate for that location, and the typical speed of the entity at that location. *Figure 5* shows statistics generated by the service for the most common elapsed time between vessel detections and the vessel behavior at that location based on the reported speed.

CLUSTER ENTITY GRAPH SERVICE

Clustering is an unsupervised machine learning approach which organizes similar data objects into groups (or clusters). The clustering service consists of machine learning clustering algorithms that enable fast updates when entities change, or new entities are added or deleted. They do not require the number of clusters to be specified, only a similarity threshold, and entities are allowed to have membership in more than one cluster. If overlap exists in the clustering results, it is encoded as a weighted graph to uncover the interconnectedness of the entity set.

Clustering properties are further correlated with additional metadata about the entities in order to statistically label the cluster. As the clusters evolve, the service detects changes between the previous and current state, such as merged clusters, split clusters, new clusters, and missing clusters and generates operator alerts.

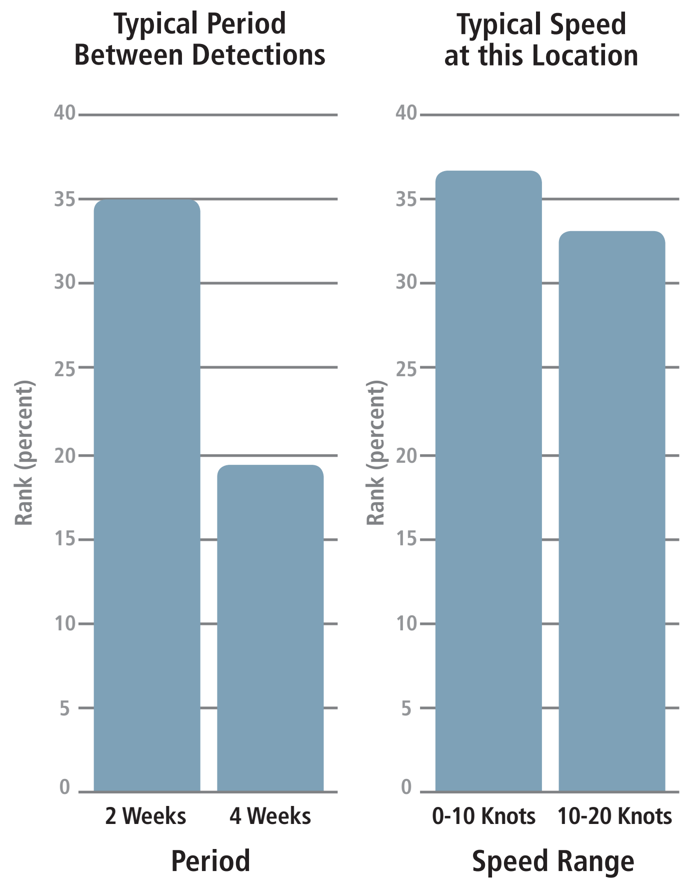


Figure 5: Intersect Sentry displays the vessel location behavior statistics provided by the PoL service

Space Situational awareness requires continuously tracking and monitoring all space objects across all orbit regimes to keep space assets safe from both adversaries and debris. Two Line Elements (TLEs) are data records containing identification and the latest orbital parameters for a satellite. The service processes publicly available TLEs from the Joint Space Operations Center for all active Low Earth Orbit (LEO) space objects. *Figure 6* shows the clusters discovered for the LEO satellite payloads and the connections between them. Red nodes represent the satellites, green nodes are the clusters. LEO satellites clusters are formed based on orbital characteristics of the satellites, grouping satellites with similar orbits together. Edges (connecting lines) between red and green nodes indicate membership within that cluster; edges between green nodes are derived associations created when two clusters share the same member.

The clustering properties consist of the orbital parameters for each satellite. The entity metadata used to label the clusters included country, users, ground stations and launch sites. By correlating the orbital parameters with the entity attributes, properties of newly launched space objects can be inferred from their orbital parameter state.

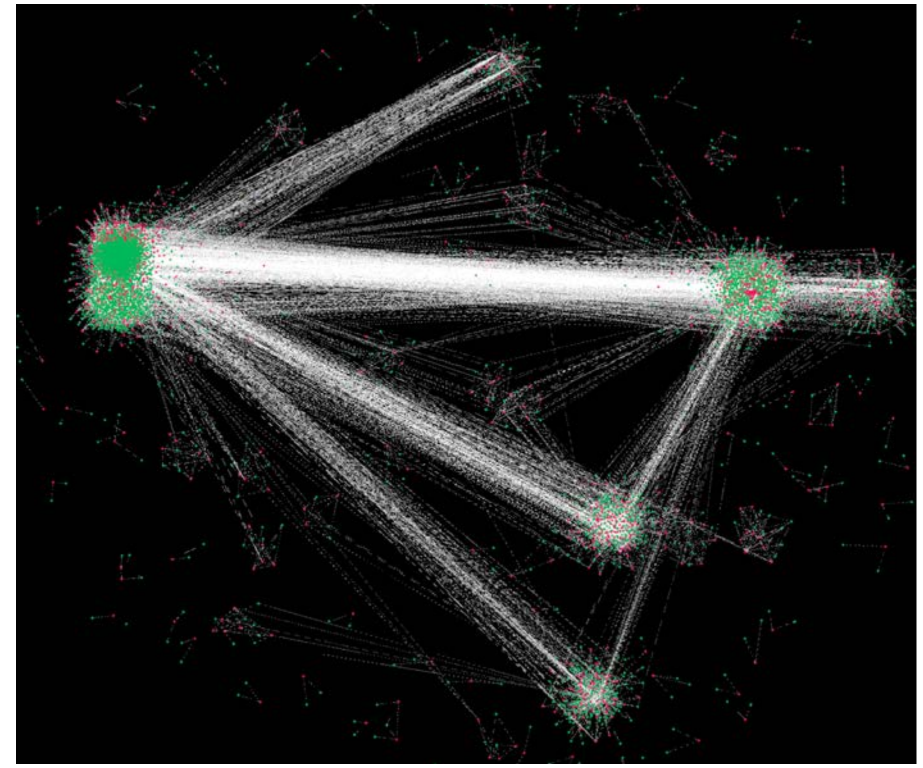


Figure 6: Intersect Sentry displays a graph of discovered LEO satellite clusters and associations

Conclusion
Raytheon is at the forefront of pattern of life discovery, detection, tracking and prediction due to its extensive investment in data, customer relationships, big data infrastructure and machine learning analytic development. Future efforts will incorporate Recurrent Neural Networks (RNN) for time series specific predictions and deployment to the cloud to ensure horizontal scaling as data volume and velocity continue to increase. RNNs are able to capture and encode complex time series feature representations that outperform systems that encode temporal windows directly in the feature space. In addition to computational scaling, implementation within the cloud enables easier access to analytic resources, machine learning models and their outputs.

Christine Nezda

Christine Nezda
Raytheon Intelligence, Information and Services

As senior scientist in IIS' Automated Sensing and Analytics Capability Center, Christine Nezda specializes in the development and refinement of machine learning (ML) techniques in a variety of big data applications. She has extensive experience in ML, particularly as applied to pattern of life (PoL) discovery and natural language processing (NLP). Nezda is the lead data scientist on several independent research and development (IRAD) efforts to create big data machine learning solutions for Activity Based Intelligence (ABI), including PoL, data fusion, text analytics and constrained resource allocation. She has also applied these techniques for many Department of Defense (DoD) and Intelligence Community (IC) projects, including those of the Intelligence Advanced Research Projects Activity and the Air Force Research Laboratory.

"Data science and machine learning analytics provide our customers with actionable insight — patterns and predictions from massive quantities of data in support of ABI activities for target discovery, identification and tracking," Nezda states. "My passion is building data-driven systems to provide the IC with increased decision advantages and opportunities to apply cutting edge computer science and machine learning techniques to problems and programs directly impacting the protection of our national security."

Before Raytheon, Nezda worked 12 years as a lead research scientist for NLP efforts focusing on computational linguistics and machine learning algorithms for the IC. She published and presented multiple technical papers detailing results from advanced prototypes, which led to her joining Raytheon to work on fast-paced IRAD ML activities. Nezda has won several awards in her field, including Top System at the Question Answering Track at the National Institute of Standards and Technology's Text Retrieval Conference, 2004-2007.

As for advice she offers engineers beginning a career in her field, Nezda responded: "When tackling a new problem, start by defining success criteria and metrics, keep an open mind, rely on first principles and communicate frequently with stakeholders."

Nezda has a Bachelor of Science in Computer Science from the University of Washington and a Master of Science in Computer Science (Intelligent Systems Track) from the University of Texas at Dallas.

RAYTHEON PREDICTIVE MAINTENANCE (RPM)

PREDICTIVE MAINTENANCE

In today's world of System Operations, there are two dominant approaches to maintenance, Reactive and Preventive. Reactive Maintenance is characterized by waiting for the system to fail, and repairing after the fact as a means of minimizing unnecessary repairs.

The problems with this approach are typically those of increased system downtime; expensive repairs, including travel for specialized repair personnel; and in the worst scenarios, catastrophic failure. Preventive Maintenance is based on replacing parts according to manufacturers' recommended schedules, with the intent of minimizing unforeseen downtime. This approach raises issues of opportunity cost of materials replaced before a failure, as well as unnecessary maintenance. Alternatively, the goal of Predictive Maintenance is having the ability to accurately predict failures in order to find an optimized balance of reduced downtime and full replacement part utilization.

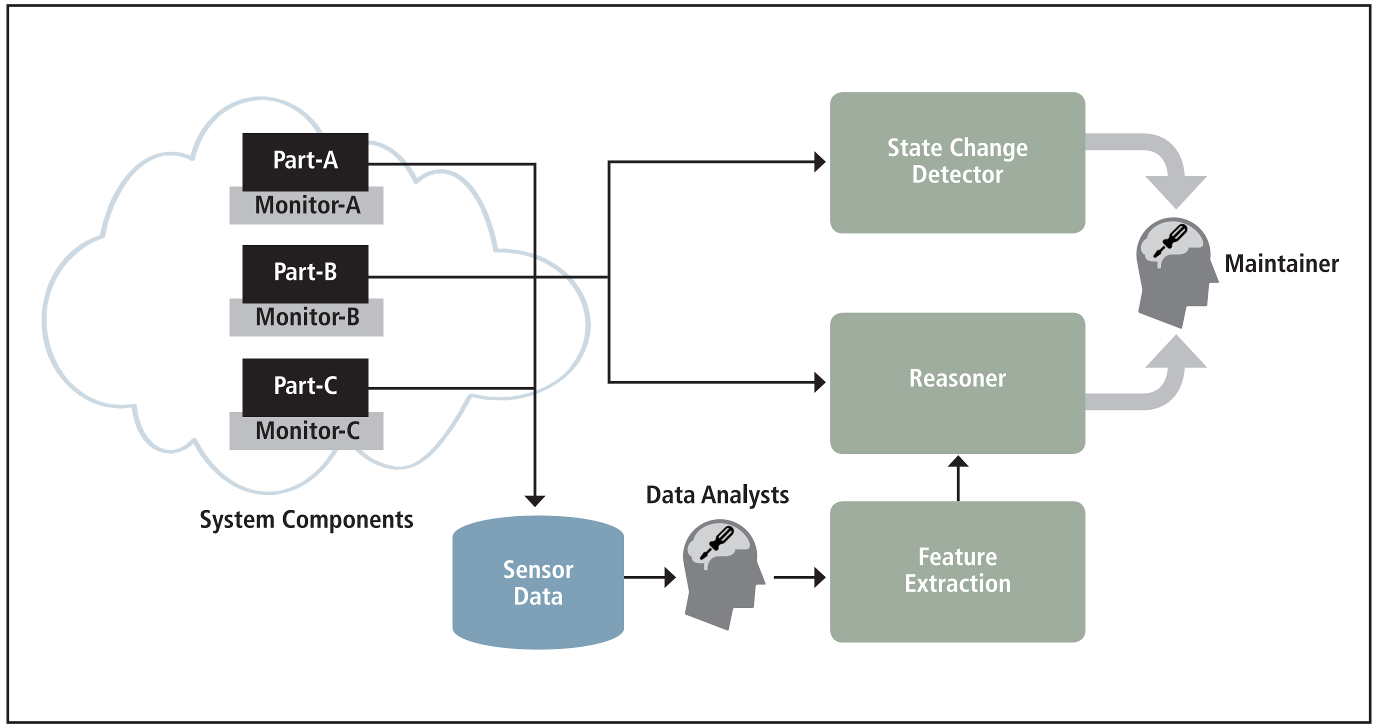


Figure 1: Raytheon Predictive Maintenance Architecture

Solving the Predictive Maintenance problem requires careful coordination between the operational maintainers and the designers and analysts who are likely at a remote site. As seen in *Figure 1*, real-time data and system operation is available to the maintenance operator, who has visual aids and dashboards for operational assessment. The maintainer also often has informal methods of checking in on the system: visual inspection, sound, smells, and general human pattern recognition of unmodeled effects that correlate with system performance. Automated methods of capturing this maintainer instinctive understanding should be one of the areas of investigation going forward. The data analysts may not have access to all of the data coming out of the sensors in real time due to Data Sovereignty,[1] communication throughput, or cost constraints at design time. Optimizing which data to pull back — and how often given project constraints — is difficult, and often hard to change after the fact. Finally, coordinating analysis between the maintainer in the field and the data analysts offsite is vital to updating models and data feeds.

Predictive Maintenance is as much a traditional engineering problem as a data science problem. First and foremost, the diagnostic data gathered is generally time series data from electronic and mechanical control systems. This means that physics of failure and theory of design are available as a starting point for understanding (or predicting) failures in simpler parts of the system. These are also the criteria for deciding, at design time, which diagnostic data will be recorded. Changing the data gathered or adding data taps after manufacture can be extremely expensive, and is typically avoided at all costs. In general, diagnostics based on Control System theory engender more trust, since they are based on theory that can be trusted beyond the regions of test data. Eventually, however, there remain unexpected system responses which lend themselves better to machine learning.

Once the interaction of system components becomes complex enough to warrant machine learning applications, those methods that allow visibility into the decision making process are preferable — taking advantage of available experience from system designers and RAM (Reliability, Availability and Maintainability) forensic analysts. In cases where the systems are fielded far from the data analysts, communication bandwidth and data sovereignty become important considerations, often imposing constraints on the ability to diagnose and/or characterize system performance. For example, if only a fraction of the sensor and failure data can be transmitted, there must be rules on the system at the front end to compress, thin and/or summarize the data. This can include anomaly detection, designer-based rules, and information theoretic methods. As much as possible, the system should be tested against full data and method availability to determine how much information is lost in

[1] Data which may be subject to restrictions or rules by the country of origin

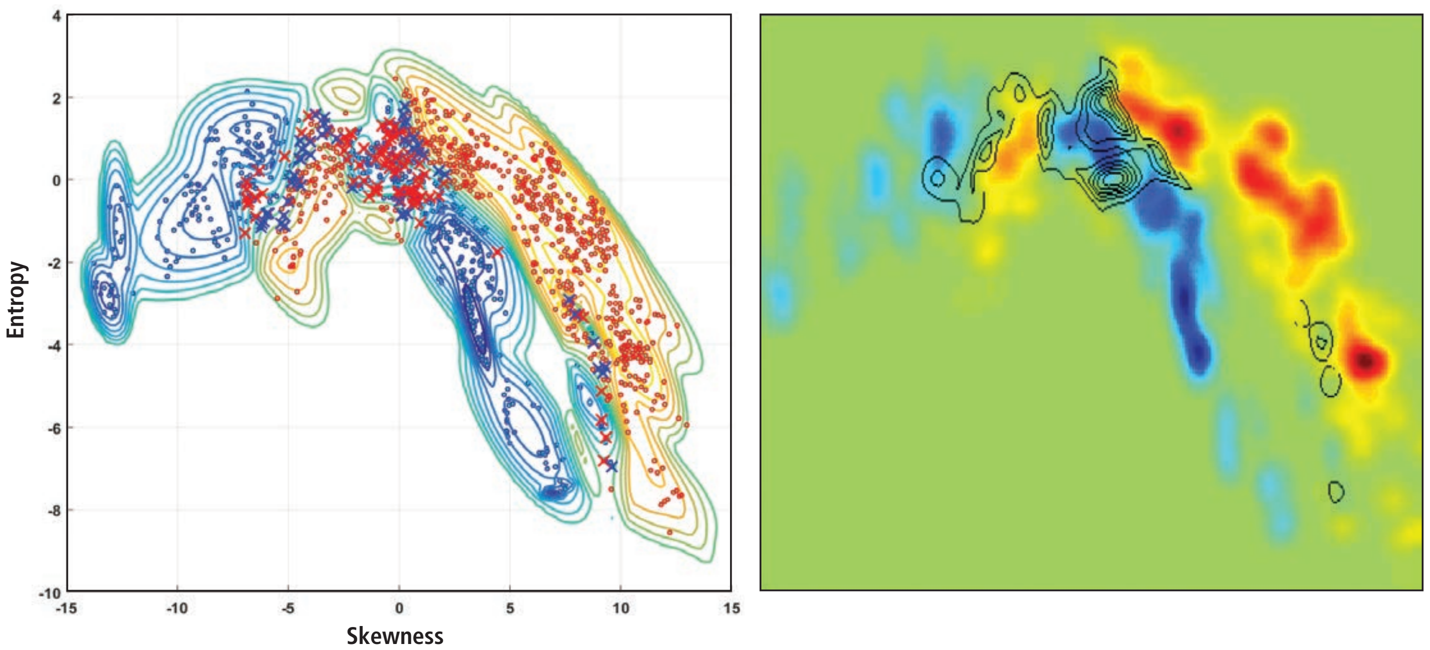


Figure 2: Classifier making decisions close to the training data

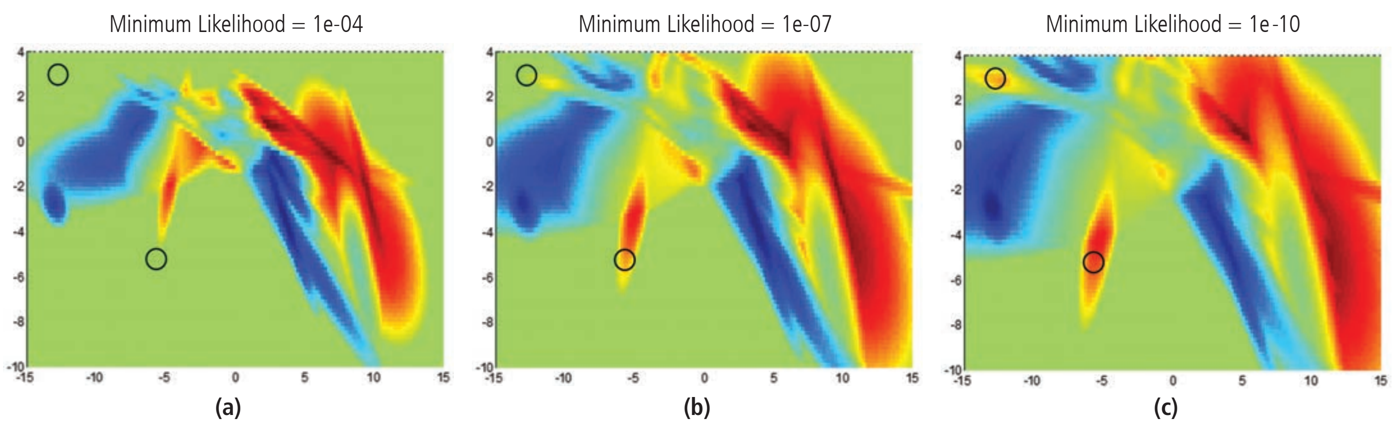


Figure 3: The "Open Set" or "Strangeness" problem. Making decisions far from training data is dangerous. (a) Initial non-decision areas bound by the black circles become decision regions as classifier restrictions are progressively loosened, (b) and (c).

the summarization process, and how much performance is lost, if any, by restricting the final solution to explainable methods. Finally, at each part of the architecture, the data analytics should have some way to update both training and decisions in real time, to avoid being overwhelmed by the sheer volume of new data coming in. This combined set of restrictions severely constrains the final predictive analytics solution space.

To illustrate the aforementioned engineering concerns with machine learning methods, a generic example is presented using a 'counterfeit vs. real banknote' dataset from the University of California at Irvine (UCI™) Data Repository.[2] The dataset of image information is separable in four dimensions (variance, skewness, kurtosis and entropy), but for the purpose of this example, we only allow ourselves two of the dimensions (skewness and entropy), in which the data has a lot of shape and overlap. One could just as easily label the data part failures vs. part non-failures. Building a classifier from this training dataset, then running the original data back through results in the decision plot shown in *Figure 2*. On the left side it can be seen that we can build classifiers that make decisions ("red" or "blue") when close to training data, but make no decision when far away from the training data, and label those as anomalies. The x's in this plot are incorrect classifications, which you expect in the areas of high conflict (overlapping data), shown on the contour plot on the right as areas with tight contour rings (or high elevations). The light green surrounding area at low elevation on the right is set to be areas where the classifier knows not to make any decision. Many classifiers may just make a decision no matter where the new test data comes from, which can cause incorrect decisions with high reported probability, as the following example illustrates.

If we loosen the restriction on areas of confident decisions, and allow the classifier to make decisions progressively further away from the training data, we are subject to the dangerous effects outlined in *Figure 3*. This is known as the "Open Set" or "Strangeness" problem. Three cases are presented with the exact same classifier and x-y scale; only the allowed decision region and the scale of the log-likelihood ratios is changing. The black circles initially bound a region of no decision (a). As the restrictions are loosened from (a) to (b) and then even further from (b) to (c) these areas become strong decision regions where the classifier is allowed to make decisions where it arguably shouldn't. This is due to the relative likelihoods being so different when far out on the tails of these multimodal distributions. Also notice the lensing effect in *Figure 3c* as the red class starts pushing "south" into the bottom circle, far away from any data of either type. This is due to the likelihoods from multiple red Gaussian Distributions focusing relative to the blue in this region. One of the advantages of Gaussian Mixture Models and other models that estimate probability density functions is that they allow for a rational threshold beyond which new points can be called outliers, and no class decision is made. These are just a few of the considerations RPM actively tracked while choosing machine learning methods.

For Raytheon Predictive Maintenance (RPM), we evaluated multiple datasets across many programs, evaluating a bank of Machine Learning methods for suitability. In general, datasets contained both continuous time series data and discrete state variables. Not surprisingly, discrete Machine Learning approaches tended to work better than continuous approaches as the number of important discrete states increased. Also, because these were control systems, it was common for there to be extremely repetitive data during normal operation, which skewed results for all of the machine learning methods that depend on density, including tree based methods, Neural Networks, and unmodified Gaussian Mixture Models. This meant that the assumption that the training data came from a representative distribution was suspect, at best. Where possible, data summarization concepts were used to not only model bandwidth restrictions, but to mitigate varying data densities as well.

Data visualization and decision justification were given high priority as evaluation criteria in RPM to enable subject matter expert (SME) feedback. Because RPM is intended to analyze complex systems that are designed to work over long periods, there is a body of expertise built up during design and integration that is included in the error analysis. Along with this come engineering questions such as: Are the assumptions in the failure models correct? If not, how do we update them? Is there a variable that is showing correlation to failure that was considered unimportant? Can we find a causality linked to such a variable?

Providing answers to these questions enabled us to not just provide a predicted probability that something was about to go wrong, but also to provide the variables and data instances that influenced the decision. As systems are deployed over longer periods of time, operational costs can increase and automated operational assessment and predictive maintenance become increasingly important. The machine learning models used in RPM are intended to grow with experience and draw upon design expertise in a feedback loop — meeting tomorrow's challenges while strengthening trust amongst the users.

Dr. Michael Salpukas

[2] Dua, D. and Karra Taniskidou, E. (2017). UCI Machine Learning Repository [http://archive.ics.uci.edu/ml/datasets/banknote+authentication]. Irvine, CA: University of California, School of Information and Computer Science.

Michael R. Salpukas, Ph.D.
Raytheon Integrated Defense Systems

With over 20 years' experience at Raytheon, Dr. Michael Salpukas is an Engineering Fellow for Raytheon Integrated Defense Systems (IDS), where he leads a Machine Learning independent research and development (IRAD) effort, an activity designed around technology insertion to provide human-assist to the warfighter and to mitigate new threats in a timely manner.

"Five years ago, the System Architecture, Design and Integration Directorate (SADID) was challenged to become more involved in innovation," Salpukas states. "That inspired me to submit multiple Raytheon Innovation Challenges and IDEA projects. Those projects led to working closely with Advanced Technology, which in combination led to the current Machine Learning IRAD."

Previously, Dr. Salpukas was a Systems Engineer working in prognostics, advanced tracking and discrimination algorithms for projects such as NATO Air Command and Control Systems (ACCS), Sea-Based X-Band Radar (SBX), Upgraded Early Warning Radar (UEWR), Japan Air Defense Ground Environment (JADGE), Terminal High Altitude Air Defense (THAAD), as well as multiple Research and Development Projects. Early technical interests included Particle Flow Filters, and applying computational topology and geometry to data analytics and predictive analytics. Dr. Salpukas also had Systems Engineering Lead roles and was a Section Manager.

On success at Raytheon, Salpukas advises, "Try to map your technical interests to the future needs of the warfighter. Understanding how much can go wrong in the field is vital to making novel solutions work in the real world, and provides a stronger appreciation for how to build early prototype frameworks."

Dr. Salpukas received a bachelor's degree in Mathematics from the University of Chicago. He received a master's degree in Statistics and a doctorate in Mathematics from the State University of New York at Albany. "My original Ph.D. was in pure mathematics, but I added a Masters in Statistics during my last two years to help my move toward industry. Learning a wide range of disparate mathematics in a short time helped me enormously starting out at Raytheon, where my first five years were like a Radar University. I had to quickly link my educational background to the mathematics of Radar, in areas such as tracking, optimization and signal processing."

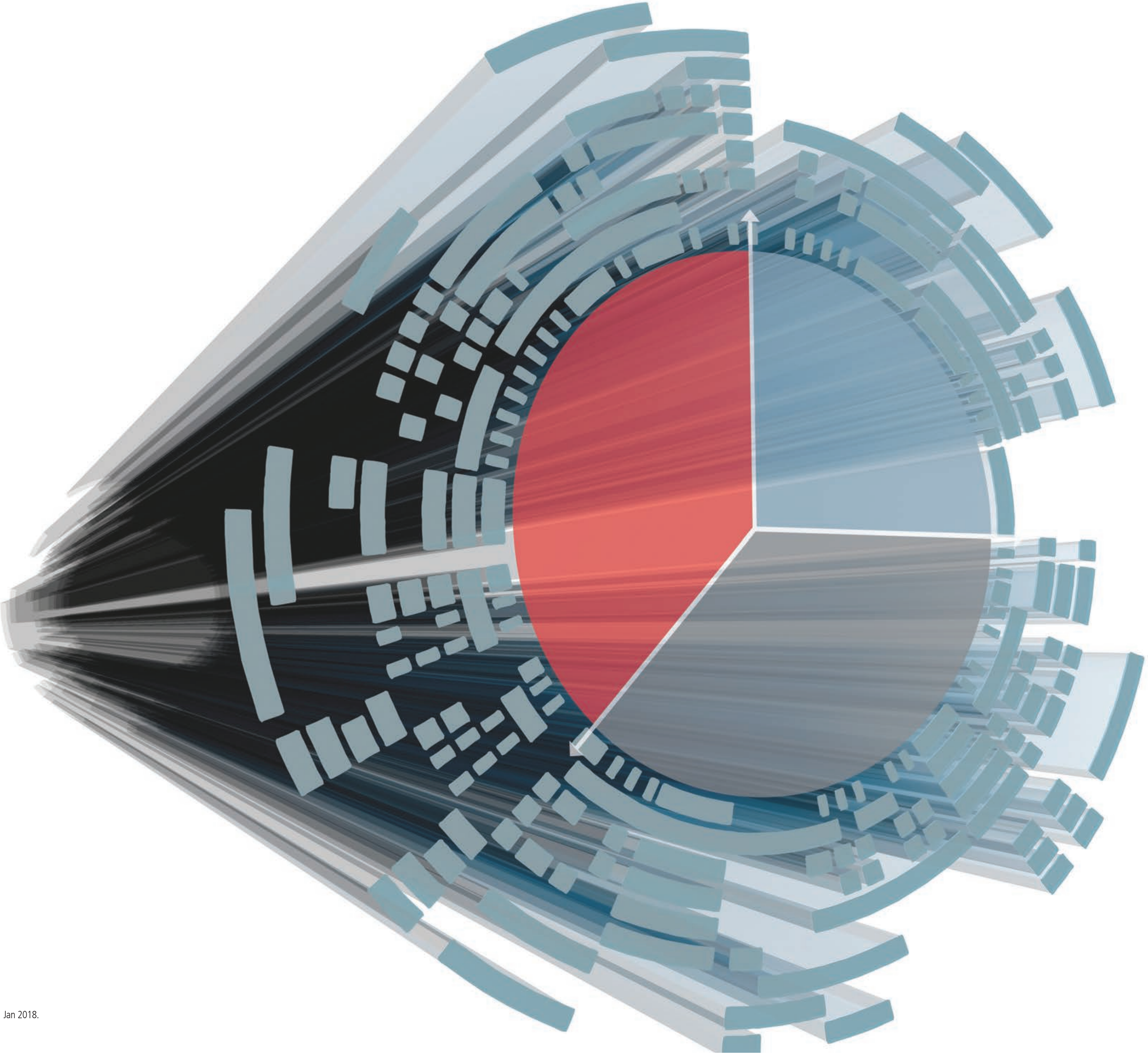
STRATEGIES FOR RAPID PROTOTYPING MACHINE LEARNING

Recent advances in computer technology are enabling scientists and engineers to solve more complex problems with Machine Learning (ML).

Significant leaps in processing power, bit depth, caching, and storage along with expansion of cloud based services, provide researchers virtually unlimited scaling of resources, bringing problems having millions of input attributes and thousands of potentially non-exclusive output classes within reach. One example is convolutional neural networks (CNNs). A CNN is a form of deep learning neural network often used in image processing, such as the Google™ 50-layer ResNet network, which contains more than 20 million computational nodes and was trained on a database of over one million images.[1] New tools, such as Python®, TensorFlow™ and Matlab®'s Artificial Intelligence (AI) tool box, have opened the door for non-machine learning scientists to build complex networks to solve a wider breadth of problems previously unexplored in the computational machine learning community.

Raytheon has leveraged both academic network models and commercially available datasets in its research of computational pattern recognition. One basic pattern recognition application is detecting objects. The difficulty is often not the complexity of the object itself, but the sheer volume of source data which must be analyzed. Time is required to acquire data, label examples, and then train the models using the labeled data. Consider the case of an image of an airport where a model is required to detect the number of aircraft on the ground. A recent Raytheon training experiment used 100,000 image chips of airplanes and approximately 100,000 background image chips. Image chips were a single band panchromatic containing 300x300 pixels. Using an Amazon Web Services (AWS™) G2.8 virtual machine (VM), batch training 32 images at a time for 10 weeks achieved an 80% probability of detection Pd at 10E-5 false alarm rate (FAR).

Within the defense industry, objects of interest and their images often pose limitations that are not addressed by commercial applications. The ability to rapidly analyze unique, camouflaged, fleeting and possibly threatening entities is increasingly important. To build and train representative models for these cases requires that training data cover the breadth of available object/image variations, environmental parameters, and characteristics of the sensors observing them *(Figure 1)*. Typically, Raytheon's customers' data provides observations of limited instance; data collected by individual sensors, across a common background, and with similar viewing geometries.[2] Consequently, data are locally sparse, yielding training databases effectively smaller than nominal training sizes, which can then cause bias in the resulting models.



[1] Yang You, Zhao Zhang, Cho-Jui Hsieh, James Demmel and Kurt Keutzer, "ImageNet Training in Minutes," arXiv:1709.05011v10 [cs.CV] 31 Jan 2018.

[2] S. Israel and E. Blasch, "Chapter 5: Context Assumptions for Threat Assessment Systems," in Context-Enhanced Information Fusion: Boosting Real-World Performance with Domain Knowledge, L. G. J. L. J. a. B. E. Snidaro, Ed., Springer International, 2016, pp. 99-124.

Overcoming these limitations is a key focus area of Raytheon's Machine Learning research and several approaches to the problem are discussed in the following sections.

ML TRAINING

Three commonly used ML training algorithms are supervised, unsupervised and semi-supervised. Supervised training typically requires large amounts of input labeled data, where each training exemplar is tagged with a known output class. Discriminant functions, generated by modeling this mapping are then used to assign (or infer) classes to new, unlabeled input examples. Unsupervised training consists of unlabeled exemplars, not tagged with a known output class, and the discriminant functions must learn how the data clusters into classes. During operations, unlabeled data are assigned to the nearest data cluster. Unsupervised learning can bias the outcomes by generating clusters during training that are not representative of specific target classes. Semi-supervised training utilizes both labeled and unlabeled exemplars. While unlabeled data help estimate data distribution, reducing the overall need for labeled data, labeled data are still required for class separation. Semi-supervised approaches are the least likely biasing training strategy as the cluster statistics are drawn predominantly by unlabeled data.

TOOLS AND APPROACHES

Raytheon has developed a number of tools and approaches to maximize training efficiency and mitigate the effects of limited training exemplars, bad labels, and noisy data. These approaches include training with a mix of both labeled and unlabeled data, the use of generative adversarial networks (GANs) to train more effectively with limited data, and the generation of quantifiable evaluation strategies and metrics for assessing performance.

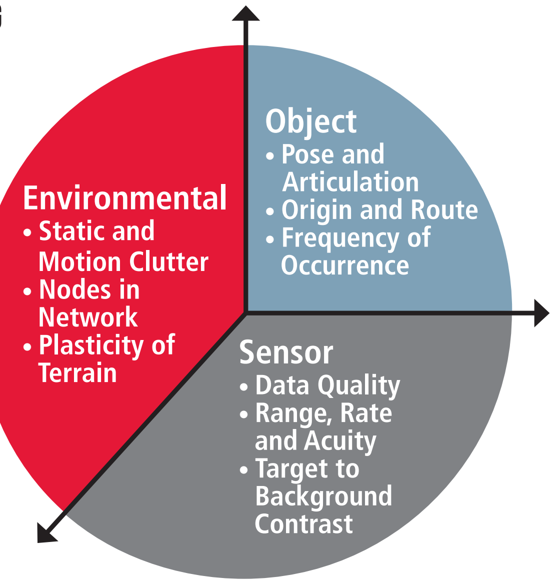


Figure 1: Object, Sensor and Environmental variations

GENERATIVE ADVERSARIAL NETWORKS

One approach to mitigating ML sample size requirements is to integrate Generative Adversarial Networks (GANs) into the training process.[3] Classically, for detection and classification problems, ML techniques focused on discriminative models which generate a mapping from input attributes to output classes. Less attention has been paid to generative models that learn the joint probability between a set of input attributes and output classes.

GANs utilize what is best described as a two-player game between a discriminator network and a generator network. Iteratively, the generator creates synthetic examples and the discriminator decides whether these examples are real or fake *(Figure 2).* The generator creates the fake examples by transforming a noise source into synthetic data. As the game continues, the generator learns to produce more realistic examples and the discriminator improves its ability to separate real from fake examples. The generator is optimized by mapping the noise signal onto the training data and the discriminator is optimized by how well it correctly detects or classifies both the real and the synthetic data. During the process, the generator is learning the training data distribution. Ideally, the system is optimized when the discriminator is only 50% confident that the generator's examples are fake.

Initially, Goodfellow's GAN experiments were replicated to prove their reduction in the training burden relative to deep learning neural networks without the GAN process.[4] In addition to reproducing results for reducing training burden for detection, or two class, problems, the GAN domain was expanded to classification problems of more than two classes. *Figure 3* displays a series of experiments with the discriminator alone (blue diamonds and gray squares) and with a GAN processor (green triangles) using different network sizes. All of the experiments provided statistically similar results and used feedforward backpropagation neural networks. The X axis represents the size of the network as network connections and the Y axis is the number of training iterations. Since performance was similar for all the experiments, the GANs trained in approximately 10 times fewer iterations.

SEMI-SUPERVISED LEARNING WITH PSEUDO-LABELS

Another approach to reduce the required amount of labeled training data is using unlabeled data with a semi-supervised learning algorithm. In many cases, unlabeled data is plentiful, even though labeled data may be scarce. Semi-supervised learning algorithms can utilize partially labeled datasets, alleviating the heavy requirement for large amounts of labeled training data. The Raytheon Machine Learning Team is currently investigating the use of pseudo-labels, labels that are created automatically for unlabeled data using a partially trained network. At first glance, this approach may seem like learning what is already known. In other words, if a network exists that can correctly label the images, then we are already done. Alternatively, if the network generates erroneous pseudo-labels then how can these help to improve the network, since they contain precisely the same mistakes that the network would already make? Yet, surprisingly, pseudo-labels can significantly improve classification accuracy and unlike other semi-supervised approaches, they are extremely simple to implement as they do not require any changes to the network architecture.

Pseudo-labeling is based on a theory known as Entropy Regularization that assumes data points exist in clusters, high-density pockets in some feature space. The pseudo-labels are created by a type of clustering algorithm, locating the decision boundaries that separate these high-density clusters. Consider a small set of labeled data points for two classes in a 2D feature space as shown in top plot of *Figure 4*. The current decision boundary of the network, determined from sparsely labeled data, is shown as a dashed line. The middle plot includes additional points from our unlabeled dataset. The centers of each point are shaded according to the unknown true class label and the outlines of the points are colored according to the current prediction of the network (pseudo-label). The training algorithm adjusts the

Figure 2: Generative Adversarial Network (GAN) Workflow

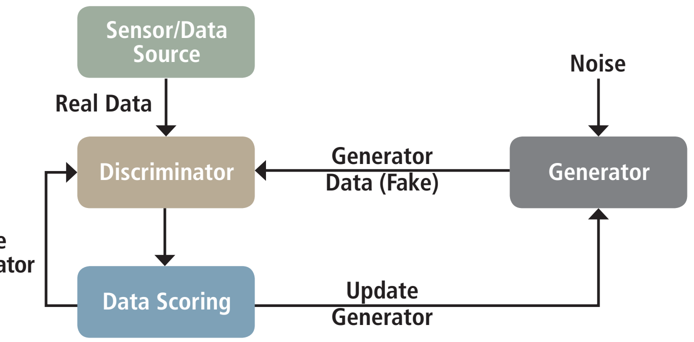


Figure 3: Significant reduction in training burden for GANs versus non-GANs

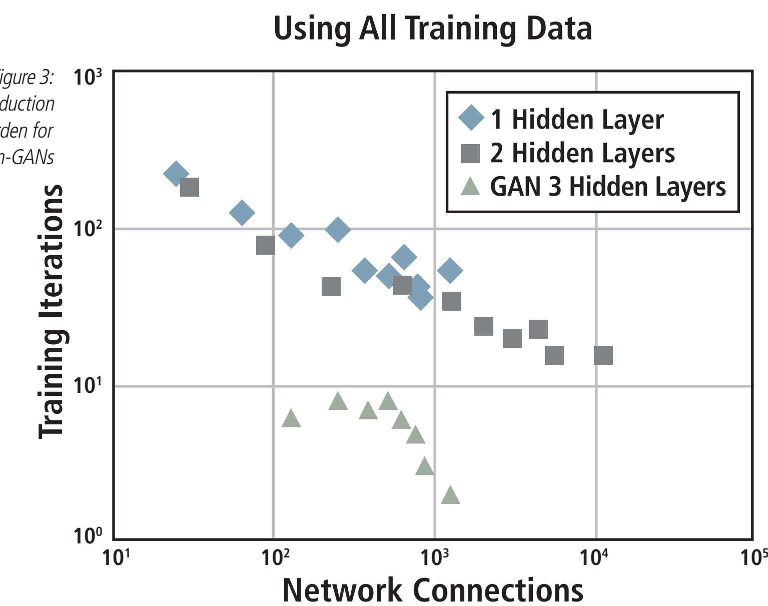
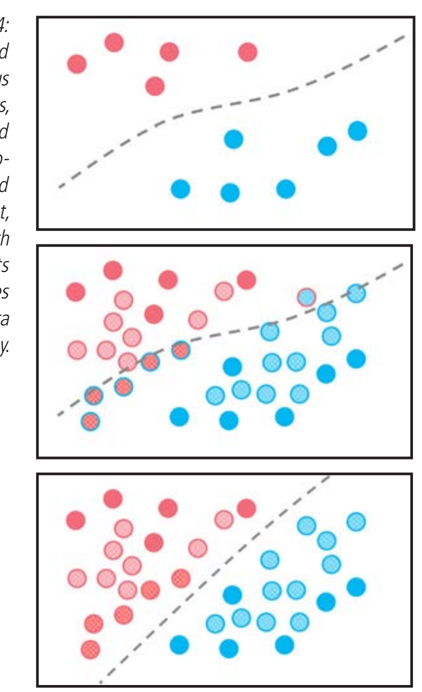


Figure 4: **TOP:** *Sparse labeled data has ambiguous class boundaries,* **MIDDLE:** *Unlabeled data with pseudo-labels (outlines) added to dataset,* **BOTTOM:** *Re-training with pseudo-labels corrects decision boundaries based on data population density.*



[3] I. Goodfellow, J. Pouget-Abadie, M. Mirza, B. Xu, D. Warde-Farley, S. Ozair, A. Courville and Y. Bengio, "Generative Adversarial Networks," no. arXiv:1406.2661v1, p. 9 pages, 2014.

[4] S. Israel, J. Golstein, J. Klein, J. Talamonti, F. Tanner, S. Zabel, P. Salle and L. McCoy, "Generative Adversarial Networks for Classification," in IEEE® Applied Imagery and Pattern Recognition Workshop: Big Data, Analytics, and Beyond, Washington, 2017.

weights of the network to accommodate as much as possible all of the data point assignments. With a high density of points located in distinct clusters, this will move the decision boundary towards the true boundary shown in the plot on the bottom. At each step, pseudo-labels are re-evaluated, allowing them to flip to correct assignments as the network discovers clusters in the unlabeled data consistent with the labeled data.

Historically, pseudo-labels have only been applied to unlabeled data. However, Raytheon has developed an informed pseudo-label algorithm that takes into account noisy labels based on a known or estimated probability of correctness. While extremely noisy labels have limited use with most supervised methods, we demonstrate that a high percentage of label errors may be tolerated using this approach. Using the MNIST (Modified National Institute of Standards and Technology) hand-written digit dataset, our method achieves greater than 98% accuracy even if 70% of the labels are chosen at random, and more than 95% accuracy if 90% of the labels are chosen at random. These results are competitive with recently published works.[5,6]

When the proportion of labeled to unlabeled data is small, pseudo-labels can become easily unbalanced, resulting in all of the points being assigned to only a few or even one class. To counter this, previous approaches restricted the amount of unlabeled data that was used, which limits the amount of information available to the algorithm and to an extent, performance. Raytheon ML scientists took a different approach, estimating the percentage of unlabeled data points in each class a priori, and enforcing a more even split during the assignment of pseudo-labels. As shown in *Figure 5,* using this approach with the MNIST dataset compares favorably to previous published studies. In the figure, average error results from the Raytheon experiment with a convolutional neural network (CNN) and

Method	Size of Labeled Subset			
	100	600	1000	3000
CNN	18.05	6.1	4.06	2.16
CNN+PL	7.14	2.43	2.05	1.82
Lee:NN	21.89	8.57	6.59	3.72
Lee:NN+PL	16.15	5.03	4.3	2.8

CNN = Convolutional Neural Network **PL** = Pseudo-labels **NN** = Neural Network

Figure 5: Average error rate (%) results for the MNIST dataset of hand-written digits using only a small number of labeled data points. Individual values represent the average error over 10 training trials, each with a different random labeled subset of MNIST. CNN+PL is the CNN trained with use of Raytheon's balanced pseudo-label algorithm for the remaining "unlabeled" training data.

the same network using pseudo-labels (CNN+PL) are compared to a similar previous study by Lee using a neural network (NN) and neural network with pseudo-labels (NN+PL).[7]

STATISTICAL METHODS FOR MEASURING ALGORITHM VERACITY AND MAXIMIZING LIMITED TRAINING DATA

When failures occur in machine object recognition algorithms, researchers often have limited information on the root causes of the failure. For example, did an algorithm fail to detect an object due to occlusion, shadow, contrast, or other known computer vision shortcoming? Was the training data not representative of the test data? Is the algorithm fundamentally flawed? Modern ML algorithms like deep neural networks are particularly opaque and provide little information to ML engineers and analysts *(Figure 6).* Along with the tremendous benefits of the use of AI and ML throughout industry, comes the need for greater empirical insight into how these algorithms are performing.

A primary underlying assumption of ML is that the relevant characteristic parameters of training data are representative of the data the algorithm will be tested with and required to discriminate in operation. Raytheon is developing a data-driven statistical confidence metric that will provide insight into some fundamental

[5] I. Jindal, M. Nokleby and X. Chen, "Learning Deep Networks from Noisy Labels with Dropout Regularization," in IEEE International Conference on Data Mining, 2016.

[6] D. Rolinick, A. Veit, S. Belongi and N. Shavit, "Deep Learning is Robust to Massive Label Noise," 31 05 2017. [Online]. Available: https://arxiv.org/abs/1705.10694. [Accessed 27 01 2018].

[7] D. Lee, "Pseudo-label: The simple and efficient semi-supervised learning method for deep neural networks," in Workshop on Challenges in Representation Learning, ICML, 2013.

Figure 6: Example results from ML algorithm[8,9]

questions about ML, such as what is the accuracy of a model's prediction given a classifier and sample of data, or which characteristics of the training data have the greatest influence on a model's accurate prediction of Sample X.

While results on many classification problems have been impressive, Raytheon's customers often have limited training data available for many applications yet require metrics that attest to the veracity of an algorithm's results. Having an innovative confidence metric based on examining scene and target statistics will provide insight to a model's applicability to a specific test sample.

Summary

Many challenges remain for the integration of ML into the systems and technologies of the defense industry, not the least of which is the ability to rapidly apply ML capabilities in dynamic environments of limited training data. Raytheon has made significant investment in this area through the Independent Research & Development (IR&D) of the approaches discussed in this article, and experimental results suggest that these techniques can provide meaningful performance improvements with customer datasets. Other methods under consideration include variational autoencoders; triplet loss; and image-to-image translation,[10] where DNN's attempt to learn the values of one modality from another, such as Electro-optical (EO) from Synthetic Aperture Radar (SAR).

The ability to effectively utilize machine learning algorithms in Raytheon products offers tremendous advantages to customer missions. Both machine learning and artificial intelligence remain a strong focus in the company's technology roadmap as key capabilities for today's defense systems.

Steven A. Israel
Philip Sallee
Franklin Tanner
Jon Goldstein
Shane Zabel

[8] F. Tanner, B. Colder, C. Pullen, D. Heagy, M. Eppolito, V. Carlan, O. C. and P. Sallee, "Overhead Imagery Research Data Set - An annotated data library and tools to aid in the development of computer vision algorithms," in IEEE Applied Imagery Pattern Recognition Workshop, Washington D.C., 2009.

[9] Images from U.S. Geological Survey Department of the Interior/USGS U.S. Geological Survey.

[10] P. Isola, Zhu, J.Y., Z. Tinghui and A. Efros, "Image-to-Image Translation with Conditional Adversarial Networks," in Computer Vision and Pattern Recognition, Honolulu, 2017.

Shane Zabel, Ph.D.
Raytheon Intelligence, Information and Services

Dr. Shane Zabel is the Artificial Intelligence and Autonomy Capability Lead for Raytheon Intelligence, Information and Services (IIS), and also leads corporate core research activities in machine learning. He holds a Ph.D. in physics from Carnegie Mellon University with a specialization in electromagnetic diffraction theory and a master's degree in applied cognition and neuroscience with a specialization in neural network theory from the University of Texas at Dallas. During his 14 years with Raytheon, he has held various roles of increasing responsibility, such as algorithm developer, team lead, business development lead, chief engineer, enterprise campaign lead and IIS capability center lead.

Dr. Zabel's current focus is on artificial intelligence (AI) and machine learning (ML), emerging technologies where he can support customer missions by providing better insight from data, at a larger scale, and with faster response times. "Artificial intelligence has the potential to bring great benefits to our customers' missions," Zabel states, "and being able to integrate AI technologies into customer solutions is very rewarding."

Dr. Zabel's subject matter expert (SME) level of knowledge and experience in electro-optical/infrared (EO/IR) and synthetic aperture radar (SAR) sensor processing, computer vision, AI and ML are generally recognized throughout the industry. For the first 7 years of his career, Dr. Zabel developed domain knowledge and experience in EO/IR and SAR processing technologies, including system calibrations, image formation and advanced exploitation methodologies. He broadened this experience through architecture development for large-scale data processing and autonomous systems.

Dr. Zabel's pivot to AI and ML began in 2012. He completed a master's degree in the subject, and strengthened his knowledge through small independent research and development (IRAD) efforts. "I started my career working in image and signal processing technology development," Zabel says. "In the 2011/2012 timeframe, when state-of-the-art in this domain pivoted to ML-based solutions, I began learning as much as I could on the subject."

In his AI and ML roles, Dr. Zabel supports enterprisewide training activities, leading the machine learning training curriculum development for IIS, and supporting companywide software and information systems and computing technology networks.

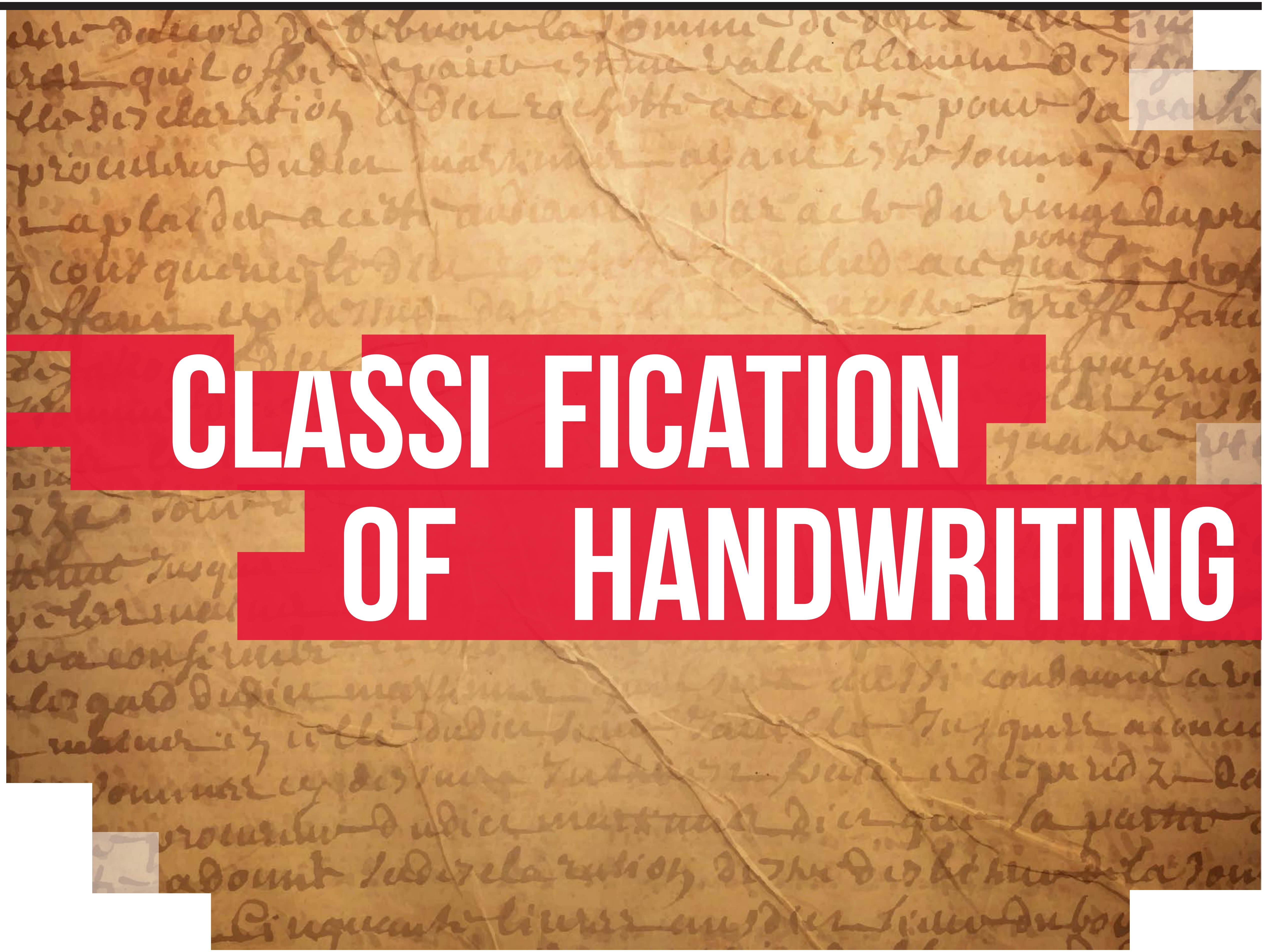
FEATURE

DETECTION, EXTRACTION AND LANGUAGE CLASSIFICATION OF HANDWRITING

The written record is considered by historians as man's transition from pre-history. More importantly, hand-writing (and accounting) enabled the further development of civilization with records such as agricultural yields, livestock, births, and land ownership, which in turn led to centralized management and the rise of cities.

With such a significant role, it's ironic that modern information processing systems cannot reliably "read" unstructured handwriting, particularly when of unknown language or mixed with printed text and images. While Optical Character Recognition (OCR) of printed text has become robust, even routine, Handwriting Character Recognition (HCR) remains stubbornly difficult except for controlled input conditions. The few successful applications, such as postal code address reading, or form scanning, require a defined input format of expected content. This article will address the general more difficult problem of extracting and classifying handwriting of unknown location, size, color, content, and language, in a document also containing undefined images and undefined printed text.

High value documents, such as mission plans, or intelligence reports, may be handwritten for cultural reasons or to frustrate electronic methods of surveillance. The age-old method of couriering sealed handwritten documents is impervious to modern threats of hacking and electronic attack. Most of today's handwritten documents do not possess such levels of intrigue, but rather reflect everyday activities



CLASSIFICATION OF HANDWRITING

such as diaries, calendar notes, letters, to-do lists and other common artifacts. However, even these seemingly mundane snippets of information can shed light on an intelligence analysis problem if properly indexed and searched. Separating the wheat from the chaff is an overwhelming task given the large volume of documents which contain unstructured handwritten notes, mixed with print and images.

The first step in solving this problem is to discover the handwriting and determine the language so that the HCR algorithm can be properly initialized. This is a big data problem due to the magnitude of document datasets. It is a machine learning challenge due to the wide variability between languages, people, sensors and environmental conditions such as poor or uneven lighting. *Figure 1* lists several techniques evaluated for a possible solution to this challenging task.

The simple process flow shown in *Figure 2* does not reflect the combined algorithmic complexity of integrating and evaluating the various segmentation, recognition and language classification approaches. For example, considering the techniques listed in *Figure 1,* the total number of system configurations is the overall product of all possible combinations of algorithms for each stage. In this case there are four binarization techniques, two recognition techniques and three language classification techniques or 24 total (=4x2x3) which, when coupled with all the parameter settings of each individual algorithm, can easily stress the test/evaluation capacities.

Dividing the processing into three stages helps confine this complexity by allowing algorithms at each stage to be optimized as an independent problem. Complexity is further managed through separation of the document handling and user interfaces from the algorithm development within the evaluation architecture as shown in *Figure 3.* In this way, the infrastructure is able to scale to available resources required to handle millions of documents in an automatic workflow and users are able to direct and annotate processing results. Users can point the system to collections of scanned images and route the processed result to the appropriate language specialist. They can also mark the machine learning results as incorrect or mark missed detections for further analysis.

Binarization Approaches	Handwriting Recognition Approaches	Language Classification Approaches
Otsu's method	Line-cuts	Speeded Up Robust Features (SURF) with Support Vector Machine (SVM) classifier
Modified Sauvola method	Deep Page Layout	N-gram features with K-Nearest Neighbor classifier
Color		Deep Learning – Convolutional Neural Networks (CNN)
Graph-based		

Figure 1: Techniques for segmentation, recognition, and language classification of handwriting

Figure 2: Simple algorithmic flow belies combinatorial complexity of technique selection and integration

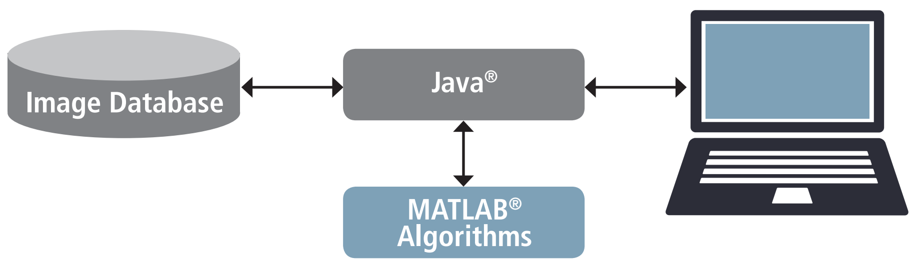


Figure 3: Separation of algorithmic processing from infrastructure enables separation of concerns for each development team

HANDWRITING BINARIZATION

The goal of binarization is to convert the input document into a background represented by 0 (zero, or logical false), and a foreground represented by 1 (one, or logical true) which includes the objects of interest, in this case handwriting. This simple procedure often proves to be a difficult task due to variations in illumination, condition of the paper, and other factors such as variations in the ink. However, the success of the later stages of handwriting recognition and language classification depends on a good binarization which makes easier the computerized interpretation and classification of the handwriting's component objects.

Otsu's Method Versus Modified Sauvola Method

Otsu's method[1] calculates a global threshold by maximizing the interclass variance between the foreground and the background. This approach can completely fail when the handwriting is a light gray, such as when using a pencil, and the rest of the image has darker interfering elements such as machine printed text or images.

Niblack[2] first applied an adaptive method to adjust the binarization threshold similar to the way a Constant False Alarm Rate (CFAR) might be adjusted by making the threshold proportional to the local mean and standard deviation of a sliding window. Subsequent experiments by Sauvola[3] showed that including a term proportional to the product of the local mean and standard deviation could provide better results. We modified Sauvola's method to first pre-process the input image using the stretch histogram in only those places that have energy over a threshold. Energy is detected by dividing the document into small sub-blocks. At each sub-block position the maximum intensity difference is recorded. The resulting sub-block image is interpolated to the original image size. Morphological operations are used to select the higher energy regions for processing. Without this technique of selective contrast stretching, the salt-and-pepper noise in non-information bearing parts of the document are amplified, causing false detects. Selectively stretching contrast in this manner contributed to better handling of lighting variations and separation of the foreground images as shown in *Figure 4.*

Color Exploitation

Separation of handwriting on top of machine printed text is much less difficult if a color difference can be exploited.

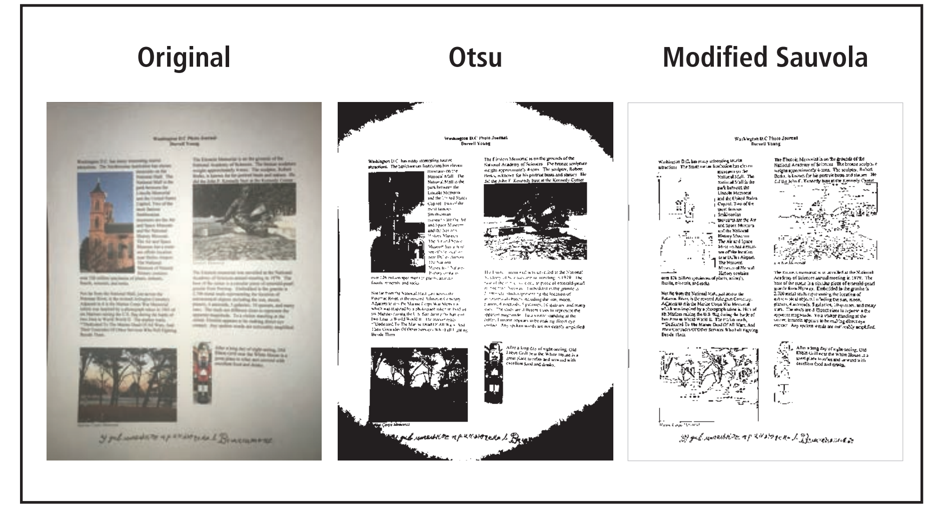


Figure 4: Modified Sauvola method adapts to variations in lighting

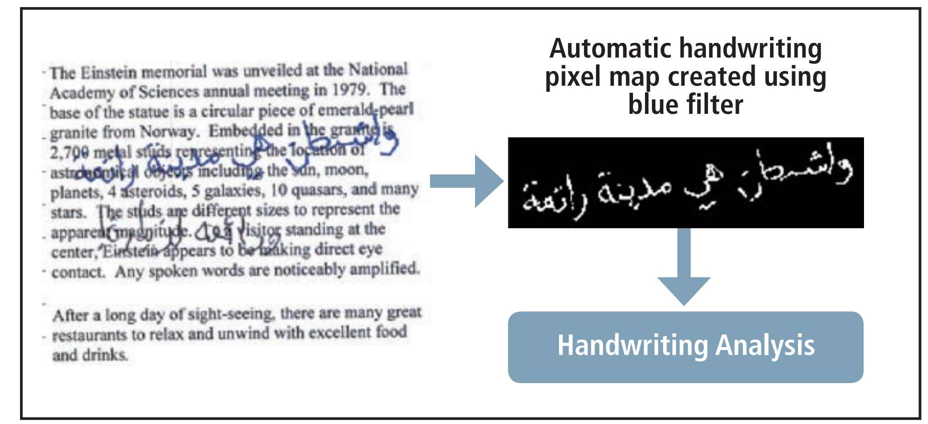


Figure 5: Blue color filter extracts handwriting written in blue ink

For example, handwriting is often in blue ink as depicted in *Figure 5.* Algorithms were created to extract these text objects by exploiting detectable color differences. The document is converted from RGB to the Lab color system in order to create color filters. The Lab color system is a mathematically described color space where L is Lightness and a and b represent the color components green–red and blue–yellow respectively.

The blue Arabic handwriting is easily extracted by the Lab color filter and sent downstream for language identification. In the figure there is black Arabic handwriting

[1] N. Otsu, "A threshold selection method from gray-level histograms," IEEE® Trans. Systems Man Cybernet., 9 (1), 1979, pp. 62-66.

[2] W. Niblack, "An Introduction to Digital Image Processing," pages 115-1 16. Englewood Cliffs, N.J., Prentice Hall, 1956.

[3] J. Sauvola, M. Pietikainen, "Adaptive Document Image Binarization," Pattern Recognition, 33, 2000, pp. 225-236.

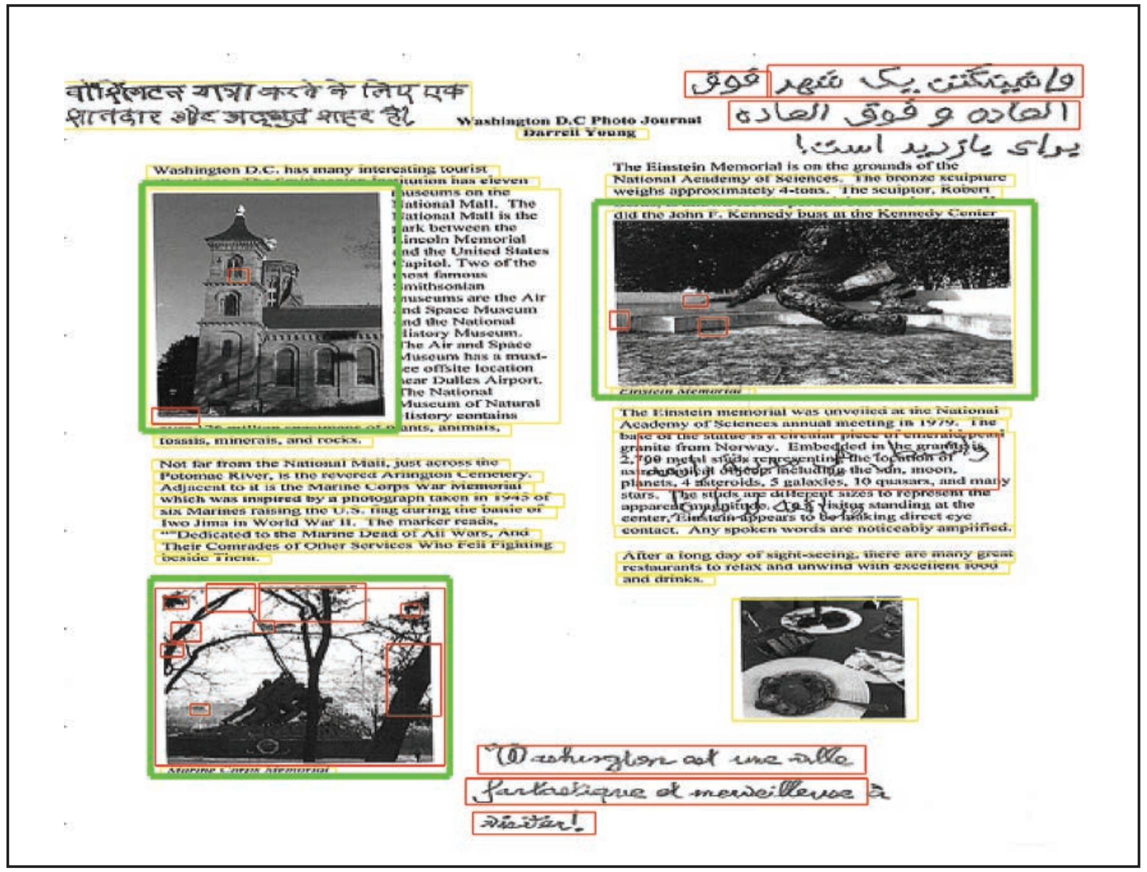


Figure 6: Page layout of a magazine article processed by the deep learning CNN. Green boxes are detected images, red are handwriting and yellow are text

below the blue that was not extracted by the blue color filter. In these cases, when there is no detectable color difference, a graph-based segmentation algorithm is used to extract the handwriting.

Deep Learning CNN Page Layout Versus Line Cuts

Characteristic features that distinguish handwriting from printed text include poor alignment of characters within a word, or between words within a phrase or sentence; variations in relative character sizes; and greater variation in character spacing than occurs in printed text. In order to capture these properties, it is necessary to first properly align the suspected handwriting, and then measure the lack of printed text uniformity. Conventional methods to distinguish handwriting from machine printed text exploit these variations using a line cut method. Non-uniformities between characters and words can be measured with a horizontal line cut. Vertical line cuts can detect the uniformity of lower and upper case variation in printed text. The problem with the line cut method is that embedded images, such as those found in magazines or news articles, also have unstructured variation which can cause the algorithm to confuse images for handwriting.

An alternate solution was evaluated using a deep learning convolutional neural network (CNN) to recognize handwriting, machine printed text, and images. The machine learning algorithm was first trained with a dataset of printed text, handwriting, and images. Then a page from a travel article about Washington D.C. written by the author was marked with handwriting and processed as an image by the algorithm *(Figure 6)*. The red boxes indicate handwriting detected by the CNN and the green boxes are detected images. Since the entire page is an image, the deep learning CNN is detecting images inside the overall image. Similar to the line cut problem, handwriting is sometimes falsely detected inside the images. However, in this implementation it is

Figure 7: Segmented word and phrase images used to build a training dataset

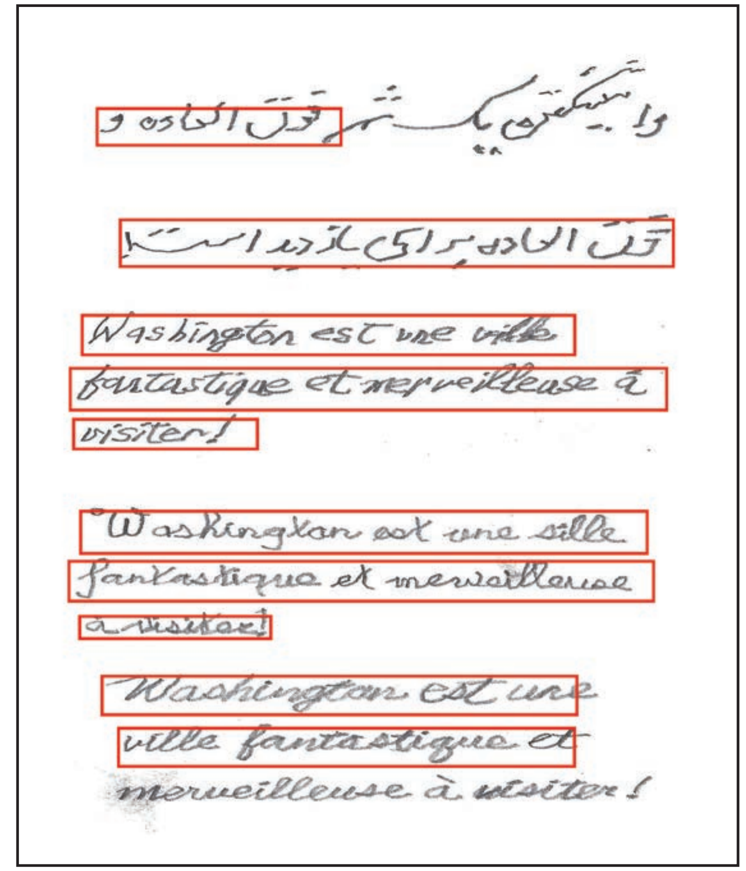
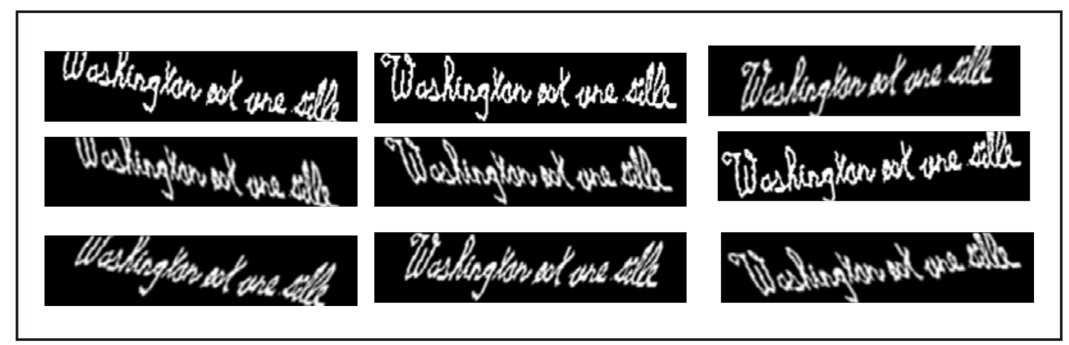


Figure 8: Augmentation. Top row center is the original and below it are affine left and right transformations. The left and right columns are rotated versions.



a configuration option to process candidate handwriting on top of detected images.

The most difficult part of machine learning is oftentimes training set preparation. In this case, the available handwriting data consisted of a collection of handwritten documents in various languages. Our approach segmented each document into a collection of small, binarized images as shown in *Figure 7*.

Once the handwriting has been extracted various versions are created using image warping routines to slant the image to the left and to the right. The middle column of *Figure 8* shows the original extracted handwriting (top) and below it, two warped versions of the image. In addition, each image is rotated left and right through 1 degree increments up to +/- 8 degrees (left and right columns).

LANGUAGE CLASSIFICATION

Three methods were evaluated to classify the detected handwriting: SURF-based features with Support Vector Machine (SVM) classifier; N-gram histogram vectors with K-Nearest Neighbor classifier; and deep learning Convolutional Neural Net.

SURF-Based Features with Support Vector Machine (SVM) Classifier
Initial experiments utilized the Speeded Up Robust Features (SURF)[4] algorithm to identify keypoints in the training set. The strongest keypoints were selected to create a visual "bag-of-words," which was then used in a Support Vector Machine to distinguish the language classes.[5] This approach worked surprisingly well as an "off-the-shelf" algorithm with no specific customization for handwriting language recognition, achieving accuracies of more than 75%.

N-gram histogram vectors with K-Nearest Neighbor Classifier
The first step in this method was to approach the problem in much the same way as early day cryptographers, by noting that n-gram character sets from secret writing, (where n is 1, 2 or 3), exhibited statistical frequencies characteristic of the language the code was concealing. By constructing sub-blocks of the text, we believed we could map their frequencies to a set of the major languages. Approximately 100 individual features were designed to capture the uniqueness of each language *(Figure 9)*. For example, the French phrase, "Où dans la forêt est le garçon étudiant naïf?" illustrates all five French accent marks: grave, circumflex, cedilla, acute and umlaut. We first detected the appearance of these marks and then encoded them as features, assigning each feature a unique number. Next, a detector was designed for each feature. Similarly, detectors for other languages were developed, such as unique

FRENCH

Où dans
la forêt est le
garçon étudiant
naïf?

KOREAN

제 눈에 안경이다

ARABIC

اصبر تنل

CHINESE

见钟情

arrangement of circles and lines found in Korean, "제 눈에 안경이다" ("beauty is in the eye of the beholder"); the curves of Arabic, "اصبر تنل" ("be patient"); the multiple orthogonal intersections of Chinese, "见钟情" ("love at first sight"); and so on for Japanese, Urdu, Persian, Bengali, Hindu, Portuguese, Russian, Swahili, Tamil, Telugu, and Turkish.

Once each feature was detected and encoded into a number, the language classification process began. The approach was patterned on the successful Cavnar and Trenkel technique[6] used on characters (not handwriting) where histograms of n-grams are formed to create a language profile. An n-gram, in this case, is an occurrence of two features together. The language profile vector of n-gram normalized counts is developed during training and stored for each language. During testing, n-gram profile test vectors of the test document are compared to the stored profile vectors. The "closest match" is the reported language.

Figure 9: Custom feature tokens detected in handwriting are used to build n-gram feature vector histograms

Line Shapes	Horseshoe Shapes	Circular Features
1 Horizontal line	15 East horseshoe	19 Big lower circle
2 Vertical line	16 North horseshoe	20 Big upper circle
3 Lower cross	17 West horseshoe	21 Small lower circle
4 Upper cross	18 South horseshoe	22 Small upper circle
5 Lower T		23 Big lower horizontal oval
6 Upper T	**Accent Features**	24 Big upper horizontal oval
7 Lower L		25 Small horizontal lower oval
8 Upper L	60 Dot	26 Small horizontal upper oval
9 Lower upside down L	61 Dash	27 Big lower vertical oval
10 Upper upside down L	62 Aigu	28 Big upper vertical oval
11 F	63 Grave	29 Small vertical lower oval
50 Diagonal line	64 Circumflex	30 Small vertical upper oval
51 Horizontal diagonal line	65 Tilde	
52 Vertical diagonal line	66 Caron	
	67 Breve	
	68 Inverted Breve	
	69 Hoi	
	70 Circle Accent	

The feature bi-gram approach takes advantage of the fact that certain handwritten strokes uniquely appear together in certain languages. For example, the letters 'th' are the most common character bi-gram in the English language. The circumflex found above the ê (e-circumflex) was assigned the feature code of 64. The top part of the "e" is coded as a "South horseshoe" feature (see *Figure 9).* The feature bi-gram formed by 18 and 64 appearing together is common for the occurrence of the e-circumflex found in Afrikaans, Dutch, French, Friulian, Kurdish, Portuguese, Vietnamese, and Welsh and would be prominent in their profile vectors. A counter-example is the diacritics found in Arabic such as the fatah and kasrah which are small diagonal marks placed above or below letters, respectively to indicate pronunciation. Depending on the personal style of the handwriter they would be assigned feature codes 50, 51, or 52. The Arabic bi-gram feature profile will have many occurrences of these feature codes which helps distinguish it from Latin languages. We evaluated various distance metrics such as Spearman, Minkowski, Mahalanobis, Jaccard, Hamming, Euclidean, Seuclidean, cosine, correlation, Chebyshev and cityblock. In general, Hamming and cosine distance measures performed the best for this application.

The approach used in this study was to form n-grams using the feature numbers. A profile n-gram histogram vector for each language was created during training and then n-gram test vectors were compared to it during test to estimate the language by choosing the profile vector that was the best match to the test vector. The experiments showed this as a viable technique, which could learn a language profile and match it against features extracted from never-before-seen data, achieving accuracies of up to 87%. The downside of this technique, however, is the complexity of coding the individual feature detectors.

[4] Herbert Bay, Andreas Ess, Tinne Tuytelaars, Luc Van Gool, "SURF: Speeded Up Robust Features," Computer Vision and Image Understanding (CVIU), Vol. 110, No. 3, pp. 346–359, 2008.

[5] Csurka, G., C. R. Dance, L. Fan, J. Willamowski, and C. Bray Visual Categorization with Bag of Keypoints, Workshop on Statistical Learning in Computer Vision, ECCV 1 (1-22), 1-2.

[6] Cavnar, William B., and John M. Trenkle. "N-gram-based text categorization." Ann Arbor MI 48113, no. 2 (1994): 161-175.

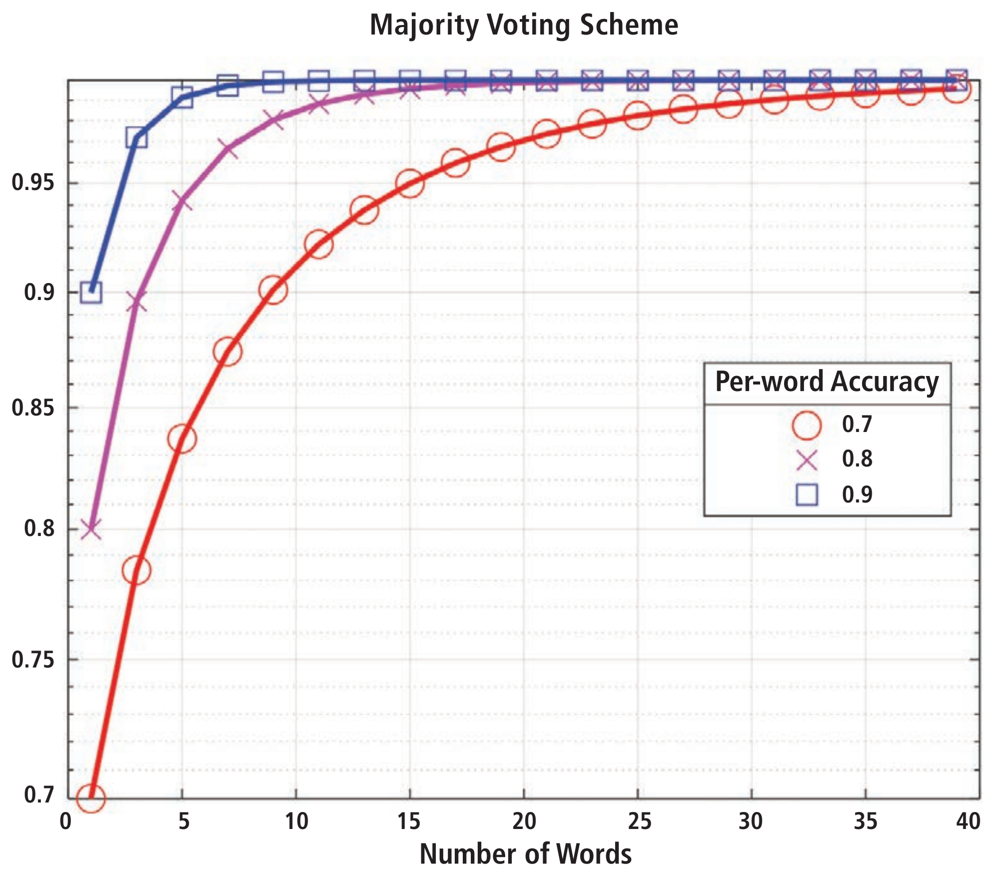


Figure 10: Document language classification accuracy improved via majority voting. Increased number of words improves overall accuracy

Deep Learning CNN Handwriting Language Classifier
Deep learning CNNs do not require the language expertise to know which features most likely differentiate handwriting systems. Instead, presumably, the deep network learns the unique characteristics of each language such as the unique L'accent marks in French and the inverted question marks (¿) in Spanish. The deep net, conceivably, removes the need for one or more language specialists that know the peculiarities and distinguishing features of each language; and one or more computer specialists to code the feature detectors.

This large gain in automation obtained from the deep net does not come without a price. A new kind of specialist is needed to organize and feed the algorithm a very large dataset of training examples. Moreover, in some cases of rare and/or vanishing languages it is difficult to obtain a sufficiently large set of handwritten samples for training.

The deep CNN approach automatically learns the features from the raw input training images. The performance of the deep learning CNN increases with the number of layers and the quality of the input training set. In the prototype experiment, each convolution layer had a rectified linear unit (ReLU) and batch normalization. The cross entropy[7] loss function was minimized to select one of the mutually exclusive language categories achieving accuracies up to 95%.

Post-Processing
The language classification results are on a per-word basis. The evidence for declaring a language increases with the number of words evaluated. If all the handwritten words in the document are from the same language, additional accuracy can be achieved by implementing a majority voting scheme. Assume that the accuracy of each language class is p, and all the misclassification error probabilities are the same, then the $P_{correct}$ of a majority voting scheme over n-words is given by the binomial equation:

$$\mathrm{P}_{\mathrm{correct}} = \sum_{k>n/2}^{n} \binom{n}{k} p^k (1-p)^{n-k}$$

The majority voting scheme can yield substantial improvement as *Figure 10* shows for per-word probabilities of 0.7 (red), 0.8 (magenta), and 0.9 (blue). A per-word classification accuracy of 0.7 converts to an overall document accuracy of .95 after only 15 words are input into the majority voting.

CONCLUSIONS

Detection, extraction, and classification of handwriting language are a prerequisite to Handwriting Character Recognition (HCR). Raytheon has developed a scalable prototype system that accomplishes these tasks. Deep learning algorithms were evaluated for both the page layout and language classification tasks. The deep learning language classification performance was compared to more conventional SURF bag-of-words features with an SVM classifier, and to a novel bi-gram handwritten feature representation with a nearest neighbor classifier. The development of the custom features requires significantly more thought and programming effort, but could be useful in those cases where there is insufficient data to fully train the other machine learning approaches.

The division of the problem into manageable segments controlled the combinatorial complexity. The end-to-end performance of the system requires each segment work as intended.

Handwriting language classification requires the handwriting to be detected, which requires correct page layout which requires good binarization and so forth.

The immense variety of the unconstrained input document types, combined with the cascade dependencies of the processing chain, continues to make the handwriting language classification on general documents of any type a challenging problem. Future work will explore the gain of various machine learning architectures including more layers and extended training sets for improved machine learning of document layout, handwriting detection and handwriting language recognition. This work could also extend the techniques developed in the prototype system to detect hand-drawn maps and circuit diagrams which could have relevance for counter-IED and other important intelligence applications.

Dr. Darrell Young
Dr. Kevin Holley

[7] Bishop, C. M. Pattern Recognition and Machine Learning. Springer, New York, NY, 2006.

LEADERS CORNER

JEFF VOLLIN, Ph.D.

Dr. Jeff Vollin is the Technology Director and Chief Technologist for emerging technology for Raytheon Missile Systems (MS). He is responsible for selection, funding and oversight of MS fundamental research and development programs, including advanced propulsion, structures and materials, radio frequency (RF) and electro-optical sensors, signal processing, as well as high-power-microwave and high-energy-laser technology. As a principal engineering fellow, Dr. Vollin specializes in the design of high-power systems, transmitters, and high- and low-voltage power systems. Previously as lead technologist for power systems, he oversaw advanced technology in that area; and earlier he was chief engineer for the Vigilant Eagle program, a high-power-microwave defense system against shoulder-fired missiles. Dr. Vollin earned a bachelor's degree in engineering from the California Institute of Technology™, a master's degree in electrical engineering from UCLA™ and a doctorate in Electrical Engineering from the California Institute of Technology.

TECHNOLOGY TODAY SPOKE WITH JEFF VOLLIN ABOUT HOW RESEARCH AND TECHNOLOGY IS MANAGED AT RAYTHEON MISSILE SYSTEMS AND HIS ROLE AND RESPONSIBILITIES AS TECHNICAL DIRECTOR.

TT: WHAT IS A BUSINESS TECHNICAL DIRECTOR (TD) AND WHAT ARE YOUR DAY-TO-DAY RESPONSIBILITIES AS A TD?

JV: While it varies a bit from business to business, at Missile Systems (MS) the TD has shared responsibilities to Corporate Headquarters and to MS. For Corporate, I interface with the Chief Technology Officer on all our advanced technology plans and strategies. I coordinate Missile Systems' attendance at major events, such as Technology Integration week and the Principal Fellows Workshop. I also answer any questions on technology from corporate leadership and monitor the MS IRAD investments relative to the other businesses, to ensure there is the maximum amount of synergy possible between IRAD investments. For MS, I oversee the annual process of selecting strategic IRAD projects, then oversee the execution of those projects throughout the year. Our office also coordinates all Missile Systems' university engagements whether they be Directed Research, Research Memberships, or just university services.

TT: HOW DID YOU GET INVOLVED IN TECHNOLOGY AND WHAT ARE YOUR HOBBIES?

JV: My involvement with technology started early in my career. I was involved in the design of Raytheon's High Power Transmitters and High Power Microwave products, and I felt it was essential to understand how these devices fit into the overall strategy of Missile Systems. Not every missile contains an active RF transmitter, and I wanted to understand which ones did and why. For example, those missiles that did not carry an active transmitter, could they include one in the future, and what obstacles might prevent their adoption? This led me into a position of coordinating IRAD investments in our Electrical Systems Directorate for not only high power transmitters, but also for all MS electronic technologies. And following this, I was offered a position on the MS Technology Staff.

As far as hobbies are concerned, I enjoy amateur astronomy, amateur radio, metal working in my home machine and welding shop, and woodworking. To support my astronomy hobby, I built a deck on the roof of my house with a fiberglass dome to house the telescope. The telescope structure required both machine work and welding. I also traveled this year to the Great American Eclipse with friends that were professional Astronomers. The experience was great, especially with like-minded friends regarding events in the sky.

TT: WHAT EXCITES YOU ABOUT TECHNOLOGY AT RAYTHEON?

JV: For me, the excitement comes from the opportunity to see all the great science I learned about in my undergraduate education at Caltech™ come into reality. Much of my career was spent narrowly focused on Power Electronics, my chosen specialty for my Ph.D. Working in the Technology office has allowed me to expand my knowledge and influence far beyond electronics into such areas as propulsion; Guidance, Navigation and Control (GNC); atomistic simulation; exotic materials and Artificial Intelligence. It is truly amazing to see all the technology our people can take from the imagination and make into working products. I do miss being THE expert on one topic, now relying on other experts in their domains, but the rewards of being involved in many technologies easily make up the difference.

TT: WHAT ARE SOME KEY EMERGING TECHNOLOGY AREAS AND WHY ARE THEY IMPORTANT?

JV: Today it is impossible to work in almost any area of technology without encountering Artificial Intelligence (AI) and Machine Learning (ML). We use it not only in obvious ways such as target recognition in complex scenes, but also in some very unexpected ways such as sharpening an out-of-focus image. Some of the AI/ML technology is making a direct impact today, while some of it will need considerably more time to mature. We are creating strategic partnerships with universities such as Caltech in the area of autonomous systems. These partnerships help move our technology ahead quickly by mixing the theoretical work of a university with the practical work of Missile Systems.

There are other key emerging technologies that I am tracking as possibly "the next big thing" in their respective fields. One is electric propellant, which is a unique combination of electricity and chemistry yielding a solid propellant that can be turned on and off, literally with the flip of a switch. When in the off position, the material will not burn energetically, providing a propellant with unprecedented safety and utility. Another emerging technology I am watching closely is Integrated Photonics. This field is just now making the transition from discrete components to complete subsystems integrated on a chip; much like electronics made the shift in the 1980s. With photonic systems, all the size, weight and power (SWAP) factors could potentially be improved by an order of magnitude or more. Commercial practice is moving quickly in this direction in the large data communications area, and our missiles use more and more high speed data all the time. There are many more emerging technology areas we are investing in, these are just a couple that may not be widely appreciated yet.

TT: HOW DOES RAYTHEON TEAM WITH UNIVERSITIES TO DEVELOP TECHNOLOGIES?

JV: We team with universities to gain access to the newest thoughts in science and technology. Many of the problems that universities deal with require extended time spent with great focus and concentration to solve. It is usually not economically practical for companies that need to make a product to spend this effort, especially when there is no guarantee of useful results. By teaming with a company like Raytheon, we can help the university to focus their thinking along practical lines, to solve real problems that the nation has. Raytheon gains from the exposure to new ideas and new ways of thinking about problems that may have been unsolvable just a few years ago.

TT: HOW DOES A PERSON GET INVOLVED IN RAYTHEON RESEARCH, TECHNOLOGY AND INNOVATION?

JV: At MS, this question has many dimensions and pathways, but they all start with an interest and a passion for what comes next. Early in my career, it became clear to me that in a competitive environment, the person who sits still quickly falls behind. Even then, the rate of technology change was so rapid that a good idea today, was common practice tomorrow. I knew I needed to be searching along multiple paths to find that next big idea. That is where it all starts, with that new idea. Once the idea has been formulated, the next step is to find a way to make that idea a reality. For that, Raytheon has many activities and programs from the basic MS Igniter crowdsourcing tool, to the more formal IDEA (Identify-Develop-Expose-Action) Program run by Technology Area Directors (TADs), and finally Independent Research and Development (IRAD) projects. There is also the MS Hackathon and Conclave, collaborative events where employees can think and innovate, sharing and building upon ideas to create solutions to real world problems. At the enterprise level, there is also the Raytheon Innovation Challenge, a terrific venue to develop ideas to solve stated challenges.

I mentioned the TADs before. These are people that take a year away from their home organization to work in advanced technology for the enterprise, in one of our key technology domains. A great way to get involved in innovation is to know the TAD associated with your area of interest, and engage with the associated Technology Network (TN). The TN provides opportunities for enterprisewide collaboration within that technology area, organizing activities for innovation such as symposia, workshops, and Technology Interest Groups. There really is something for everyone — so long as there is a passion and a good idea.

"THERE REALLY IS SOMETHING FOR EVERYONE — SO LONG AS THERE IS A PASSION AND A GOOD IDEA."
— JEFF VOLLIN

MECHANICAL MODULAR OPEN SYSTEMS ARCHITECTURES

Raytheon has enterprisewide technology networks established to communicate and coordinate technology needs and developments across the company. These networks help ensure discriminating technologies are available to our system solutions that, in turn, provide our customers with the highest performance capability at the lowest possible cost.

One particular technology network is the Mechanical, Materials, and Structures (MMS) Technology Network (MMSTN) that focuses primarily on electronics packaging, advanced structures, emerging materials, and thermal management. This article discusses industry shifts toward open standards designs and how these shifts change and exert influence on the MMS technology domain.

OPEN STANDARDS AND ARCHITECTURE FOR COMPUTING SYSTEMS

Raytheon produces computing hardware and also adapts other vendors' hardware for use in areas such as communications, cyber, electronic warfare, radar, surveillance and weapons. Many of the computing systems Raytheon builds on these platforms are considered *embedded* — systems designed to perform specific functions within a larger system. Recently, there has been a shift in customer requirements towards using embedded computing systems with modular open systems architectures. This is due in large part to the 2017 National Defense Authorization Act (NDAA) requiring all major defense acquisition programs receiving Milestone A or B approval after January 1, 2019 to be designed and developed with a Modular Open System Approach (MOSA) to the maximum extent practicable.[1]

MOSA divides systems into modules connected through well-defined interfaces. This enables customers to minimize "vendor lock",[2] increase competition, maximize interchangeability, and facilitate technology refresh whereby pieces of a system are upgraded to improve or augment capabilities without replacing the entire system. Open architectures, generally agreed to reduce cost and spur innovation through open competition[3], may also come at the expense of performance and reliability.[4]

Open architecture is commonly misunderstood as a systems engineering philosophy that impacts only systems engineers and system architects. However, architecture is "the fundamental organization of a system[5]" embodied in its modules and interfaces, including mechanical, electrical, and software interfaces. An open architecture will follow defined standards for these interfaces, often down to the module level, impacting the MMSTN engineering disciplines.

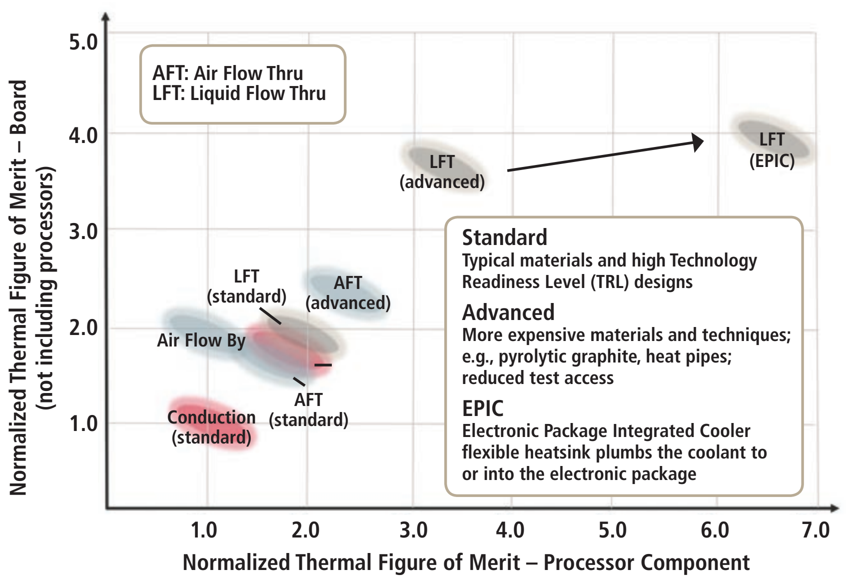


Figure 1: Board and Processor Figures of Merit (FOM) for VITA 48 Cooling Architectures

The VITA[6] Standards Organization is responsible for developing and defining key open standards specifications for embedded computing systems and modules. VITA 48, commonly known as VPX-REDI,[7] establishes the latest mechanical formats and interfaces between the computing module and the chassis. Within the VITA 48 framework are standards for different cooling schemes, including standard air cooling (VITA 48.1), conduction cooling (VITA 48.2), air flow through cooling (VITA 48.5), and air flow by cooling (VITA 48.7). The relative thermal performance of each of these is presented in *Figure 1*.

Air flow by (AFB) cooling techniques employ convective cooling across the board surface by placing it in an airstream. Air flow through (AFT) and liquid flow through (LFT) techniques plumb the cooling fluid into a finned heat exchanger frame, conductively cooling the board to the heat exchanger. As shown in *Figure 1,* LFT cooling achieves superior thermal performance compared to alternative methods. It can also support high altitude operation. While conduction cooled applications may suffice in many current ruggedized processing module applications, liquid cooling will be necessary to transfer the heat dissipated by state-of-the-art processor solutions in the near future.

In response to interest from Raytheon and others, VITA formed a new working group in early 2015, chaired by Raytheon, to write the standard on liquid-flow-through VPX-REDI (VITA 48.4). Participation in a standards working group gave Raytheon and other members early access to the new standard and lessons learned, and provided them an opportunity to steer requirements and help drive the pace of the standard development milestones to meet program needs. The VITA 48.4 standard was ANSI (American National Standards Institute) ratified in 2018 and is available for use by any VITA member.

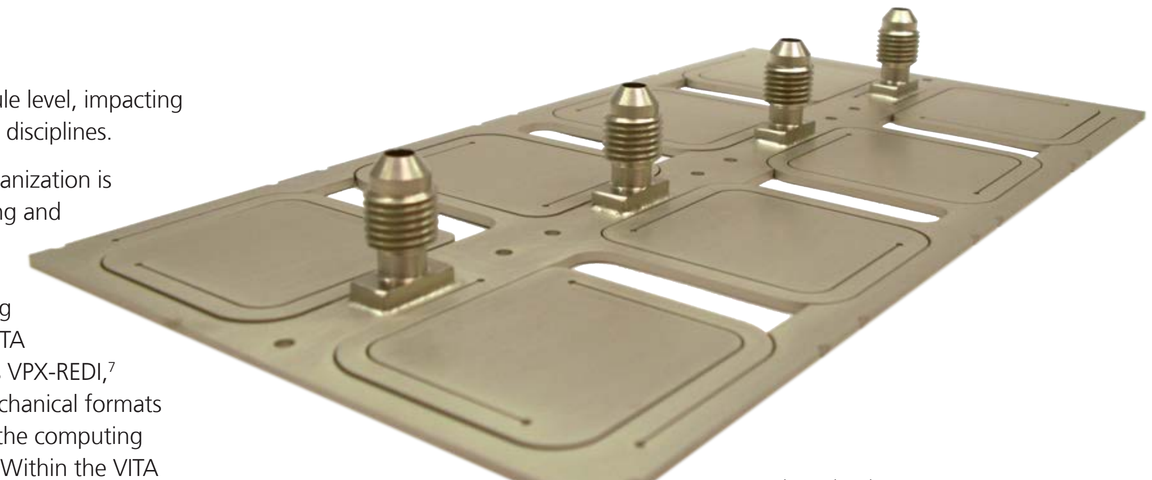


Figure 2: Enhanced Package Integrated Coldplate — an array of eight coolers for demonstration testing

Open standards specify external mechanical requirements, such as mounting, outline, and interfaces. Internal components, for example circuit card assembly (CCA) and heat exchanger, are mostly customizable. An example of a customized internal component that still supports external open standards is the Raytheon developed Enhanced Package Integrated Coldplate (EPIC),[8] *Figure 2.* EPIC is a thin (less than 2mm in thickness) flexible microchannel heat exchanger that can directly couple to the processor lid or die without the need for silicone based conforming gap filler materials. The mechanical flexibility enables EPIC to bring the coolant closer to the heat source, rejecting nearly twice as much heat from a processor as other state-of-the-art cooling solutions (pyrolytic graphite, heat pipes, etc.), extending the thermal limit of embedded computing processors well into the future.

More specific to United States military products, the Sensor Open Systems Architecture (SOSA)™ Consortium[9] is developing consensus-based, open technical standards specifying a reference architecture primarily aimed at Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) sensor systems, including electro-optical and infrared (EO/IR), radar, signals intelligence (SIGINT), communications, and electronic warfare systems. The hardware working group within SOSA "specifies relevant existing standards and, as necessary, develops new standards to achieve modularity, interoperability, and scalability within a chassis" for all subsystems within a sensor product.[10] SOSA is about two years old and is in the early stages of identifying and adopting relevant standards that extend to the entire sensor system.[11] Future sensor pursuits will require conformance with SOSA standards that extend beyond embedded computing to other subsystems and interfaces within the sensor system, the radar antenna for example.

Chris Koontz

[1] *National Defense Authorization Act for Fiscal Year 2017.* Sec. 805 Subsection 2446a "Requirement for modular open system approach in major defense acquisition programs; definitions." PUBLIC LAW 114–328—DEC. 23, 2016.

[2] "Vendor lock," also known as vendor lock-in, refers to a situation where a product architecture is customized or otherwise protected by intellectual property rights to the point where all upgrades must be performed by the original developer to avoid substantial switching costs

[3] Baldwin, C. and Clark, K. "Managing in an Age of Modularity." Harvard Business School™ Publishing, 1997.

[4] Christensen, C., Raynor, M. *The Innovator's Solution.* Harvard Business School Publishing, 2003, p 133.

[5] ISO/IEC 42010 - IEEE® Std 1471-2000 "Systems and software engineering — Recommended practice for architectural description of software-intensive systems."

[6] VME (Virtual Module Europa) International Trade Association.

[7] VPX (ANSI/VITA standard 46.0), REDI (Ruggedized Enhanced Design Implementation).

[8] US Patents 8,368,208 and 9,553,038.

[9] Raytheon Space and Airborne Systems is a sponsor-level member in the SOSA Consortium.

[10] "Sensor Open Systems Architecture: SOSA Overview." *The Open Group.* opengroup.org. January 30, 2018.

[11] McHale, John. "Sensor Open Systems Architecture (SOSA), an Overview." Military Embedded Systems. March 17, 2017.

FROM ONE ROBOT-MAKER TO ANOTHER

WOMEN ENGINEERS MENTOR 100 NEXT-GEN ROBOT-MAKERS AT FIRST® COMPETITION

Hundreds of students packed a Pomona, California, fairplex; makers of robots that would do battle at the Los Angeles Regional FIRST® Robotics Competition. The atmosphere in the arena, themed to recall the 8-bit video games of the 1980s, was electric as teams made last-minute modifications.

Stephanie Yung, mechanical engineer, hosts a table of aspiring engineers. She was one of eight Raytheon engineers who offered advice to more than 100 young women from the Los Angeles Regional FIRST Robotics Competition.

The competition brought together high school students from across Southern California to compete head-to-head with robots they designed and built over a six-week period. Raucous cheers bounced off the walls as each team's robot hit the arena floor. Operators, armed with controllers designed by their teammates, deftly moved their robots along the arena floor, picking up bright yellow boxes and depositing them into bins for points.

During a break in the competition's action, 100 of the young women behind the robots met with eight Raytheon women engineers at a speed-mentoring event in the conference center next door. Their mission? Share important lessons about making it in a field where women are often underrepresented.

"I am most looking forward to learning about confidence," said one of the students before the speed-mentoring event. "I know women are held to a different standard to do things a certain way. I think that talking about it helps relieve the stress of wanting to be perfect in a society where no one is perfect."

> "YOU NEED TO PLAY TO YOUR STRENGTHS. AS YOU GO THROUGH HIGH SCHOOL AND COLLEGE AND THEN GET INTO THE WORKPLACE YOU'RE GOING TO HAVE AN OPPORTUNITY TO FIND WHAT YOUR STRENGTHS ARE."
> — ANGELA JURANEK
> RAYTHEON SPACE SYSTEMS PROGRAM MANAGER

The engineers encouraged the young women to own their chair as future leaders in science, technology, engineering and math — the subjects known as STEM.

"You need to play to your strengths. As you go through high school and college and then get into the workplace you're going to have an opportunity to find what your strengths are," advised Angela Juranek, a Raytheon Space Systems program manager. "My strengths are motivating and inspiring teams to get the job done, and that's how I ended up becoming a program manager."

After six weeks of design and testing, the robots hit the competition floor. Teams competed in 2.5 minute rounds, where their robots picked up and moved "power cubes" to earn points.

As the young women rotated from table to table, the conversations covered a wide variety of subjects, from choosing a college to tips on navigating a career. Many of the attendees were interested in hearing the engineers tell their own career stories.

"'Higher education will open doors of opportunity,'" said April Sanders, a Raytheon systems engineer, when asked about her story. "These are words that I heard repeatedly as a child of a single mother and high school dropout."

In an ongoing effort to narrow the gender gap and increase diversity in the workplace, Raytheon sponsors FIRST Robotics teams from across the country. Employee volunteers spend thousands of hours coaching robotics team members and providing mentorship to students looking to make their mark in science, technology, engineering and math.

After the speed-mentoring event, the next generation of robot-makers charged back to the arena floor, ready to take on the challenges at the competition — and beyond. Juranek and her fellow engineers hope that the advice they offered will inspire the young women to join their ranks in STEM careers.

"I support STEM programs with the hope that I will be able to help young women see the potential in themselves," said Juranek. "The new generation of women engineers approach problems differently than my generation did — I want them to be part of my future teams, sit at the table with other engineers and design incredible things."

STEM advocate Angela Juranek shares college and career advice with future women engineers at the speed-mentoring event.

THE INVENTION ENGINE

RAYTHEON RECEIVES THE 10 MILLIONTH U.S. PATENT IN HISTORY

LEFT TO RIGHT: *USPTO Director Andrei Iancu; Commerce Secretary Wilbur Ross; President Donald Trump; Principal Engineering Fellow at Raytheon, Joe Marron; Raytheon Chairman and CEO Dr. Tom Kennedy*

OFFICIAL WHITE HOUSE PHOTO BY SHEALAH CRAIGHEAD

Joe Marron knew he had a good idea. But he had no idea it would make history.

Marron, an optical engineer at Raytheon, found a new way to get real-time readings from large laser radars, which use reflected light to measure speed and distance. Through Raytheon, he applied for a patent, and three years later, he got one. Not only did it confirm that his idea was novel, it made him the inventor behind the 10 millionth patent in the history of the United States.

"It's equivalent to a guy who buys a lottery ticket every month," Marron said of his noteworthy new patent number. "Eventually, it hits."

The odds of securing such a significant patent number are long, but they improve when you consider Marron's achievements and Raytheon's long history of innovation. Marron has turned his ideas into more than 20 patents over the years, starting with a 1991 concept to improve upon bifocal lenses. And Raytheon holds more than 13,000 active patents — 4,500 in the U.S. alone — with more than 4,300 applications pending.

Those numbers tell a story, Raytheon Chairman and CEO Thomas A. Kennedy said.

"Raytheon engineers and researchers like Joe have been pushing the bounds of what's possible for generations. It's what we do. We innovate, we solve hard problems, and we create solutions that explore new frontiers to shape an exciting future," said Kennedy, an electrical engineer with a Ph.D. and holder of four U.S. patents.

THE INNOVATION NEVER STOPS

Raytheon's history of innovation stretches back to its founding in 1922. Its first successful invention was engineer Charles G. Smith's design for a tube that made it practical to run home radio sets from a wall socket rather than big, messy batteries.

Marron's patent story starts just a few years ago, when he was working on the electronics design for an advanced laser sensor.

One problem with large laser sensors is that light fluctuates very quickly, creating an enormous amount of data to process. That means large laser radar arrays rely on a series of converters and processors just to create a coherent picture of what they're seeing. They can do it, it just takes time.

To get that information faster and with high fidelity, Marron called upon his knowledge of two familiar technologies: digital cameras and FM radio.

By redesigning a laser radar like a digital camera, he could spread that data out across many pixels, each with its own processing electronics. Then, using an approach called quadrature detection, which underlies many forms of wireless communications, those pixels would report only the bits of data the sensor would need to draw a picture; in essence, it's a form of data compression.

"We can take terabytes of information and translate it down into something that can be digested by a computer," he said.

The potential applications are many, he said, including autonomous cars; a laser radar that can identify objects with speed and clarity could help a car's artificial intelligence make better decisions.

And that would be another entry in Raytheon's near-century-long record; along with Smith's revolutionary S-tube, the company's famous breakthroughs include Percy Spencer's 1943 patent application for mass-producing magnetron tubes, which helped meet a critical supply need for radars in World War II. The following year, Spencer struck again, this time with a way to use the magnetron to cook food, resulting in the first commercial microwave ovens.

Raytheon's more recent patents cover many areas of emerging technology, such as a way to detect malicious code in a computer system and a sensor that can detect a single, low-energy light particle, which could pave the way for quantum communication.

For Marron, having his idea alongside those historic breakthroughs — not to mention the cool patent number — is "a real career highlight."

"As an inventor," he said, "to be able to say I have Patent 10,000,000, that's pretty good for the resume."

PATENTS ISSUED TO RAYTHEON

At Raytheon, we encourage people to work on technological challenges to make the world a safer place and develop innovative commercial products. Part of that process is identifying and protecting our intellectual property (IP). Once again, the U.S. Patent Office has recognized our engineers and technologists for their contributions in their fields of interest. We congratulate our inventors who were awarded patents from January 2016 through June 2018.

TEN MILLIONTH U.S. PATENT

JOSEPH MARRON
Coherent LADAR using intra-pixel quadrature detection
10000000 United States of America

RALPH KORENSTEIN, CHRISTOPHER S. NORDAHL, HUY Q. NGUYEN, RANDAL W. TUSTISON, RICHARD GENTILMAN, JOSEPH M. WAHL
Long wave infrared transparent window and coating materials
10000642 United States of America

DAVID N. SITTER JR
Optical configurations for optical field mappings for back-scanned and line-scanned imagers
10001636 United States of America

ANDREW WILBY
Laser synthetic aperture sonar for buried object detection
10006997 United States of America

JEFFREY A. SHUBROOKS, TRAVIS MAYBERRY
Ultrasonic consolidation with integrated printed electronics
10010020 United States of America

MONTY D. MCDOUGAL
Systems and methods for malware nullification
10021128 United States of America

ADAM M. KENNEDY, THOMAS ALLAN KOCIAN, BUU DIEP, STEPHEN H. BLACK, ROLAND GOOCH
Wafer level packaged infrared (IR) focal plane array (FPA) with evanescent wave coupling
9227839 United States of America

ERIC J. GRIFFIN, WALLACE H. SUNADA, MICHAEL L. BREST
Vacuum stable mechanism drive arm
9228645 United States of America
243007 Israel
6227770 Japan

KENT P. PFLIBSEN, BRIAN KEITH MCCOMAS
Imaging system with multiple focal plane array sensors
9228895 United States of America
2856093 France
602013012145.1 Germany
2856093 United Kingdom

GEORGE D. HAMMACK
Adaptive dynamic cluster deinterleaving
9229095 United States of America

JAMES FLORENCE, JOHN R. STALEY
Systems and methods for protection of eyepiece displays
9229216 United States of America

JOHN D. BLOOMER, IAN S. ROBINSON, BRADLEY A. FLANDERS
Method and apparatus for image processing
9230333 United States of America
220760 Israel

VALERI I. KARLOV, PATRICK BARRY, ADAM C. DURST
Video-assisted target location
9230335 United States of America
2901236 France
2901236 Germany
2901236 United Kingdom

THOMAS E. KAZIOR, EDUARDO M. CHUMBES, SHAHED REZA, GERHARD SOLLNER
Double heterojunction group III-nitride structures
9231064 United States of America
I577012 Taiwan

CLIFFORD S. BURNES, RYAN D. DEWITT
Isothermal terminator and method for determining shape of isothermal terminator
9231287 United States of America

BENJAMIN L. CANNON, JARED JORDAN
Multi-bandpass, dual-polarization radome with compressed grid
9231299 United States of America
2912721 France
602013030914.0 Germany
2912721 Turkey
2912721 United Kingdom

HOANG K. DO, CHRISTOPHER A. LEDDY, STEPHEN R. NASH
Integrating image frames
9232119 United States of America
244955 Israel

DONALD DENIS
Multispectral camera using zero-mode channel
9232130 United States of America

JONATHAN T. LONGLEY, JOEL N. HARRIS, WEN-TE WU, JEREMY C. HERMANN, JAMES H. ROONEY III, HOWARD R. KORNSTEIN
Hull robot drive system
9233724 United States of America

JAMES W. RAKEMAN
Optically augmented weapon locating system and methods of use
9234963 United States of America

ARTURO CAIGOY
Optical air slit and method for manufacturing optical air slits
9235115 United States of America
221840 Israel

STEVEN M. STOLTZ
Creation of a maximally entangled quantum state
9235811 United States of America

JUSTIN KASEMODEL
Broadband array antenna enhancement with spatially engineered dielectrics
9236652 United States of America
227052 Israel

ROBERT D. JOHNSON, NATHAN L. EVANS, REED W. NYGHT
Electromagnetic attenuating object and method of electromagnetic attenuation
9236660 United States of America

DAVID M. FILGAS, NATHAN P. DAVIS, JUAN C. SOTELO, ROBERT D. STULTZ, MATTHEW J. KLOTZ, VICTOR LEYVA
Laser system and method for producing a linearly polarized single frequency output using polarized and non-polarized pump diodes
9236703 United States of America
221536 Israel

SAIKAT GUHA
Holevo capacity achieving joint detection receiver
9236883 United States of America

DANIEL ELLARD, DAVID MANKINS, CHRISTINE JONES, VICTORIA MANFREDI, ALDEN JACKSON, WILLIAM STRAYER, JOSH KARLIN
Destination address control to limit unauthorized communications
9237027 United States of America

DAVID E. MUSSMANN, MARK J. BEALS
Method and apparatus to provide simultaneous sensing and transmission for dynamic spectrum access
9237043 United States of America

MICHAEL DEAN
Method and apparatus for dynamic mapping
9237059 United States of America

GHASSAN C. MAALOULI, BRETT J. YOUNG
Extracting spectral features from a signal in a multiplicative and additive noise environment
9239372 United States of America
2895877 France
2895877 Germany
2895877 United Kingdom

MICHAEL Y. JIN
Wide beam SAR focusing method using navigation solution derived from autofocus data
9239383 United States of America
6072240 Japan

WILLIAM SHANE POWELL, THOMAS L. CHEN
System, method, and software for cyber threat analysis
9241008 United States of America

DELMAR L. BARKER, WILLIAM RICHARD OWENS
Infrared scene projector
9241115 United States of America

STEPHEN P. SHAFFER
Use of sulfur hexafluoride gas to prevent laser induced air breakdown
9242311 United States of America

PRESTON POWELL, CHARLES L. HORVATH
Weapon posturing system and methods of use
9243869 United States of America
2742309 France
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2742309 United Kingdom

BRIAN S. BOTTHOF, HENRI Y. KIM, GARRETT L. HALL, KIM L. CHRISTIANSON
Low-collateral damage directed fragmentation munition
9243876 United States of America
3172525 France
3172525 Germany
3172525 Norway
3172525 Poland
3172525 United Kingdom

DAVID G. GARRETT, LEONARD D. VANCE, CHRIS E. GESWENDER
Correction of navigation position estimate based on the geometry of passively measured and estimated bearings to near earth objects (NEOs)
9243914 United States of America

MICHAEL S. BIELAS
Adaptive electronically steerable arry (AESA) system for multi-band and multi-aperture operation and method for maintaining data links with one or more stations in different frequency bands
9244155 United States of America

CHRISTOPHER J. BEARDSLEY, LUAN B. DO
Video contrast enhancement with sub-segments
9245331 United States of America

STEVEN R. WILKINSON, TODD O. CLATTERBUCK, GABRIEL PRICE, JEFFREY L. SABALA, MATTHEW T. CASHEN
Precision photonic oscillator and method for generating an ultra-stable frequency reference using a two-photon rubidium transition
9246302 United States of America
6081076 Japan

DAVID A. ROCKWELL, VLADIMIR V. SHKUNOV
Method and apparatus for temporally concentrating pump power to support generation of high peak-power pulse bursts or other time-varying laser output waveforms
9246303 United States of America
6345348 Japan

SHANE D. BLAIR, MICHAEL R. PATRIZI, RONALD LAPAT
Electronically reconfigurable bandwidth and channel number analog-to-digital converter circuit for radar systems
9250313 United States of America

YUEH-CHI CHANG, JIAN WANG, TONY M. PONSFORD, ELI BROOKNER, BRADLEY FOURNIER, PETER R. DRAKE
Methods and apparatus for 3D radar data from 2D primary surveillance radar and passive adjunct radar
9250317 United States of America

ANDREW L. URQUHART
System and method for indexing of geospatial data using three-dimensional cartesian space
9251191 United States of America

MATTHEW T. CASHEN, STEVEN R. WILKINSON, TODD O. CLATTERBUCK
Distribution system for optical reference
9252795 United States of America
2652564 France
2652564 Germany
2652564 United Kingdom

MATTHEW NEUMANN, MICHAEL W. SMITH
Distributed network encryption key generation
9253171 United States of America

SCOTT H. ALLEN, TIMOTHY I. MANN, JONATHAN T. LONGLEY, HOWARD R. KORNSTEIN, JOEL N. HARRIS, JAMES H. ROONEY III
Hull robot with rotatable turret
9254898 United States of America

ROBERT MARTZ, DAVID MATTHEWS
Synthetic processing diversity within a homogeneous processing environment
9256431 United States of America

RICHARD W. ELY
Method for detecting and recognizing boats
9256619 United States of America

JOHN G. WATTS, RICHARD J. KENEFIC
Method and system for identifying clusters within a collection of data entities
9256681 United States of America

SARAH ANNE LAFARELLE, A HENRY MUSE
Calculation of numeric output error values for velocity aberration correction of an image
9256787 United States of America

JOE A. ORTIZ
Shield for toroidal core electromagnetic device, and toroidal core electromagnetic devices utilizing such shields
9257224 United States of America

JOSEPH A. TURNER
System for scan organizing, managing and running enterprisewide scans by selectively enabling and disabling scan objects created by agents
9258387 United States of America

JOSEPH M. GWINN IV, JACK J. SCHUSS
Methods and apparatus for highly reliable signal distribution
9261587 United States of America

DANIEL T. DONOHOO, VANESSA BATTAGLIA, CHRISTOPHER B. GROUNDS
Heat map carousel for displaying health and status information for an electro-mechanical system
9262055 United States of America

JOSEPH M. ANDERSON, HERBERT A. LEACH, CHARLES G. GILBERT
Scanned antenna having small volume and high gain
9263791 United States of America

PATRICK CICERO
Directive, instantaneous wide bandwidth antenna
9263792 United States of America

BORIS S. JACOBSON, DONALD H. DESROSIERS
Wide input DC/DC resonant converter to control reactive power
9263961 United States of America

GREGARY B. PRINCE
Low complexity non-integer adaptive sample rate conversion
9264065 United States of America

WILLIAM B. NOBLE, HARRY B. MARR, DANIEL THOMPSON, STEVEN G. DANIELSON, LARISA ANGELIQUE NATALYA STEPHAN, JULIA L. KARL, PAUL YUE
Runtime creation, assignment, deployment and updating of arbitrary radio waveform techniques for a radio waveform generation device
9268551 United States of America
3014495 Denmark
3014495 France
3014495 Germany
242950 Israel
3014495 United Kingdom

JODY D. VERRET, GRANT B. BOROUGHS, RICHARD W. ELY
System and method for automatically registering an image to a three-dimensional point set
9269145 United States of America

ANTHONY SOMMESE, IAN S. ROBINSON, BRADLEY A. FLANDERS
Rapid anomaly detection (RAND)
9269162 United States of America

FRANCIS J. MORRIS
Integrated capacitively-coupled bias circuit for RF mems switches
9269497 United States of America
I579874 Taiwan

VALERY S. KAPER, ANTHONY KOPA
Differential-to-single-ended transmission line interface
9270002 United States of America

WILLIAM J. MINISCALCO
Free-space optical mesh network
9270372 United States of America
2014299312 Australia
6141459 Japan
2015/05372 South Africa

ROBERT J. COLE, HEIDI KRUESI, RICHARD WRIGHT, MAC A. CODY
Method for determining future position boundary for a moving object from location estimates
9273965 United States of America

HARRY B. MARR, JEFFERY JAY LOGAN, DANIEL THOMPSON
Creation of radio waveforms according to a probability distribution using weighted parameters
9274542 United States of America

WAYNE P. O'BRIEN
System and method for developing an object-oriented system
9274762 United States of America

JODY D. VERRET
System and method for automatic registration of 3D data with electro-optical imagery via photogrammetric bundle adjustment
9275267 United States of America

PREMSAGAR GAZULA, ARTHUR R. CULBERTSON
System and method for probabilistic name matching
9275339 United States of America

LARISA ANGELIQUE NATALYA STEPHAN, THOMAS F. BRUKIEWA, WILLIAM B. NOBLE
Memory based electronically scanned array antenna control
9276315 United States of America
2803112 Finland
2803112 France
602012041648.3 Germany
2803112 United Kingdom

ANDREW D. PORTNOY
System, method, and software for image processing
9277141 United States Of America

MATTHEW T. KUIKEN, STEPHEN H. BLACK
Infrared thermal imaging system and method
9277142 United States of America
235861 Israel

RANDAL E. KNAR, TIFFANIE RANDALL, LUKE M. FLAHERTY
Gum rosin protective coating and methods of use
9277638 United States of America

BRADLEY A. FLANDERS, IAN S. ROBINSON, JOHN D. BLOOMER
Imaging spectrometer with extended resolution
9279724 United States of America
247532 Israel

ROBERT D. STULTZ, BRIAN F. BOLAND
Methods and apparatus for idler extraction in high power optical parametric amplifiers
9280031 United States of America

CODY B. MOODY, ANDREW MALCZEWSKI, FRANCIS J. MORRIS
Switchable capacitor
9281128 United States of America
ZL201280074863.2 China
6042984 Japan
10-1669033 South Korea / Republic of Korea

JULIA L. KARL, KENNETH E. PRAGER, LLOYD J. LEWINS, HARRY B. MARR
Minimizing power consumption in asynchronous dataflow architectures
9281820 United States of America

MARCO K. KWAN, ROBERT D. SCHAEFER, LOWELL A. BELLIS, MICHAEL JOSEPH ELLIS, BRIAN R. SCHAEFER
Non-rotating flexure bearings for cryocoolers and other devices
9285073 United States of America
6251807 Japan

MICHAEL L. BREST
Variable aperture mechanism for creating different aperture sizes in cameras and other imaging devices
9285653 United States of America

SCOTT RITTER, MATTHEW DAILY, JASON HOLMES, MICHAEL NICOLETTI, JACOB BEAL, CHRISTOPHER PARK
Smart garment and method for detection of body kinematics and physical state
9285788 United States of America

THOMAS OHKI, ANDREW KENT
Magnetic memory system and methods in various modes of operation
9286962 United States of America

CODY B. MOODY
Hermetically sealed wafer packages
9287237 United States of America
I545665 Taiwan

DAVID C. COOK, DAVID A. FAULKNER, DYLAN MARTIN, JOHN OKERSON CRAWFORD, PATRICK L. MCCARTHY, NICHOLAS D. TRAIL
Multi-mode signal source
9287615 United States of America

MARK E. STADING, RICHARD D. YOUNG, DENPOL KULTRAN, MARK T. RICHARDSON, JEFFREY SAUNDERS, GEORGE W. GERACE
High speed, high efficiency, high power RF pulse modulating integrated switch
9287870 United States of America

RONALD L. RONCONE
Multimode shared aperture seeker
9291429 United States of America
2989410 France
602014022050.9 Germany
2989410 United Kingdom

ERIK F. ITEM
Catamaran surface vessel with removable mission-specific payload module
9291438 United States of America

JOHN D. BLOOMER, IAN S. ROBINSON
Configurable combination spectrometer and polarizer
9291500 United States of America
3100012 France
602015009082.9 Germany
3100012 United Kingdom

ERIC M. MOSKUN, IAN S. ROBINSON, LACY G. COOK
High efficiency multi-channel spectrometer
9291501 United States of America
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JASON G. MILNE
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ANDREW D. MCKIE, LINDA A. PALMACCIO, DANIEL P. RESLER
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MARK S. LANGELIER, JOHN C. COCHRAN, JASON D. ADAMS, BORIS S. JACOBSON
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3245470 France
3245470 Germany
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MARY O'NEILL, L SWEENY
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EMMANUEL FIERRO, ROBERT K. BRATTON, KELVIN L. KEELS, LYALE F. MARR
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2012340002 Australia
2850529 Canada
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2012347737 Australia
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MU-CHENG WANG, STEVE DAVIDSON, YI-CHAO SIMON CHUANG
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2013235426 Australia

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2013246525 Australia
2871181 Canada
2837060 France
602013013446.4 Germany
502017000006137 Italy
2837060 United Kingdom

JOHN H. VANPATTEN, ANTHONY T. MCDOWELL, WILLIAM H. DAVIS, LEE A. MCMILLAN
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2013263206 Australia
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JOHN H. VANPATTEN, WILLIAM H. DAVIS
Method and system to analyze interference susceptibility of a radio receiver design
2013263207 Australia
2873728 Canada
702006 New Zealand

TERRY ANTHONY DORSCHNER, IRL W. SMITH
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2013266151 Australia

LEE M. SAVAGE, DAVID WILSON, JEFFREY J. BECKER, JAMES E. HENRY
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2013272236 Australia
2859376 Denmark
2859376 France
602013021239.2 Germany
2859376 United Kingdom

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2013287229 Australia

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JOHN CARCONE, DOMENIC F. NAPOLITANO
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2013312453 Australia
2892800 France
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2892800 United Kingdom

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2013348304 Australia
2884886 Canada
705926 New Zealand
2523017 United Kingdom

MACIEJ D. MAKOWSKI, STEPHEN D. NORDEL, GARY D. COLEMAN, WILLIAM J. MINISCALCO
Laser relay for free space optical communications
2014250066 Australia
6204567 Japan

IRL W. SMITH, TERRY ANTHONY DORSCHNER
High power optical switch
2015246091 Australia
2874615 Canada
2856253 France
2993517 France
602013010633.9 Germany
702303 New Zealand
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201810639 Australia
201812198 Australia
004697464 European Union
143826 Switzerland

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004709012-0001 European Union
1605948 Japan
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KEVIN BURGESS WAGNER, RYAN NOBES, BRIEN ROSS
Reticle of aiming or targeting device
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BRIEN ROSS, KEVIN BURGESS WAGNER, RYAN NOBES
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201812200 Australia

RYAN NOBES, KEVIN BURGESS WAGNER, BRIEN ROSS
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2387826 Belgium
2387826 France
602010045180.1 Germany
6034565 Japan
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2387847 Belgium
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2453141 Belgium
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602013025398.6 Germany
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2669682 Canada

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LARRY L. STERN, STEVEN T. CUMMINGS, GEORGE A. BLAHA
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DAVID E. BOSSERT, RAY SAMPSON, JEFFREY N. ZERBE
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2777851 Canada
112010004675 Germany
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JEROME H. POZGAY
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2793316 Canada
2556562 France
602011023822.1 Germany
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2798623 Canada
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Methods of etching carbon nanotube sheet material for electrical circuit and thin film thermal structure applications
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STEPHEN H. BLACK, ADAM M. KENNEDY, THOMAS ALLAN KOCIAN, ROLAND GOOCH, BUU DIEP
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2924123 Canada
ZL201480055529.1 China

FRANCIS J. MORRIS, CODY B. MOODY, BRANDON W. PILLANS
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ZL 201280071504.1 China
6017677 Japan
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ROBERT W. BYREN, DUANE SMITH
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ZL 201380070346.2 China
2946230 France
602013014573.3 Germany
10-1641614 South Korea / Republic of Korea
2946230 United Kingdom

MARK A. LOMBARDO, DAVID KOCH, BENJAMIN DOLGIN, JOHN HILL III, MICHAEL BRENNAN, JORAM SHENHAR, LUIS GIRALDO
Drilling apparatus, method, and system (drilling apparatus, method and system, hill)
ZL201210165490.1 China

JEFFREY R. LAROCHE, THOMAS E. KAZIOR, RAM CHELAKARA
Gold-free ohmic contacts
ZL201280020021.9 China
6057990 Japan

THOMAS E. KAZIOR, JEFFREY R. LAROCHE, WILLIAM E. HOKE
Method and structure having monolithic heterogeneous integration of compound semiconductors with elemental semiconductor
ZL201280047838.5 China

MICHAEL G. ADLERSTEIN, JEFFREY SAUNDERS
Distributed power conditioning with DC-DC converters implemented in heterogeneous integrated circuit
ZL201280049415.7 China
10-1647568 South Korea / Republic of Korea

LACY G. COOK
Full-field geo imager optics with extended spectral coverage
ZL201280070806.7 China
2615209 Russian Federation

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High-bandwidth optical communications relay payload
ZL201380047919.X China
6046814 Japan

YUCHOI F. LOK, PETER R. DRAKE
Methods and apparatus for integration of distributed sensors and airport surveillance radar to mitigate blind spots
2419755 Czech Republic
2419755 France
602010042546.0 Germany
502017000088960 Italy
2419755 Netherlands
2419755 Romania
2419755 Spain
2419755 United Kingdom

JAMES KENDALL VILLARREAL, RICHARD D. LOEHR
Electrically operated propellants
2935848 Czech Republic
2935848 Denmark
2935848 France
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2935848 Italy
2935848 Norway
2935848 Poland
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ALBERTO F. VISCARRA, CINDY W. MA, DEREK PRUDEN, KEVIN C. ROLSTON
Adhesive reinforced open hole interconnect
2381750 Denmark
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602011039251.4 Germany
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WILLIAM P. HAROKOPUS
Patch antenna
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JAR J. LEE, STAN W. LIVINGSTON, DENNIS T. NAGATA
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2304846 Finland
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2304846 Norway
2304846 Sweden
2304846 Switzerland
201717587 Turkey
2304846 United Kingdom

JEFFREY PAQUETTE, SCOTT R. CHEYNE, DIMITRY ZARKH, JOHN D. WALKER
Busbar connector
2412065 Finland
602010030868.5 Germany
6009428 Japan
6046224 Japan
2412065 Poland
2412065 Turkey
2412065 United Kingdom

MATTHEW S. NOELL
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2439549 Finland
2439549 France
2439549 Germany
2439549 Italy
5868064 Japan
I544222 Taiwan
2439549 United Kingdom

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2544302 Finland
2544302 France
602012036843.8 Germany
2544302 Sweden
2544302 United Kingdom

FRANCIS J. MORRIS, CODY B. MOODY, BRANDON W. PILLANS
CNRF micro-electro-mechanical system (MEMS) capacitive switch
2845216 Finland

BUU DIEP, ROLAND GOOCH
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1159992 France
216011 Israel

THOMAS ALLAN KOCIAN, ROLAND GOOCH, BUU DIEP
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1159998 France
215681 Israel
6157799 Japan
I541909 Taiwan

STEPHEN H. BLACK, THOMAS ALLAN KOCIAN
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1160677 France
216514 Israel

THOMAS ALLAN KOCIAN, STEPHEN H. BLACK, BUU DIEP
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1160718 France
I526710 Taiwan

GARY A. FRAZIER, JAMES R. TOPLICAR, PAUL E. DOUCETTE, KRISHNA AGARWAL, G. VAN ANDREWS
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1195017 France
60049563.9 Germany
1195017 United Kingdom

DAVID D. CROUCH, WILLIAM E. DOLASH
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1463965 France
60351057.4 Germany
1463965 United Kingdom

KEVIN W. CHEN, RICHARD M. WEBER
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1525617 France
60351167.8 Germany
1525617 United Kingdom

PETER S. LYMAN, WILLIAM E. HOKE
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1568082 France
1568082 Germany
1568082 Italy
1568082 United Kingdom

THOMAS DRAKE, THOMAS L. OBERT, KENNETH W. BROWN
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1579465 France
60348962.1 Germany
1579465 United Kingdom

WILLIAM H. WELLMAN, CHARLES STALLARD
Window mounting for optical sensor
1616357 France
602004048457.1 Germany
1616357 United Kingdom

ALEXANDER A. BETIN, OLEG EFIMOV
Outcoupler with bragg grating and system and method using same
1624545 France
602005053177.7 Germany
1624545 United Kingdom

ALEXANDER A. BETIN, KALIN SPARIOSU
Self-coherent combining technique for high power laser implementation and method
1648056 France
602005054033.4 Germany
1648056 United Kingdom

JOE A. ORTIZ, FRANK H. WANG, JOSEPH MIYAMOTO
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1687888 France
1687888 Germany
1687888 United Kingdom

GARY A. FRAZIER
Method and apparatus for detecting radiation at one wavelength using a detector for a different wavelength
1690070 France
1690070 Germany
1690070 United Kingdom

WILLIAM F. DIXON, TROY FUCHSER
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1690107 France
602004051132.3 Germany
1690107 United Kingdom

FREDERICK DINAPOLI
Method and system for swimmer denial
1738352 France
341058 Norway
1738352 United Kingdom

KIUCHUL HWANG
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1749313 France
1749313 Germany
1749313 United Kingdom

ROBERT C. EARL, ROBERT M. OLSON, JOHN R. GUARINO
Corrosion resistant connection system
1750995 France
602005049794.3 Germany
502016000097599 Italy
1750995 United Kingdom

VINH ADAMS, WESLEY DWELLY
Short pulse/stepped frequency radar system
1754080 France
602005051582.8 Germany
1754080 United Kingdom

MICHAEL J. RAMIREZ, KENNETH PRICE, MICHAEL H. KIEFFER, JULIAN A. SHRAGO, MICHAEL C. BARR, ROBERT C. HON
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1762795 France
1762795 Germany
1762795 United Kingdom

LE T. PHAM
Method and apparatus providing single bump, multi-color pixel architecture
1817802 France
1817802 Germany
1817802 United Kingdom

MICHAEL G. ADLERSTEIN, KIUCHUL HWANG
Monolithic integrated circuit having enhancement mode/depletion mode filed effect transistors and field effect transistors
1846951 France
1846951 Germany
1846951 United Kingdom

RICHARD DRYER, NEAL M. CONRARDY
Methods and apparatus for selectable velocity projectile system
1851501 France
602006050586.8 Germany
1851501 Spain
2017/00445 Turkey
1851501 United Kingdom

ARTHUR SCHNEIDER
Guided kinetic penetrator
1866599 France
60206055398.6 Germany
1866599 Poland
1866599 United Kingdom

JAMES F. ASBROCK, GEORGE W. DIETRICH, LLOYD LINDER
Sample and hold circuit for laser detection and ranging (LADAR) system
1872154 France
1872154 Germany
1872154 United Kingdom

MICHAEL A. LEAL, DANIEL CHASMAN, STEPHEN D. HAIGHT
Missile control system and method
1875153 France
602006049124.7 Germany
1875153 United Kingdom

S RAJENDRAN, JAMES MASON, JOHN BEDINGER
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1894241 France

BARBARA E. PAUPLIS
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1902537 France
602006051683.5 Germany
1902537 Italy
1902537 United Kingdom

DAVID MANOOGIAN, GERALD M. PITSTICK, JOHN CANGEME
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1904870 France
1904870 Germany

KEVIN J. HIGGINS, MARK L. BOUCHARD, CHARLES D. LYMAN, MATTHEW B. CASTOR, AARON HEIDEL
Ejectable aerodynamic stability and control
1917495 France
1917495 Germany
1917495 United Kingdom

PAUL A. MEREMS, RANDY W. HILL
Methods and apparatus for airborne unpowered rotor delivery systems
1919774 France
602006055375.7 Germany
1919774 United Kingdom

WILLIAM G. WYATT, MORRIS E. FINNEBURGH
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1920204 France
1920204 Germany
1920204 Italy
1920204 Spain
1920204 Turkey
1920204 United Kingdom

BYRON B. TAYLOR, DAVID G. JENKINS
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1946034 France
602006054198.8 Germany
2017/18723 Turkey
1946034 United Kingdom

VLADIMIR V. SHKUNOV, ALEXANDER A. BETIN
Laser amplifier power extraction enhancement system and method
1949509 France
602006054485.5 Germany
1949509 United Kingdom

LACY G. COOK
Two-channel imaging spectrometer utilizing shared objective, collimating, and imaging optics
1988372 France
602008045177.1 Germany
1988372 United Kingdom

TODD L. BAKER, MICHAEL A. LEAL, KENT P. PFLIBSEN
Multiple kill vehicle (MKV) interceptor with autonomous kill vehicles
1989501 France
602007051793.1 Germany
1989501 United Kingdom

GERALD CHIANG, FRANK C. LAM
Onboard guidance method for ballistic missiles
1999528 France
602007052222.6 Germany
1999528 United Kingdom

RICHARD M. WEBER, WILLIAM G. WYATT
System and method for separating components of a fluid coolant for cooling a structure
2000753 France
2000753 Germany
2000753 United Kingdom

LEONARD P. CHEN, DAVID R. RHIGER
Multi-layer pixellated gamma-ray detector
2005215 France
2005215 Germany
2005215 Italy
2005215 United Kingdom

CHRISTOPHER ROTH, PHILIP C. THERIAULT, ANTHONY O. LEE
Adjustable optical mounting and method
2008140 France

MICHAEL USHINSKY, ROBERT W. BYREN, DAVID SUMIDA
Solid-state laser with spatially-taylored active ion concentration using valence conversion with surface masking and method
2011201 France
2011201 Germany
2011201 United Kingdom

LAWRENCE D. SOBEL
Mixed gas refrigerants
2018413 France
602007052274.9 Germany
2018413 United Kingdom

JON N. LEONARD, MICHAEL DAILY, RONALD AZUMA, HOWARD NEELY
Beacon-augmented pose estimation
2029970 France
602007044882.4 Germany
2029970 United Kingdom

RANDAL B. WALTERS, JOSEPH HENNING, BERNARD RADZA, JOHN K. MINCER, SUNNY ALI
Airborne look-down doppler radar tracking of hovering helicopters using rotor features
2033011 France
602007049789.2 Germany
2033011 United Kingdom

CHRIS E. GESWENDER
Methods and apparatus for missile air inlet
2038601 France
602007052614.0 Germany
2038601 United Kingdom

JAR J. LEE, CLIFTON QUAN, STAN W. LIVINGSTON
Airship mounted array
2047557 France
602007048323.9 Germany
2047557 United Kingdom

MICHAEL STIMPSON
Methods and apparatus for multiple part missile
2049865 France
602007045598.7 Germany
2049865 United Kingdom

ROBERT W. BYREN, CHAUNCHY F. MCKEARN, WILLIAM B. KING, CHUNGTE CHEN
Beam director and control system for a high energy laser within a conformal window
2054749 France
2054749 Germany
2054749 United Kingdom

WILLIAM HAWKINS, HENRI Y. KIM, E. RUSS ALTHOF
Warhead booster explosive lens
2057437 France
602007047659.3 Germany
2016/16632 Turkey
2057437 United Kingdom

ARTHUR SCHNEIDER, ANDREW J. HINSDALE
Inductive power transfer system and method
2069712 France
602007048925.3 Germany
2069712 United Kingdom

STAN W. LIVINGSTON, CLIFTON QUAN, JAR J. LEE
Dual band space-fed array
2070158 France
602007045362.3 Germany
2070158 United Kingdom

CLIFTON QUAN, MARK S. HAUHE
Antenna array
2074677 France
602007049448.6 Germany
2074677 United Kingdom

WILLIAM RICHARD OWENS, DELMAR L. BARKER, ABRAM YOUNG
Frequency modulation structure and method utilizing frozen shockwave
2082284 France
602007053420.8 Germany
2082284 United Kingdom

DANIEL CHASMAN, STEPHEN D. HAIGHT
Propulsion system with canted multinozzle grid
2084387 France
602007045365.8 Germany
2084387 Spain
2084387 United Kingdom

MICHAEL RAY, ALAN HOFFMAN, RICHARD BORNFREUND
Dual band imager with visible or swir detectors combined with uncooled LWIR detectors
2084501 France
602007047873.1 Germany
2084501 United Kingdom

WESLEY DWELLY, VINH ADAMS
Biometric radar system and method for identifying persons and positional states of persons
2100153 France
2100153 Germany
2100153 United Kingdom

DELMAR L. BARKER, WILLIAM RICHARD OWENS
Apparatus and method for controlling transmission through a photonic band gap crystal
2104879 France
602008052961.4 Germany
2104879 United Kingdom

CHUNGTE CHEN, JOHN S. ANDERSON
Common aperture optical system incorporating a light sensor and a light source
2115515 France
602007051076.7 Germany
2115515 United Kingdom

JOHN S. ANDERSON, CHUNGTE CHEN
System and method for capturing image data over a wide field of view with high resolution
2119221 France
2119221 Germany
2119221 United Kingdom

ANDREW B. FACCIANO, CHIN SHIAU
Scalable electronics architecture
2122296 France
602007047310.1 Germany
2122296 United Kingdom

ROSS D. ROSENWALD, WILLIAM RICHARD OWENS, DELMAR L. BARKER
Quantum computing device and method including qubit arrays of entangled states using negative refractive index lenses
2140408 France
60 2008 053 857.5 Germany
2140408 United Kingdom

MIRON CATOIU
RF re-entrant combiner
2140547 France
2140547 Germany
502017000001154 Italy
2140547 United Kingdom

WILLIAM C. STRAUSS
Connector for an electrical circuit embedded in a composite structure
2147482 France
2147482 Germany
2147482 United Kingdom

KENNETH W. BROWN
Dual use RF directed energy weapon and imager
2149057 France
602008046826.7 Germany
2149057 Turkey
2149057 United Kingdom

MICHAEL G. ADLERSTEIN, FRANCOIS Y. COLOMB
Microwave integrated circuit package and method for forming such package
2156467 France
2156467 Germany
2156467 Italy
6227609 Japan
2156467 United Kingdom

RICHARD D. LOEHR
Hydroxyl amine based staged combustion hybrid rocket motor
2158395 France
2158395 Germany
2158395 Poland
2158395 United Kingdom

DAVID G. JENKINS
Concentrating photovoltaic kaleidoscope and method

2158616	France
602008050783.1	Germany
502017000097070	Italy
2158616	Turkey
2158616	United Kingdom

MATTHEW JONAS
Method and system for adjusting a position of an object (nutating mass deroll)

2165111	France
6020080494977	Germany
2165111	United Kingdom

ROBERT C. HON, CYNDI H. KESLER, LOWELL A. BELLIS
Stirling cycle cryogenic cooler with dual coil single magnetic circuit motor

2165125	France
2165125	Germany
2165125	United Kingdom

KENNETH W. BROWN, FREDERICK A. AHRENS
High power phased array antenna system and method with low power switching

2165387	France
2165387	Germany
2165387	Poland
2165387	United Kingdom

LOWELL A. BELLIS, ROBERT C. HON
Cryocooler split flexure suspension system and method

2167807	France
2167807	Germany
2167807	United Kingdom

ROBERT C. HON, MICHAEL C. BARR, CYNDI H. KESLER, LOWELL A. BELLIS, CARL KIRKCONNELL
Cryocooler with moving piston and moving cylinder

2167886	France
2167886	Germany
2167886	United Kingdom

ROBERT S. ISOM, JAMES M. IRION II
Dual polarized low profile antenna

2201646	France
602008041916.9	Germany
2201646	United Kingdom

KENNETH PRICE, CARL KIRKCONNELL, ANTHONY FINCH, GERALD PRUITT, SIDNEY YUAN
Inertance tube and surge volume for pulse tube refrigerator

2203695	France
2203695	Germany
2203695	United Kingdom

JAMES F. KVIATKOFSKY, TIMOTHY E. ADAMS, CHRISTOPHER MOSHENROSE, WILLIAM G. WYATT, JAMES A. PRUETT
Topping cycle for a sub-ambient cooling cycle

2203696	France
2203696	Germany
2203696	United Kingdom

JOHN C. TREMBLAY, MATTHEW C. TYHACH, COLIN S. WHELAN, RAGHUVEER MALLAVARPU
Impedance matching circuit

2203974	France
2203974	Germany
2203974	Italy
2203974	Poland
2203974	Sweden
2203974	United Kingdom

PATRICK D. KRANKING, LLOYD KINSEY JR
Methods and apparatus for transforming unmanned aerial vehicles

2212198	France
602008048602.8	Germany
2212198	United Kingdom

KENNETH W. BROWN, VINCENT GIANCOLA
Systems and methods for waveguides

2215522	France
602008053542.8	Germany
2215522	United Kingdom

ERIK A. FJERSTAD
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2222551	France
602008041946.0	Germany
2222551	Spain
2222551	United Kingdom

SAMUEL D. SIRIMARCO, GERALD E. VAN ZEE
Torsional spring aided control actuator for a rolling missile

2223035	France
602008053900.8	Germany
2223035	United Kingdom

WILLIAM E. DOLASH, DAVID D. CROUCH
Methods and apparatus for multilayer millimeter-wave window

2232626	France
602009044443.3	Germany
2232626	Spain
2232626	United Kingdom

TERRY M. SANDERSON, JAMIE CLARK
Methods and apparatus for adjustable surfaces

2234876	France
2234876	Germany
2234876	United Kingdom

GARY A. FRAZIER, CATHERINE TRENT
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2245507	France
2245507	Germany
2245507	United Kingdom

WILLIAM B. KING, CHUNGTE CHEN, LACY G. COOK, ROBERT W. BYREN
Low order adaptive optics by translating secondary mirror of off-aperture telescope

2257847	France
2257847	Germany
207082	Israel
2257847	United Kingdom

ROBERT T. COCK, RALPH T. TADAKI
Antenna system having feed subarray offset beam scanning

2260539	France
602009052217.5	Germany
2260539	Poland
2260539	United Kingdom

GIB LEWIS
Overlapping subarray architecture

2264834	France
602006050167.6	Germany
2264834	United Kingdom

STEVEN R. WILKINSON, JOSHUA THORNES, ROBIN A. REEDER
Lcd based polarization, phase and amplitude spatial light modulator

2264839	France
602010045683.8	Germany
2264839	United Kingdom

KENNETH M. WEBB
Method and apparatus for phased array antenna field recalibration

2273614	France

NATHAN M. MINTZ, KALIN SPARIOSU
Quantum dot based radiation source and radiometric calibrator using the same

2280255	France
602010045324.3	Germany
2280255	United Kingdom

NICHOLAS E. KOSINSKI, GARY L. FOX, SHAWN B. HARLINE
Methods and apparatus for isolation system

2286138	France
602009035838.3	Germany
2286138	United Kingdom

JOHN HOOS, LACY G. COOK, DOMINIC R. GOODEN, ANDREW J. AVRICK, RONALD LOVERIDGE
Multi-axis articulated solar stray light shade for space based secsors

2287075	France
602010037087.9	Germany
2287075	United Kingdom

JON E. MAENPA, PATRICK M. SAIN, ANDREW M. HAUTZIK
System and method for correcting global navigation satellite system pseudorange measurements in receivers having controlled reception pattern antennas

2293103	France
602010037433.5	Germany
2293103	United Kingdom

KIM L. CHRISTIANSON, HENRI Y. KIM, TRAVIS P. WALTER
Low collateral damage forward firing warhead with fragment pattern control device

2297542	France
602009038745.6	Germany
2297542	United Kingdom

LLOYD KINSEY JR, ROBERT CAVALLERI
Integral thrust vector and roll control system

2297544	France
602009046752.2	Germany
2017/12089	Turkey
2297544	United Kingdom

DARRELL W. MILLER, BRIAN W. JOHANSEN, JAMES M. IRION II
Dual-polarized antenna array

2301107	France
602009040308.7	Germany
2301107	United Kingdom

KENNETH D. CAREY, GREGORY LEEDBERG, GEORGE W. SPENCER JR.
System and method for message filtering

2301209	France
2301209	Germany
502016000049946	Italy

JAMES S. WILSON, JAMES MASON
Dynamically correcting the calibration of a phased array antenna system in real time to compensate for changes of array temperature

2319123	France
602009035684.4	Germany
2319123	United Kingdom

RICHARD JANIK, DORON STRASSMAN
Multi-stage hyper-velocity kinetic energy missile

2329216	France
602009037597.2	Germany
2329216	United Kingdom

DAVID G. JENKINS, BYRON B. TAYLOR
Multimode seeker system with RF transparent stray light baffles

2347469	France
602009046551.1	Germany
2347469	United Kingdom

DAVID U. FLUCKIGER
Differential mode laser detection and ranging device

2350582	France
602009036850.8	Germany
2350582	Italy
2350582	United Kingdom

JEFFREY MAZUREK, ROBERT J. MCGURRIN, RICHARD CIOSEK, FRANCIS J. FOTHERGILL, RONALD FOWLER, MATTHEW DAILY, RICHARD MULLEN
Wearable shooter localization system

2350683	France

TRAVIS P. WALTER, JAMES H. DUPONT, HENRI Y. KIM
Dual-mass forward and side firing fragmentation warhead

2352963	France
602009041988.9	Germany
2352963	United Kingdom

ALAN G. SILVER, STEPHEN H. BLACK, ANDREW D. PORTNOY
Imaging system

2362641	France
602011036136.8	Germany
2362641	United Kingdom

IAN S. ROBINSON
Hyperspectral image dimension reduction system and method

2368215	France
2368215	Germany
2368215	United Kingdom

DAVID M. FILGAS
Glass core planar waveguide laser amplifier

2369384	France
2369384	Germany
210960	Israel
2369384	United Kingdom

LACY G. COOK
All-reflective wide-field-of-view telescope with beneficial distortion correction

2381286	France
602011047052.3	Germany
2381286	United Kingdom

VLADIMIR V. SHKUNOV, DAVID A. ROCKWELL
Monolithic signal coupler for high-aspect ratio solid-state gain media

2382498	France
2382498	Germany
213016	Israel
2382498	United Kingdom

WILLIAM K. WALLACE, PAUL H. GROBERT
GPS aided open loop coherent focusing

2387170	France
602011030064.4	Germany
211318	Israel
2387170	United Kingdom

MATTHEW J. KLOTZ, JEAN-PAUL BULOT
Method and apparatus for synthesizing and correcting phase distortions in ultra-wide bandwidth optical waveforms

2393224	France
2393224	Germany
2393224	United Kingdom

IAN S. ROBINSON
Optimized imaging system for collection of high resolution imagery

2394427	France
602010051239.8	Germany
2394427	United Kingdom

LACY G. COOK
All-reflective afocal four-mirror telescope

2396689	France
602010035967.0	Germany
2396689	United Kingdom

CHRISTOPHER MONTI
Optical element and stress athermalized hard contact mount

2399156	France
602010044442.2	Germany
502017000121444	Italy
2017/15927	Turkey
2399156	United Kingdom

ROLAND TORRES
+28V aircraft transient suppression

2401754	France
2401754	Germany
10-1771582	South Korea / Republic of Korea
2401754	United Kingdom

DAVID MANOOGIAN, HENRY J. NIZKO, JONATHAN H. WALZER, WALTER G. WOODINGTON, MARK E. RUSSELL, MAURICE J. TOOLIN
System and method for occupancy detection

2404194	France
602010040192.8	Germany
502017000047481	Italy
2404194	Poland
2404194	United Kingdom

WILLIAM H. WELLMAN, JOSEPH F. BORCHARD
Method and apparatus for multiple field-angle optical alignment testing

2407814	France
2407814	Germany
2407814	United Kingdom

LACY G. COOK
Real-time optical compensation of orbit-induced distortion effects in long integration time imagers

2411857	France
602010034453.3	Germany
215255	Israel
2411857	United Kingdom

KELVIN CHENG
Data diode system

2415198	France
2415198	Germany
2415198	United Kingdom

DAVID D. CROUCH
Wireless power transmission system and method

2417690	France
2417690	Germany
10716932.8	Spain
2017/01929	Turkey
2417690	United Kingdom

MIKEL J. WHITE
Broadband balun

2418726	France
2418726	Germany
212943	Israel
2418726	United Kingdom

PETER V. MESSINA, WILLIAM B. KING, RONALD G. HEGG, CHAUNCHY F. MCKEARN
System for automatic alignment, stabilization, and focus for an off-axis telescope using biased angle sensors

2423728	France
2423728	Germany
2423728	United Kingdom

LACY G. COOK
Dual field of view refractive optical system with external pupil and internal stabilization

2426540	France
602011023793.4	Germany
213913	Israel
2426540	United Kingdom

CHRIS E. GESWENDER
Low cost deployment system and method for airborne object

2427721	France
2427721	Germany
2427721	United Kingdom

DANIEL J. MOSIER, ANEES AHMAD, DAVID J. PARK, BYRON B. TAYLOR, DAVID G. JENKINS, DWIGHT L. DENNEY, JOHN R. RUTKOWSKI, DANIEL VUKOBRATOVICH
High energy laser beam director system and method

2427783	France
602010039334.8	Germany
2017/05040	Turkey
2427783	United Kingdom

KENNETH W. BROWN, STEVEN L. KAUFMAN, JACK E. WHITE
Explosive material detection

2431735	France
2431735	Germany
243962	Israel
2431735	United Kingdom

KIRK A. MILLER
Fast-steering, deformable mirror system and method for manufacturing the same

2431784	France
2431784	Germany
214150	Israel
2431784	United Kingdom

THOMAS J. WETHERELL, BRIAN S. SCOTT, RONALD L. RONCONE, BYRON B. TAYLOR
Multi-band seeker with tiltable optical/receiver portion

2438385	France
602010046353.2	Germany
2438385	Turkey
2438385	United Kingdom

CHRIS E. GESWENDER, STEPHEN E. BENNETT
Self clocking for distributed projectile guidance

2438389	France
2438389	Germany
2438389	Spain
2438389	United Kingdom

IAN S. ROBINSON
Compensation of clock jitter in analog-digital converter applications

2439849	France
602011024532.5	Germany
2439849	Netherlands
2439849	United Kingdom

THOMAS A. OLDEN, ROBERT CAVALLERI
Modular divert and attitude control system

2443413	France
602010045068.6	Germany
502017000129151	Italy
2443413	Spain
2017/17089	Turkey
2443413	United Kingdom

CHING-JU J. YOUNG
Scene based non-uniformity correction for infrared detector arrays

2445192	France
2445192	Germany
214636	Israel
2445192	United Kingdom

VLADIMIR V. SHKUNOV, FRIEDRICH STROHKENDL, DAVID A. ROCKWELL
Compensation of thermally induced refractive index distortions in an optical gain medium or other optical element

2447748	France
2447748	Germany
214724	Israel
2447748	United Kingdom

STEPHEN M. PALIK
First-in-first out (FIFO) buffered median scene non-uniformity correction method

2450849	France
2450849	Germany
214967	Israel
2450849	United Kingdom

WILLIAM E. HOKE, JEFFREY R. LAROCHE, RALPH KORENSTEIN, STEVEN D. BERNSTEIN
Boron aluminum nitride diamond heterostructure

2455973	France
2455973	Germany
2455973	Italy
2455973	United Kingdom

JACOB KIM, GILBERT M. SHOWS
Alignment system

2456009	France
2456009	Germany
6273078	Japan
2456009	United Kingdom

STEVEN D. BERNSTEIN, STEVEN B. WAKEFIELD, ROBERT P. MOLFINO, ERIK F. NORDHAUSEN, DAVID H. ALTMAN
Nano-tube thermal interface structure

2462613	France
602010031217.8	Germany
502016000057000	Italy

BENJAMIN DOLGIN, WILLIAM SULIGA, JOHN WITZEL, STEVEN COTTEN, MICHAEL BRENNAN, JORGE GUTIERREZ
Search and rescue using ultraviolet radiation

2473401	France
5913453	Japan
2473401	United Kingdom

ROBERT W. MARTIN
Torsion stop deployment system for airborne object

2488820	France
602010036093.8	Germany
218480	Israel
2488820	United Kingdom

PATRICK L. MCCARTHY
Projecting guidance system including a compact semi-active laser seeker with immersed filter stack and field lens(compact SAL lens with immersion field lens)

2491332	France
602010040765.9	Germany
2491332	United Kingdom

HOWARD S. NUSSBAUM, LOAN T. DAVIDOFF, JACKSON Y. CHIA
Configurable filter and receiver incorporating same

2493074	France
602005048318.7	Germany
340237	Norway
2493074	Sweden

CHRISTOPHER K. SOLECKI, ALLEN L. KELLY, KEVIN M. CHAPLA, WILLIAM C. STRAUSS
Apparatus for producing a vitreous inner layer on a fused silica body, and method of operating same

2505564	France
602012027902.8	Germany
2505564	Greece
217836	Israel
502017000040737	Italy
I534111	Taiwan
2017/05271T4	Turkey
2505564	United Kingdom

BRIAN GAHAN, WILLIAM C. STRAUSS, DERRICK J. ROCKOSI, CHRISTOPHER K. SOLECKI, ALLEN L. KELLY, RICHARD GENTILMAN
Fused silica body with vitreous silica inner layer, and method for making same

2505565	France
602012022095.3	Germany
217822	Israel
2505565	Italy
2505565	United Kingdom

DANIEL W. OTTS
Filtering sensor data to provide estimates of structures

2524238	France
2524238	Germany
2524238	United Kingdom

JOHN D. ISKER, CHAUNCHY F. MCKEARN, WILLIAM B. KING, ERIC J. GRIFFIN
Retractable rotary turret

2527779	France
602012014283.9	Germany
218819	Israel
2527779	United Kingdom

C THOMAS THOMAS HASTINGS JR, GARY D. COLEMAN, WILLIAM J. MINISCALCO, JAMES MCSPADDEN, JOHN F. SILNY
Extensible high bandwidth global space communication network

2528248	France
2528248	Germany
218820	Israel
2528248	United Kingdom

DONALD P. COX
Chemical and biological sensor

2550527	France
602011040354.0	Germany
2550527	United Kingdom

JOHN P. BETTENCOURT, VALERY S. KAPER
Digital-to-analog converter (DAC) having high dynamic range

2550743	France
602011040124.6	Germany
2550743	United Kingdom

IAN S. ROBINSON, BRADLEY A. FLANDERS, ERIC P. FRANS
Multiply adaptive spatial spectral exploitation

2560129	France
2560129	Germany
2560129	United Kingdom

DAVID M. FILGAS, THOMAS H. ALFORD, ROBERT F. STIFFLER, MICHAEL S. LACKEY
High-efficiency, dual current sink laser diode driver

2562935	France
602012029126.5	Germany
220081	Israel
2562935	United Kingdom

NICHOLAS D. TRAIL, JAMES P. MILLS, ERIC C. FEST, JIM R. HICKS
Optical transceiver built-in test (BIT)

2564147	France
602011037783.3	Germany
2564147	United Kingdom

LACY G. COOK
Integrated 3-channel gas detection and measurement spectrometer

2573529	France
602012039706.3	Germany
2573529	United Kingdom

GEORGE GOULD, MARK S. HAUHE, JASON G. MILNE, TERRY C. CISCO, PAUL NAHASS, NICK ZAFIROPOULOS
Aerogel dielectric layer

2573805	France
602012025950.7	Germany
502017000016824	Italy
2573805	Netherlands
2573805	Spain
2573805	Sweden
2573805	United Kingdom

JESSE H. BLAKE, CARLOS E. GARCIA, MATTHEW GLENN MURPHY
Optically-coupled communication interface for a laser-guided projectile

2577215	France
602011026757.4	Germany
502016000080361	Italy
2577215	United Kingdom

STEPHEN R. REID, DAVID J. KATZ
Chip interface with synchronization

2586151	France
602011042686.9	Germany
502018000000718	Italy
2586151	United Kingdom

JEAN-PAUL BULOT, MATTHEW J. KLOTZ
Method and apparatus for range resolved laser doppler vibrometry

2587231	France
2587231	Germany
221961	Israel
2587231	United Kingdom

RALPH H. KLESTADT, JAVIER VELEZ
Aerodynamic flight termination system and method

2593746	France
602011029382.6	Germany
2593746	Turkey
2593746	United Kingdom

ANDREW L. BULLARD
Multi-stage flexural pivot

2594984	France
2594984	Germany
221990	Israel
2594984	United Kingdom

RICHARD DRYER, CHRIS E. GESWENDER
Projectile modification method

2596317	France
602011026878.3	Germany
2596317	United Kingdom

ROBERT J. BENNETT, FRANK L. SHACKLEE, MICHAEL D. ERNEST
Weapon station and associated method

2598824	France
602011043369.5	Germany
223739	Israel
2598824	United Kingdom

RANDALL S. FIROR
Aerodynamic fin lock for adjustable and deployable fin

2598833	France
2598833	Germany
2598833	United Kingdom

DAVID D. CROUCH
A power combiner/divider for coupling n-coaxial inputs/outputs to a waveguide via a matching plate to provide minimized reflection

2599158	France
602011038322.1	Germany
2599158	United Kingdom

MARK R. SKIDMORE, JOHN F. SILNY
Position optimization

2602633	France
2602633	Germany
5977363	Japan
2602633	United Kingdom

MATTHEW J. KLOTZ, MAURICE J. HALMOS, JEAN-PAUL BULOT
Range-resolved vibration using large time-bandwidth product ladar waveforms

2605040	France
602012031237.8	Germany
222703	Israel
2605040	United Kingdom

JEAN-PAUL BULOT, ROBERT J. CODA, MATTHEW J. KLOTZ
Doppler compensation for a coherent ladar

2605042	France
602012043584.4	Germany
222552	Israel
2605042	United Kingdom

ROBERT D. STULTZ
Multi-stage lyot filter and method

2605058	France
2605058	Germany
2605058	United Kingdom

IAN S. ROBINSON, BRADLEY A. FLANDERS
Basis vector spectral image compression (BVSIC)

2632161	France
2632161	Germany
2632161	United Kingdom

ROBERT D. TRAVIS
Projectile that includes propulsion system and launch motor on opposing sides of payload and method

2652438	France
602011039380.4	Germany
2652438	Spain
2652438	Turkey
2652438	United Kingdom

BRIAN L. BISWELL
Deconfliction of guided airborne weapons fired in a salvo

2686634	France
602012040804.9	Germany
2686634	United Kingdom

RICHARD D. LOEHR, JEREMY C. DANFORTH, KEVIN P. MURPHY
Closed gas generator and micro power unit including the same

2699780	France
602012016725.4	Germany
2699780	Spain
2699780	United Kingdom

MARK J. GUGLIUZZA, ROGER L. CLARK, BENJAMIN J. ANNINO, WILLIAM W. COOPER
Low noise oscillators

2700157	France
602012024563.8	Germany
I523411	Taiwan
2700157	United Kingdom

MICHAEL K. BURKLAND
Absolute position encoder

2702365	France
602012028236.3	Germany
2702365	United Kingdom

MARTIN S. DENHAM
Shift register with two-phase non-overlapping clocks

2705659	France
602012021045.1	Germany
2705659	United Kingdom

MICHAEL A. MOORE, WAID A. PAINE, JOHN BEDINGER
Radome film

2706612	France
2706612	Germany
2706612	Greece
502017000065549	Italy
2017/05100	Turkey
2706612	United Kingdom

DMITRI JERDEV
Local area contrast enhancement

2740101	France
6020120301.39.2	Germany
230452	Israel
6239505	Japan
2740101	United Kingdom

ROBERT F. BURKHOLDER, STEPHEN H. BLACK, BORYS PAWEL KOLASA, MICHAEL A. GRITZ
Antenna-coupled antenna arrays

2748891	France
602012030741.2	Germany

JAMES A. PRUETT, JERRY M. GRIMM
Method and apparatus for detecting radome damage

2748892	France
602012030447.2	Germany
2748892	United Kingdom

CHARLES L. HORVATH, GARY F. WAHLQUIST, TIMOTHY J. IMHOLT, HERMAN B. VAN REES
Method and apparatus for armor having integrated battery power

2764322	France
2764322	Germany
2764322	United Kingdom

DARIN S. WILLIAMS
Blur-calibration system for electro-optical sensors and method using a moving multi-focal multi-target constellation

2767093	France
602012029675.5	Germany
6114289	Japan
2767093	United Kingdom

CHRISTOPHER E. PENTLAND, PAUL M. LYONS
System and method for charging and sealing pressure vessels

2773898	France
602012013664.2	Germany
2773898	Turkey
2773898	United Kingdom

MICHAEL GEILE
Non-contiguous spectral-band modulator and method for non-contiguous spectral-band modulation

2798806	France
2798806	United Kingdom

NEIL R. NELSON, STEVEN R. WILKINSON
Synchronization of remote clocks

2799941	France
2799942	France
2799943	France
2799943	Germany
602011028494.0	Germany
2799941	United Kingdom
2799942	United Kingdom
2799943	United Kingdom

FUSUN YAMAN SIRIN, JACOB BEAL, AARON ADLER, RONALD WEISS, NOAH JUSTIN DAVIDSOHN

Methods of evaluating gene expression levels

2800813	France
602012026904.9	Germany
2800813	United Kingdom

MICHAEL Y. JIN

Sar autofocus for ground penetration radar

2802896	France
602012031465.6	Germany
2802896	United Kingdom

ZACHARIAH A. SEASLY, ELAINE E. SEASLY

Automated non-contacting cleaning

2810721	France
60206048761.4	Germany
2810721	United Kingdom

JOHN A. THOMAS, RONALD L. RONCONE, GARY H. JOHNSON, THOMAS H. LIND

Bi-polymer infrared optics for high-g applications

2812745	France
602012030811.7	Germany
2812745	United Kingdom

JERRY M. GRIMM, RAYMOND SAMANIEGO

Systems and methods for image sharpening

2817655	France
602013036491.5	Germany
2817655	Poland
2817655	United Kingdom

KIRK A. MILLER

Shock-resistant device and method

2839243	France
2839243	Germany
2839243	United Kingdom

IAN S. ROBINSON

Fourier transform infrared spectrometer with enhanced readout speed

2839255	France
602013023085.4	Germany
2839255	United Kingdom

CHET L. RICHARDS

Stereo rectification method

2839431	France
602013006259.5	Germany
5917767	Japan
2839431	United Kingdom

VICTOR KHITROV

Optical fiber coupler for coupling signal beams into a non-circularly shaped optical beam

2841983	France
2841983	Germany
5876612	Japan
2841983	United Kingdom

GARY A. CLAYTON, BRUCE CHARLES FITZ-PATRICK, BYRON E. SHORT JR

Electronics enclosures with high thermal performance and related system

2848106	France
2848106	Germany
2848106	Poland
2848106	United Kingdom

MARC BERTE, JOHN A. KOGUT

Multi-spectral imaging system and method for remote biometric measurement of human physiological parameters

2858566	France
2858566	Germany
235743	Israel
6005858	Japan
2858566	United Kingdom

LACY G. COOK

All reflective real pupil telecentric imager

2862017	France
602012038717.3	Germany
5970129	Japan
2862017	United Kingdom

JAMES A. COVELLO, DAVID LARACUENTE, TORMOD FRETHEIM

Non-causal attitude estimation for real-time motion compensation of sensed images on a moving platform

2865175	France
602013032318.6	Germany
2865175	United Kingdom

NICOLE M. QUACKENBUSH, TIM B. BONBRAKE, BRADLEY M. BIGGS

Intermediate voltage arming

2867609	France
602013028857.7	Germany
2867609	United Kingdom

PHILIP T. SHIMON, LLOYD J. LEWINS, KENNETH E. PRAGER

Doppler tracking in presence of vehicle velocity uncertainty

2872919	France
2872919	Germany
236444	Israel
2872919	United Kingdom

CHRISTOPHER D. MARR, CHRISTOPHER E. PENTLAND, WAYNE L. SUNNE

Vehicle having a nanocomposite optical ceramic dome

2880395	France
2880395	Germany
2880395	United Kingdom

ROBERT W. VON MAYR, JOHN WILLEMS, DAVID J. REYES, THOMAS ANDREW BLACK, ERIK A. FJERSTAD

Fin buzz system and method for assisting in unlocking a missile fin lock mechanism

2883016	France
2883016	Germany
2883016	United Kingdom

JAMES KENDALL VILLARREAL, STEPHEN D. HAIGHT, DANIEL CHASMAN

Slotted multi-nozzle grid with integrated cooling channels

2906809	France
2906809	Germany
2906809	United Kingdom

BUU DIEP, ADAM M. KENNEDY, THOMAS ALLAN KOCIAN, STEPHEN H. BLACK, ROLAND GOOCH

Integrated bondline spacers for wafer level packaged circuit devices

2915190	France
602013034236.9	Germany
2915190	Norway
2018/05880	Turkey
2915190	United Kingdom

PAUL A. MEREMS

Umbilical cable disconnect

2920541	France
2920541	Germany
2920541	Poland
2920541	United Kingdom

MAURICE J. HALMOS

Bistatic synthetic aperture LADAR system

2929368	France
602013034093.5	Germany
2929368	United Kingdom

JOHN J. ANAGNOST, ANDREW L. BULLARD

Hung mass accelerometer with differential eddy current sensing

2932275	France
602013016758.3	Germany
239265	Israel
2932275	United Kingdom

CHET L. RICHARDS

Pixel multiplication using code spread functions

2932463	France
602013018263.9	Germany
238083	Israel
2932463	United Kingdom

BRUCE A. JENSEN, BRIAN A. GUNN, JAYOUNG NAM

High-resolution link-path delay estimator and method for estimating a signal-path delay

2965470	France
2965470	Germany
240767	Israel
2965470	United Kingdom

MICHAEL GEILE

System and method for communicating with shaped cyclic time-domain waveforms

2987291	France
2987291	United Kingdom

CARISSA L. PICHON, MICHAEL E. YEOMANS, JACK LEE, JAMES P. DUMAIS

Synchronous data system and method for providing phase-aligned output data

2992636	France
2992636	Germany
2992636	Italy
6121622	Japan
2992636	Norway
10-1710825	South Korea / Republic of Korea
2992636	Spain
2992636	United Kingdom

DAVID H. ALTMAN, WILLIAM J. DAVIS

Method for creating a selective solder seal interface for an integrated circuit cooling system

2994936	France
602014007872.9	Germany
502017000058175	Italy
6169783	Japan
10-1704592	South Korea / Republic of Korea
2994936	United Kingdom

MICHAEL L. BREST, JEFFREY P. YANEVICH, KENNETH L. MC ALLISTER, ERIC J. GRIFFIN

Variable aperture mechanism for cryogenic environment, and method

3008812	France
3008812	Germany
3008812	Poland
3008812	United Kingdom

MICHAEL A. GRITZ, ZHAOYANG C. WANG, STEVEN M. LARDIZABAL

Loss-less frequency dependent dicke-switched radiometer

3014231	France
602014008357.9	Germany
6074116	Japan
3014231	United Kingdom

RICHARD H. BELANSKY, CECIL VERGEL DE DIOS, ANDREW R. ROLLINGER

Analog optical fiber-based signal distribution system and method

3030945	France
3030945	Germany
3030945	United Kingdom

IAN S. ROBINSON, JOHN D. BLOOMER

Configurable combination spectrometer and imager

3039391	France
602015003231.4	Germany
3039391	United Kingdom

JASON M. SHIRE, RICHARD POLLY, THOMAS H. BOOTES, GEORGE DARRYL BUDY, JESSE T. WADDELL, WAYNE Y. LEE

Enhanced fragmentation for hard target penetrator warhead

3105533	France
3105534	France
3105536	France
3105538	France
3105533	Germany
3105534	Germany
3105536	Germany
3105533	Italy
3105534	Italy
3105536	Italy
3105538	Italy
3105533	Spain
3105534	Spain
3105536	Spain
3105538	Spain
2017 16910	Turkey
3105533	Turkey
3105536	Turkey
TR2017 16750 T4	Turkey
3105533	United Kingdom
3105534	United Kingdom
3105536	United Kingdom
3105538	United Kingdom

HOWARD S. NUSSBAUM

Flexible chirp generator

3114541	France
602015010905.8	Germany
I558093	Taiwan
3114541	United Kingdom

JAMES R. SACKETT

Predictive semi-active laser pulse correlator and method

3146288	France
3146288	Germany
3146288	United Kingdom

MICHAEL H. KIEFFER, DAWSON R. BRUCKMAN

Adaptive phase control of cryocooler active vibration cancellation

3180669	France
3180669	Germany
3180669	United Kingdom

WILLIAM E. ELIAS, JAMES R. CHOW, THEODORE J. CONRAD

Method for forming lanthanide nanoparticles

3188861	France
3188861	Germany
3188861	United Kingdom

CRAIG ARMIENTO, JAMES R. CHOW, THEODORE J. CONRAD, WILLIAM E. ELIAS

Cryocooler containing additively-manufactured heat exchanger

3189287	France
3189287	Germany
3189287	United Kingdom

JAMES GABURA, GEOFF HARRIS

Rapid-response electron-beam deposition system having a controller utilizing leading and trailing deposition indicators

102006003108.3	Germany

DAVID J. MARKASON, DAVID G. JENKINS, BYRON B. TAYLOR

Co-boresighted dual-mode SAL/IR seeker including a SAL spreader

112010003767	Germany
2484231	United Kingdom

DAMON C. TURNER, BRETT J. YOUNG

Target-tracking radar and method for responding to fluctuations in target SNR

112012001478	Germany

JASON A. JOHNSON, BRETT J. YOUNG

Target-tracking radar classifier with glint detection and method for target classification using measured target epsilon and target glint information

112012001722	Germany

JOHN COOLIDGE, JOSEPH SMITH, STANLEY TURNER

Launcher platform

1529002	Germany
1529002	Netherlands
300239207	Spain
1529002	United Kingdom

PETER BARBELLA, BARBARA E. PAUPLIS, TAMARA L. FRANZ

Technique for non-coherent integration of targets with ambiguous velocities

1590684	Germany
338595	Norway
1590684	United Kingdom

EBERHARDT PRAEGER, BRUCE W. CHIGNOLA, KEVIN E. MARTIN, GARO K. DAKESSIAN, DENNIS R. KLING, BORIS S. JACOBSON, WILLIAM WESOLOWSKI

Electrical transformer (planar magnetic assembly with embedded core transformers)

1593131	Germany
1593131	Sweden
1593131	United Kingdom

THOMAS A. OLDEN, ROBERT P. JOHNSON, CHARLES HOWLAND

Entrapment systems and apparatuses for containing projectiles from an explosion

2409111	Germany
2409111	United Kingdom

BRYAN D. STEPHAN, HARSHA MODUR SATHYENDRA

Target identification for a radar image

2523016	Germany
2523016	Italy
2523016	Norway
2523016	Poland
2523016	Portugal
2523016	Spain
2523016	United Kingdom

PATRICK S. LEWIS, DOUGLAS P. GUGLER

High and low speed serial interface multiplexing circuit

2671335	Germany
2671335	United Kingdom

ANDREW EUGENE DOLPHIN

Guidance system and method for missile divert minimization

2691729	Germany
2691729	United Kingdom

SYLVIA A. TRAXLER, STEVE KEARSLEY, CHRISTOPHER J. GRAHAM, LESLIE A. LEDDA, PAUL C. HERSHEY, NIRAJ N. SHAH, MU-CHENG WANG

Mobile and one-touch tasking and visualization of sensor data

2780862	Germany
2780862	United Kingdom

RICK WILLIAMS, CHRIS E. GESWENDER

Obturator ring with interlocking segments

3025117	Germany
3025117	United Kingdom

PHILIP C. THERIAULT, ANTHONY O. LEE, CHRISTOPHER ROTH

Adjustable optical mounting

60 2007 052 966.2	Germany
2008140	United Kingdom

CHRIS E. GESWENDER, PAUL VESTY, GEOFFREY W. FROST, BRUCE E. MORGAN, DORON STRASSMAN

Rolling vehicle having collar with passively controlled ailerons

602012036952.3	Germany
2017/17151	Turkey
2748558	United Kingdom

FRANK C. SULZBACH, JOHN R. STALEY

Method and apparatus for range finding with a single aperture

602005051773.1	Germany
1723384	United Kingdom

S RAJENDRAN, JAMES MASON, JOHN BEDINGER

Reduced inductance interconnect for enhanced microwave and millineter-wave systems (polymer on metal (POM) interconnect fabrication structure)

602006053885.5	Germany
1894241	United Kingdom

ROBERT J. SCHALLER, DONALD R. HOUSER, MICHAEL SNYDER, ANTHONY K. TYREE, WILLIAM J. SCHMITT

All-digital line-of-sight (LOS) processor architecture

602009045416.1	Germany
2326967	United Kingdom

STEVEN COTTEN, BENJAMIN DOLGIN, JOHN WITZEL, MICHAEL BRENNAN, JORGE GUTIERREZ, WILLIAM SULIGA
Search and rescue using ultraviolet radiation
602010034079.1 Germany
6013913 Japan

KENNETH M. WEBB
Method and apparatus for phased array antenna field calibration
602010047617.0 Germany
2273614 United Kingdom

NEIL R. NELSON, STEVEN R. WILKINSON
Synchronization of remote clocks
602011029997.2 Germany

DAVID D. CROUCH
Active retrodirective antenna array with a virtual beacon
602012036273.1 Germany
2017/16077 Turkey
2726810 United Kingdom

JERRY R. HINSON
Digital frequency channelizer
GC0004625 Gulf Cooperation Council

JERRY R. HINSON
Digital fractional integrator
GC0004742 Gulf Cooperation Council

JOHN P. HIGBY
Cable reel axle shaft with integrated radio frequency rotary coupling
GC0005350 Gulf Cooperation Council

TUNGLIN L. TSAI, KATHE I. SCOTT, DONALD A. BOZZA, PATRICIA S. DUPUIS, JOHN B. FRANCIS, ANGELO M. PUZELLA
Scalable, analog monopulse network
GC0005363 Gulf Cooperation Council
I533512 Taiwan

JOSEPH M. CROWDER, PATRICIA S. DUPUIS, ANGELO M. PUZELLA, MICHAEL C. FALLICA, JOSEPH LICCIARDELLO, JOHN B. FRANCIS
Tile sub-array and related circuits and techniques
275285 India

GREGG J. HLAVACEK, ANDREW B. FACCIANO, ROBERT T. MOORE
Separable structure material
279734 India

HOWARD C. CHOE
Information processing system
286102 India

LARRY L. LAI, DEVON J. PRICE, JOSE MELENDEZ
Foam layer transmission line structures
286881 India

STEPHEN D. MILLIGAN, JAMES BARGER, MARSHALL BRINN, RICHARD MULLEN
Systems and methods for estimating a shooter range by detecting shock wave and muzzle blast
291068 India

DANIEL C. HARRISON, WAYNE L. SUNNE, JAMES P. MILLS, FRANK E. SMITH III, DAVID J. KNAPP, DAVID G. GARRETT, DAVID G. ANTHONY, DANIEL W. BRUNTON, EMMET ANDERSON, JIM R. HICKS
Gimbaled optical pointer
190309 Israel

ANDREW B. FACCIANO, CHIN SHIAU
Digital interface unit (DIU) and method for controlling stages of a multi-stage missile
199520 Israel

LACY G. COOK
Pointable optical system with coude optics having a short on-gimbal path length
202210 Israel

MILTON BIRNBAUM, KALIN SPARIOSU
Modulated saturable absorber controlled laser
206208 Israel

ROBERT W. BYREN, DARIN S. WILLIAMS
Textured pattern sensing and detection, and using a charge-scavenging photodiode array for the same
208586 Israel

JAMES BARGER, SCOTT RITTER
Systems and methods for detecting shooter locations from an aircraft
209797 Israel

SCOTT M. JOHNSON, JUSTIN GORDON ADAMS WEHNER
Multi-band, reduced-volume radiation detectors and methods of formation
209861 Israel

LACY G. COOK
Flat field schmidt telescope with extended field of view
210272 Israel

TERRY C. CISCO
Microwave directional coupler
211106 Israel

JEFFREY B. WEBER, FANGCHOU YANG, JAR J. LEE, STAN W. LIVINGSTON
Dual-patch antenna and array
211317 Israel

IAN S. ROBINSON
Resolution on demand
211477 Israel

ROHN SAUER, CLIFTON QUAN, MARK S. HAUHE
Systems and methods for providing a reconfigurable groundplane
211611 Israel

ROBERT C. HON, JOHN F. SILNY
Time domain vibration reduction and control
211790 Israel

DEREK PRUDEN, LARRY L. LAI, DAVID T. WINSLOW, KYLE W. MAXHIMER
Lightweight antenna attachment structure
211885 Israel

FANGCHOU YANG, ALBERTO F. VISCARRA, CLIFTON QUAN, HEE KYUNG KYUNG KIM, SHAHROKH HASHEMI-YEGANEH, ROBERT W. LADERA
Systems and methods for exciting long slot radiators of an RF antenna
211959 Israel

ANTHONY L. VICICH, MARTIN G. FIX, CHARLES K. ROGERS, JAYSON KAHLE BOPP
Aircraft canister design
212068 Israel

ALEXANDER A. BETIN, VLADIMIR V. SHKUNOV, DAVID A. ROCKWELL
Method and apparatus for generation and amplification of light in a semi-guiding high aspect ratio core fiber
212124 Israel

LEONARD LE, EPIFANIO P. GONYEA, KEITH R. BURRELL, THOMAS L. KEHL
Integrated locking hinge
212327 Israel
I528887 Taiwan

STEVEN E. LAU, WILLIAM J. WOLFGONG, CHRISTOPHER T. SNIVELY, CINDY W. MA, THOMAS K. DOUGHERTY
X-ray opaque coatings and application
212569 Israel

BRANDON W. PILLANS, MICHAEL K. HOLZ, ANTHONY ROSS, GREGORY V. BURNETT, NATHAN M. MINTZ
System and method for detection of concealed cargo in a vehicle by center of mass measurement
212666 Israel

IAN S. ROBINSON
Method for hyperspectral image dimension reduction
212769 Israel

STAN W. LIVINGSTON, SCOTT E. ADCOOK
Plug-in antenna
212892 Israel
I520431 Taiwan

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