THE CONTRIBUTION OF NANOTECHNOLOGY, ROBOTICS AND ARTIFICIAL INTELLIGENCE TO MILITARY SPACE SYSTEMS DEVELOPMENT 2015-2025

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In recent years the space systems industry has realized tremendous benefits originating from discoveries made in the fields of nanotechnology, robotics and artificial intelligence (NRai). Advancements in space systems development have been enabled by these fields thanks to their independent contributions, though as technological challenges present themselves, further progress will be achieved through each of these technologies drawing upon one another. As researchers work to overcome tomorrow's commercial and military space challenges, the progressive convergence of these respective fields will make possible the future development of advanced space technology and ultimately space warfare systems.

In 1965 Moore's Law charted an exponential growth pattern in the complexity of integrated semiconductor circuits and data storage. The unprecedented explosion of computational potential, and in turn affordability, that Moore accurately predicted drove widespread discoveries in the field of computer science, such as the creation of the internet, complicated algorithms, and early human machine interfacing (HMI).[1] In 2001 Kurzweil's Law of Accelerating Returns extended the growth pattern described in Moore's Law to transcend computers and reach into many other areas of science. Most remarkable is that this scientific and technological growth, which Kurzweil revealed, is not linear but exponential; and it is not limited to just the technology, as humanity accelerates its own potential as well. The way that one technology seems to reach its potential and then suddenly converges with another to become something greater was also observed with the marriage of early of genetics research and advanced computer processors. According to Kurzweil's Law this would constitute an example of two technologies having pushed and pulled with one another, engaging in almost evolutionary fashion to become more than just the sum of their parts. The result in this case was the mapping of the genome, leading to improved health care and longer human life expectancy.[2]

Due to the interdisciplinary nature of NRai technologies, advancements in future space systems will experience an exponential growth cycle similar to that observed in the human genome project. Though there is tremendous potential for advances in civilian fields such as space exploration, communications and engineering through this convergence, such a process would also be the primary driver leading to advanced arms racing and evolved methods of space warfare. The convergence of nanotechnology, robotics, and artificial intelligence relative to space warfare systems as a function of time is outlined below.

2015

***Artificial Intelligence*:** In support of cyber warfare and countless advanced military research programs, the field of artificial intelligence (A.I.) has been growing in importance, and this is no more apparent than in the arena of military space systems. In 2015, A.I. touches directly and indirectly upon nearly every advanced system in the space warfare toolkit. The potential inherent to these A.I. systems and the speed of their evolution will increase exponentially, driven by their own ability to learn, become cognitive and not only enhance “their” potential, but the potential of the human warfighter as well. A.I. will enable seamless and real-time responses to a broad spectrum of challenges posed at all levels of military operations. Conversely, with the increasing speed of military operations and size of operations supporting data flows, the human element will become increasing unable to deliver effective response times in this rapidly accelerating information environment.[3]

Cyber warfare: Cyber warfare is a daily threat, as many nations’ individual systems and networks are now targeted by hundreds of thousands, and sometimes millions, of attacks per day. Such remote attacks, not only appear to originate from governments and militaries, but also from mischievous individuals, loosely-affiliated international hacking organizations, and non-state terrorist organizations. Such a capability is not limited to any specific nation or group and is a method of attack that requires a constantly evolving capacity to respond to innovative challenges. Both the advanced cyber-soldier and non-state hacker are now well equipped to deliver compromising attacks against many aspects of space and cyber-supported military functions.[4] As nations that are dependent on space to conduct military operations race to reduce network access points, recruit qualified professionals, and identify methods to deter and respond to cyber threats, these rogue attacks are proving increasingly destructive.[5] Furthermore, in 2015, the economic and societal effects of a large-scale cyber attack against an industrialized nation's critical information infrastructure may have the potential to virtually cripple many industrial and governmental functions, including those that incorporate commercial and military space systems.[6]

***Nanotechnology*:** Innovations in the field of lithography and multi-gate processing, such as double- and tri-gate transistors, will also contribute to dramatic increases in processing speed and efficiency when compared to the traditional and increasingly more archaic silicon chip.[7] Both independently and hand-in-hand with A.I., recent discoveries in the field nanotechnology, specifically carbon nanotubes and nanomaterials, are beginning to radically enhance not only traditional military space systems, but the entire spectrum of miniaturized military technologies. New nanomaterials with revolutionary abilities will provide thermal protection, structural integrity improvements, and power-generation abilities to satellites and other critical space assets. Due to the inherent and unique properties of these materials, widespread application to the structural and electronic components of space systems is inevitable. Nanoscale applications working alone and in concert with A.I. will begin to move from the laboratories of the world into the theaters of war. Just as A.I. systems are now being wholly integrated into military decision-making processes such as allowing satellites to deter attacks autonomously, in complementary fashion, nanotechnology is providing the fabric for military space development.

2020

***Artificial Intelligence & Cyber Warfare*:** In 2020 artificial intelligence (A.I.) and cyber warfare systems and their corresponding areas of responsibility relating to military space systems and space warfare technologies have fully converged, and hence their sections are merged below.

Specific combat operations are now being conducted by human and artificial operators working together in a virtual environment that delivers a real-time view of the target area with semi-autonomous and autonomous attack options just a blink or a voice-command away. In 2020, A.I.-driven systems are supplying consolidated information and refined military options to high-level decision makers, who are now unable to decipher and analyze vast data flows alone. The role of the war planner is now found to be most critical during the process of selecting war fighting strategies generated and provided by A.I. systems.

The entire sphere of global military operations in 2020 has the potential to be fully interconnected for those with the means and the desire to do so, as successful military operations are decided by this complex network of systems. In the years leading up to 2020, efforts to reduce network access points into military and national security systems and to centralize individual architectures have proven to be a critical decision for many advanced military powers. As governmental network access points are reduced, and their decentralized layout is eventually integrated, the potential for security breaches is greatly decreased. However, should a cyber denial of service or brute force attack prove successful, a full or near-full spectrum catastrophic failure could result.[8] Scenarios such as these must be considered before the complete consolidation of information architectures is achieved. Decentralized systems lead to an increased potential for vulnerabilities; however they defuse the effects of successful attacks, thus minimizing the potential for significantly debilitating operational effects.

Threats posed to computer networks that support critical military satellite systems have become increasingly complex and are occurring more frequently. Specifically, attacks targeting ground stations and command centers threaten military connectivity and the seamlessness of the Command, Control, Communications, Computer, Intelligence, Surveillance and Reconnaissance systems (C4ISR).[9] Such attacks have the potential to effectively induce a systems blackout. A military's ability to adequately secure C4ISR systems and protect ground segments ensures success not only in space, but in all dimensions of warfare.[10] Advances in cryptology, quantum cryptology, and related technologies such as ciphers and crypto-keys for performing encryption and decryption of these data streams are vital to ensuring space systems security. Specifically, the preservation of secure crosslink/uplink/downlink data transmissions will require constant enhancement efforts due to the availability of advanced computer processing capabilities and the adaptive nature of highly skilled adversaries. As with all military space-supporting computer systems, threat sources are not limited to code breakers and hackers trying to exploit weaknesses from outside government facilities in faraway lands, but from within the host government as well. In an environment where trust is everything, a weakness in the human element of security could jump all other protection measures.[11] Additionally, if an attack were to succeed against the C4ISR supporting space systems, a self-healing capability or Self-Regenerative Systems (SRS) solution must be executed immediately in order to repair and secure the affected network. Such abilities to survive a debilitating space systems attack will be made possible by advances in A.I.[12]

Nanotechnology: It will be nearly impossible to find nanotechnology detractors as universal applications are benefiting industries located around the world in this multidisciplinary field.[13] Up to this point, nanotechnology discoveries that improved military space capabilities had appeared mostly in the form of new materials that enhanced solar power generation, asset survivability, and structural integrity.

By 2020 advances in nanotechnology have led to electrically-charged based devices being replaced by non-charged based devices that are non-volatile. A manifested example of this leap ahead will incorporate flexible thin-film-transistors (TFTs) that will revolutionize the way in which a human subject interacts with one's computer and related accessories. Imagine, for example, the features and capacity of a personal computer, cellular phone and global positioning system (GPS) integrated into a simple handheld device that is similar in size to a credit card. Garments would contain TFTs that would generate solar energy during the day and convert heat generated by the body during the evening. For soldiers on the battlefield, the benefits would include increased mobility and reduced vulnerability. Moving a step further, when combined with GPS and imaging technology integrated into a virtual display employed across multiple soldiers, a triangulated 3D non-line-of-sight capable image of the battlefield is revealed. This visual data would then be transmitted to an aircraft and forwarded onto an in-theater regional command center where it would be fused with complimentary intelligence, or transmitted via satellite for global connectivity. This fusion process, executed primarily by A.I.

driven systems and to a lesser extent human operators, would deliver full-spectrum awareness to soldiers and war planners.[14]

Flexible nanoelectronic devices as thin as paper and mounted to a thin flexible substrate such as a plastic would provide a flexible, conductive and multiuse material that would then be integrated into countless space systems. A very attractive manifestation of this application would be in the form of a substrate on which electronic circuits could be printed on demand. Such a nanomaterial would also be durable and could be rolled up and stored. Flexible substrates and the use of various conductive materials will lead to thin-film solar cells for space applications or thin-film semiconductors that are incorporated into military space systems.[15] [16]

In space, micro-electro-mechanical systems (MEMS) and micro-opto-electro-mechanical systems (MOEMS) are beginning to lead to further improvements in sensors, such as Attitude Determination and Control (ADCS) and other components such as actuators.[17] As a result of research into the materials sciences having now been underway for nearly 25 years, novel applications are currently appearing and addressing key challenges. Specifically, developments made in the areas of carbon nanotubes (CNT) are resulting in materials capable of superior thermal and electrical conduction for space systems. Additionally, CNT in the proper configurations have led to the creation of materials with unprecedented ballistic protection, heat-shielding and load-bearing strength, including the ability to defuse and insulate against the effects of high-energy lasers or directed energy (DE) weapons. For example, lightweight 3D aerogels and xerogels are in 2020 capable of withstanding load-bearing pressures as extreme as tens of thousands of pounds per square inch.[18] One can imagine numerous applications for such materials, especially when we factor in advances in oxide options. Nanocomposite materials such as those utilizing silica or polystyrene even demonstrate an ability to shield against the effects of high powered microwaves (HPM) and radio frequency (RF) weapons. This field of science is also delivering applications that provide the ability to blend an asset's thermal, visual and radar appearance into its background.[19] [20]

More elaborate, yet feasible, concepts are being pursued such as a Faraday-like Cage built on a nanoscale level, which would require doped and multi-walled carbon nanotubes (MWCNT). This concept uses carbon nanotubes to develop an enclosure for satellite subsystems and smaller satellite classes such as picosats and nanosats and could provide insulation against various DE threats, including the effects of an electromagnetic interference (EMI), electromagnetic pulse (EMP) and radio frequency (RF) effects. [21] [22]

Self-healing materials are helping space systems to address damages such as those sustained in orbit as a result of a collision with space debris or from space-asset attacks that could lead to satellite failure. These materials would use composite structures that contain nanoscale spheres, which encapsulate an unhardened polymer resin. When a satellite is hit, the resin would spread and then fill surface cracks to prevent further damage and structural degradation.[23]

The next level: Molecular nanotechnology (MNT) promises to revolutionize countless products by engineering mechanical and electronic systems, including advanced materials, at the molecular scale. Such a capacity for discovery will touch upon every aspect of military technology in the realm of military space systems.[24] This rearranging of individual atoms is an emerging technology with serious implications that will demand the attention of the entire international community, as efforts to control the proliferation of such a powerful capability could potentially arrive well ahead of an appropriate legal and ethical framework. Furthermore, in anticipation of molecular scale military systems capable of delivering destructive effects and tools facilitating acts of espionage, the development MNT detection systems have been pursued. Once such systems are developed and deployed, nonproliferation efforts to control the spread of MNT military technology will be tremendously difficult.[25] As with nearly every program contained in this report, this forefront technology is being explored by various nations, with assistance from multi-tiered collaborations that may include military researchers, university students and professors, and private companies.

2025

Nanotechnology/Robotics/Artificial Intelligence (NRai): As the arrival of Strong A.I. draws ever closer, along with it will come the realization that computing on such a scale and breadth is beyond our human ability to maintain and monitor, even with the assistance of the machines themselves. We will begin to turn over the keys to the IT department to the computer within it, as non-biological intelligence has the ability to drive its own evolutionary cycle, with human oversight existing from afar, at specific points in the data stream. This is the liftoff for military space systems, and our final approach towards a victory over the Turing Test.

In the years leading up to 2020 we have witnessed the devices for human involvement in netcentric warfare leave the point-and-click mouse behind in exchange for voice-command and evolved human-computer collaboration, presented under the banner of HMIs. In 2025 technology takes a step further towards Brain-Computer Int

erfaces (BCI), also known as Brain-Machine Interfaces (BMI). Working, but limited, examples of this technology, such as the Berlin Brain-Computer Interface (BBCI) have exhibited proven results as far back as 2002.[26] [27] BCIs will empower and accelerate the remaining human factors involved in seamless military operations across the five theaters of combat—land, sea, air, space, and cyberspace—through advances in the field of neural networks, a computational data-analysis method based on the architecture of the neuronal connections within the human brain. Such a system will allow human integration into the data stream and in time will not only allow interaction via one single human function, but instead BCIs will be comprised of central nervous system connections, alpha and beta brainwaves, eye movement, and voice and facial recognition. The first manifestations of this technology have been dual-use and have led to tremendous improvements in freedom and mobility for the severely disabled; additional limited civil applications are mostly in the area of video gaming.[28] Military and national security applications of BCI in 2025 include the control of logistics, supply chains, terrestrial-based weapons systems, unmanned aerial platforms, and space systems.

BCIs will exist in parallel with a virtual world, though they will not be the virtual boxes developed many years prior such as Cave Automatic Virtual Environments (CAVEs). BCIs have combined with a technological ability to create 3-D stereoscopic images direct to the eye, located in interpupillary distance of the warfighter.[29] These virtual domains, when fully integrated with connections to the central nervous system, alpha and beta brain waves and voice and facial recognition, will provide far more than virtual theaters for war gaming and interactive displays for pilots and troop training – we will have effectively and irreversibly fused human intelligence (HI) and A.I. Such a system could ultimately combine with real-time, secure uplink and downlink data transmissions to a satellite in space which, in turn, could direct a small-scale unmanned aerial vehicle (UAV) or unmanned ground vehicle (UGV) utilizing advanced nano-electro-mechanical systems (NEMS) and nano-opto-electro-mechanical systems (NOEMS) derived sensors and optics delivering, for example, streaming video of the battlefield. The truly transformational role of these merged technologies will be difficult to imagine until we witness the warfighter speak, think or signal the fire command, and an enemy target is neutralized.

A specific military application of these technologies that is more likely to be available by 2025 would be to automatically target objects on the ground from space with hyperspectral imaging integrated into a microsatellite platform. This imaging capability would be combined with principal component analysis (PCA), which is used to reduce the volume of data to a manageable size for analysis, and a multi-layer perception (MLP) neural network, which uses multiple layers of neurons to turn vast amounts of data into a consolidated form. This could lead to a system capable of educating neural networks on how to execute a specific task, such as delivering strike options in real-time to the war planner via satellite communications to a comprehensive BCI interface.

On a much smaller physical scale, military robotics programs have been enhanced by progress in the field of molecular nanotechnology (MNT), resulting in devices such as molecular motors. This development has spawned numerous concepts that are now in the research and development programs of all leading NRai nations, such as India, China, Russia, and Japan. These robotics concepts, with molecular-scale subsystems measuring less than a few centimeters, might range from miniature flying vehicles with numerous applications to ground-based robots, both of which, with the help of A.I. can collectively combine their effects in a swarm-like fashion.[30] The continued reductions in the size of technology will span all industries and countless military systems, including space systems. For instance, such small, flying devices could be contained within a relatively larger rendezvous capable microsatellite, which would then release the smaller molecular devices or bots to execute acts of sabotage against rival space systems, with a reduced chance of being detected or targeted. Advancements in the field of MEMS-driven micro-thrusters would provide propulsion as reductions in the size of computer systems would allow for control of the devices, either autonomously or remotely through a ground segment.[31] Miniaturized unmanned ground vehicles (UGVs) acting alone or in swarms, will soon mimic biological entities such as insects through MNT processes and be used in military- or intelligence-related operations – as will also be the case with aerial systems. Such systems by 2025 will be available for deployment as military off-the-shelf (MOT) systems and as commercial off-the-shelf (COT) systems.

The role of ground segments in 2025 will continue to remain a critical area of military and national security operations. In corresponding fashion with the steps forward witnessed by many other areas of military space systems, the ground segment is reaping the benefits of NRai as well. The vulnerabilities that weakened this bridge between earth- and space-based military functions have been significantly reduced, thanks to improvements in the areas of: miniaturization, maneuverability, survivability, and redundancy.[32] The ground segment of the past has become the unattended ground sensor (UGS), a transportable and affordable, small box-on-the-ground. Deployable in large numbers, providing multiple layers of redundancy and effective terrestrial-based communications and space-to-earth uplink/downlink, this device will have effectively mitigated the threat to ground stations, though such a solution is likely to be temporary.

It is important to note once again that discoveries such as those mentioned in this analysis are the byproduct of dual-use systems with clear military and commercial applications, many of which have been developed by the U.S. in concert with commercial- and university-based contributors worldwide. These systems, for example, are openly talked about by professors, scientists, company representatives and foreign nationals at academic conferences and emerging technology trade shows, effectively undermining the purpose of developing such systems to enhance national security.

For the arms control community that is focusing primarily on banning space weapons currently in development, nearing deployment, and in some cases already deployed, efforts should also be focused towards lobbying the international community to address NRai. It will be found that by doing so, next generation space warfare systems and space security threats can, as a result, be prevented long before they have a chance to further undermine peace in outer space.

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[1]http://www.intel.com/technology/silicon/mooreslaw/eml_demo/demo.htm?iid=tech_mooreslaw+body_demo

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[14] Personal conversations with Dr. Sivasubramanian Somu of the NSF Nanoscale Science and Engineering Center for High-rate Nanomanufacturing at Northeastern University, in Boston, MA
[15] Attended presentation by Steven Novack, Advisory Scientist, Idaho National Laboratory (INL)
[16] http://www.microcontinuum.com/flexible.htm
[17] http://www.design.caltech.edu/micropropulsion/
[18] http://stardust.jpl.nasa.gov/aerogel_factsheet.pdf
[19] Attended presentation by Nicholas Leventis, Univ. of Missouri (Rolla) in Boston ,MA.
[20] Personal conversations with Dr. Sivasubramanian Somu of the NSF Nanoscale Science and Engineering Center for High-rate Nanomanufacturing at Northeastern University, in Boston, MA
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[22] Attended presentation by Mool Gupta, Langley Distinguished Professor and Director of NSF I/UCRC Center for Lasers and Plasmas, University of Virginia
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