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Machine Learning in the Military

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ABSTRACT

Artificial intelligence and machine learning are being integrated with everything that the Army and Department of Defense does. They are intersecting so many different domains. They have become a major point of interest for both Army veterans and data scientists. The lion's share of soldiers' training has been spent honing their craft against both peers and inanimate targets. Machine learning is prepared to disrupt this status quo and drastically alter the way troops prepare for combat. It should be used in educating and training Army scientists, engineers, military personnel, managers, directors, and others from different backgrounds and application interests. This paper introduces the reader to various uses of machine learning in the military.

KEYWORDS: *machine learning, artificial intelligence, deep learning, military, Army, Department of Defense.*

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INTRODUCTION

AI is a rapidly growing field of technology with potentially significant implications for national security. As such, the United States and other nations are developing AI applications for a range of military functions. US military forces utilize AI and ML to improve and streamline military operations and other national security initiatives. Already, AI has been incorporated into military operations in Iraq and Syria, where computer vision algorithms have been used to detect people and objects of interest. As other nations, particularly China and Russia, are making significant investments in AI for military purposes, it remains of utmost importance for the United States to maintain a strategic position to prevail on future battlefields [1].

Machine learning is now a critical component in modern warfare systems. AI/ML improves self-control, self-regulation, and self-actuation of combat systems due to its inherent computing and decision-making capabilities; a critical aspect to consider due to the nature of combat. The future for the US and our allies requires moving to a connected battlespace, where information flows between entities and across all domains.

WHAT IS MACHINE LEARNING?

Machine learning is a subfield of artificial intelligence that uses algorithms trained on data sets to create models capable of performing tasks that would otherwise only be possible for humans, such as categorizing images, analyzing data, or predicting price fluctuations. It uses algorithms (essentially lists of rules) trained on data sets to create self-learning models capable of predicting outcomes and classifying information without human intervention. It focuses on algorithms that can "learn" the patterns of training data and, subsequently, make accurate inferences about new data. This pattern recognition ability enables machine learning models to make decisions or predictions without explicit, hard-coded instructions. To ensure such algorithms work effectively, however, they must typically be refined many times until they accumulate a comprehensive list of instructions that allow them to function correctly [2]. A symbol of machine learning is shown in Figure 1 [3].

Generally speaking, a learning problem considers a set of samples of data and then tries to predict properties of unknown data. ML builds heavily on statistics because when we train a machine to learn, we have to give it a statistically significant random sample as training data. Intelligent machines are increasing doing incredible things: Facebook recognizes faces in photos, Siri understands voices, and Google translates websites [4].

Machine learning techniques are transforming many fields including computer science, engineering, mathematics, physics, neuroscience, and cognitive science. We are surrounded by ML-based technologies: search engines learn how to bring us the best results, digital cameras learn to detect faces, credit card transactions are secured by a software that detects frauds, and cars are equipped with accident prevention systems that are built using ML algorithms [5]. In ML, data plays an indispensable role, and the learning algorithm is used to learn from the data. ML algorithms are now easy to use. One can download packages in Python. Programming languages used in ML include C++, Java, Python.

As its name indicates, machine learning works by creating computer-based statistical models that are refined for a given purpose by evaluating training data, rather than by the classical approach where programmers develop a static algorithm that attempts to solve a problem. Because the algorithm adjusts as it evaluates training data, the process of exposure and calculation around new data trains the algorithm to become better at what it does. Algorithms are the computational part of a machine learning project. Once trained, algorithms produce models with a statistical probability of answering a question or achieving a goal. Unlike in expert systems, the logic by which a machine learning model operates is not explicitly programmed; it is learned through experience. Machine learning has come to dominate the field of AI: it provides the backbone of most modern AI systems, from forecasting models to autonomous vehicles to large language models (LLMs) and other generative AI tools. Machine learning has become a household term in recent years as the concept moved from science fiction to a key driver of how businesses and organizations process information [6].

As shown in Figure 2 [7], there are different types of machine learning. The four major types of machine learning are supervised learning, unsupervised learning, semi-supervised learning, and reinforcement learning, each suited to different kinds of data and outcomes. Different types of machine learning include the following [8]:

- *Supervised Learning*: The program is "trained" on a pre-defined set of "training examples" from a "teacher," which then facilitate its ability to reach an accurate conclusion when given new data. In this case, the data comes with additional attributes that we want to predict. A common case of supervised learning is to use historical data to predict statistically likely future events. Under supervised ML, we have regression ML and classification ML.
- *Unsupervised Learning:* As their name suggests, unsupervised learning algorithms can be broadly understood as somewhat "optimizing themselves." Unsupervised algorithms do not need to be trained with desired outcome data. The program is given a bunch of data and must find patterns and relationships therein. A typical goal of unsupervised learning may be as straightforward as discovering hidden patterns within a dataset. Without being told a "correct" answer, unsupervised learning methods can look at complex data and organize it in potentially meaningful ways.
- *Reinforcement Learning:* Reinforcement learning models are trained holistically through trial and error. Reinforcement learning is a method with reward values attached to the different steps that the algorithm must go through. So, the model's goal is to accumulate as many reward points as possible and eventually reach an end goal. Reinforcement learning is an area of machine learning concerned with how software agents ought to take actions in an environment so as to maximize some notion of cumulative reward.
- *Deep Learning:* Deep learning (DL) is a specialized form of machine learning that uses artificial neural networks to mimic the human brain. It is a type of machine learning technique that is modeled on the human brain. It is an advanced technique for handling complex tasks like image and speech recognition. The way in which neural networks are trained can be described as deep learning. It is called deep because the network of neurons is arranged in several hierarchical levels. Deep learning laid the foundation for advances in generative artificial intelligence.

MACHINE LEARNING IN THE MILITARY

Technology development in artificial intelligence (AI) and machine learning (ML) are among the highest research and development priorities for the US Department of Defense (DOD) to provide enabling technologies for applications like, command, control, and situational awareness. The US Air Force

experimental X-62 VISTA aircraft incorporates machine learning and specialized software to test autonomous aerial combat flying. Air Force researchers are trying to apply AI to command and control, and to consider enemy AI use in mission planning by pursuing a switch from monolithic command and control node to distributed command and control. The goal is to take advantage of all available geospatial data from traditional and non-traditional sources to create cost-efficient actionable intelligence.

The rapid progress in computer vision made possible by deep learning techniques has favored the large diffusion of applications based on artificial intelligence (AI). The ability to analyze different kinds of images and data from heterogeneous sensors is making this technology particularly interesting for military and defense applications.

APPLICATIONS OF MACHINE LEARNING IN THE MILITARY

AI/ML is being deployed in almost every military application. Machine learning (ML) is used in the military for a variety of applications, including enhancing data analysis, improving decision-making, automating tasks to increase speed and efficiency, improving situational awareness, predicting enemy movements and logistical needs through predictive analytics, automating target recognition, and supporting human-machine teaming. Here are major military applications where machine learning will prove its importance in the years to come [9,10]:

- *Cybersecurity:* A critical area where AI is making an impact is cybersecurity. As digital warfare becomes a central aspect of modern conflicts, AI-driven cybersecurity solutions apply AI to enhance digital defenses, autonomously detecting and responding to cyber threats, safeguarding critical military infrastructure and classified communications in accordance with international law. AI-enabled web security systems can record the pattern of cyber attacks and develop counter-attack tools to tackle them. The military faces constant cyber threats, including network infiltration, misinformation campaigns, and electronic warfare. AI-enhanced cybersecurity platforms autonomously detect and respond to digital attacks, safeguarding critical military infrastructure and classified communications.
- *Logistics and Transportation:* The effective transportation of goods, ammunition, armaments, and troops is an essential component of successful military operations. AI is expected to play a crucial role in military logistics and transportation. Integrating AI with military transportation can lower transportation costs and reduce human operational efforts.
- *Target Recognition:* Traditional machine learning techniques focus on aided target recognition. This requires a large training image database of target images captured under conditions such as background terrain, target pose, lighting, and partial occlusion. AI techniques are being developed to enhance the accuracy of target recognition in complex combat environments. These techniques allow defense forces to gain an in-depth understanding of potential operation areas by analyzing reports, documents, news feeds, and other forms of unstructured information.
- *Battlefield Healthcare*: In war zones, AI can be integrated with Robotic Surgical Systems (RSS) and Robotic Ground Platforms (RGPs) to provide remote surgical support and evacuation activities. The US in particular is involved in the development of RSS, RGPs, and various other systems for battlefield healthcare.
- *Combat Simulation and Training*: Beyond battlefield operations, AI plays a crucial role in military training and simulation. Military services rely on modeling, simulation, and training systems to enhance warfighter readiness. The training systems are composed of hardware and software components that experience wear and tear and require upgrades, repairs, or replacement over time. AI-powered war-gaming platforms enable military strategists to recreate real-world combat scenarios, assess different strategies, and analyze potential outcomes. Simulation and training constitute a multidisciplinary field that pairs system engineering, software engineering, and computer science to construct computerized models that acquaint soldiers with the various combat systems deployed during military operations. The US is investing increasingly in the simulation and training applications. The military has been relying on simulations lacking machine learning to augment troop training and test the overall efficacy of virtual reality. Figure 3 shows an example of combat training [11].
- *Electronic Warfare:* The integration of AI and ML in defense computer systems is revolutionizing defense capabilities globally. The integration is reshaping and revolutionizing the modern warfare system. AI is now revolutionizing the domain of electronic warfare by enhancing signal processing. Weaponry warfare systems and weapons now come embedded with AI, making them more efficient

and less dependent on human operation. For example, BAE Systems unveiled military computer systems using AI that can detect and classify radio frequency signals to help defense forces neutralize enemy electronic threats. A typical war zone is shown in Figure 4 [12]. AI and machine learning have an important role to play in enhancing situational awareness and decision-making in the Air Force. With the collaborative combat aircraft, the Air Force is not following a linear development pattern. Instead of developing the aircraft step by step, the service is "doing it all at once," with the help of both autonomous integration and human involvement. Figure 5 shows air force combat aircraft [13].

- *Autonomous Warfare Technologies:* Electronic warfare (EW) and communications present important opportunities for AI and machine learning. Waveform-agile radar is able to change the time, frequency, space, polarization, and modulation of its signal from pulse to pulse to enhance its sensitivity, or to confuse potential adversaries about its design and use. AI-driven autonomous drones, robotic combat units, and unmanned vehicles will operate with higher levels of independence, executing reconnaissance missions, resupplying troops, and engaging threats with minimal human intervention. These systems will rely on advanced neural networks to make split-second decisions in dynamic combat environments. Figure 6 shows drone use in the military [14], while Figure 7 shows how soldier conduct drone test flights and software troubleshooting [15].
- *Command, Control, Communications, Computer and Intelligence (C4I):* C4I system rely on artificial intelligence to process massive amount of intelligence data, improve situational awareness, and automate communication networks. The US Department of Defense invested in artificial intelligence based autonomous computing systems that can minimize human intervention in military operations. Northrop Grumman integrated AI into military command centers, enabling seamless data fusion and real time threat assessments.

BENEFITS

AI is a rapidly growing field of technology with potentially significant implications for national security. AI powered military computer system optimize logistics through streamlining supply chain operations and predictive maintenance. From decision making and cybersecurity to logistics and electronic warfare, AI integrated computing system is transforming and revolutionizing military efficiency and strategic planning. Other benefits include the following [10]:

- *Automation:* The phrase "software is eating the world" was coined in 2011 to reflect the growing use of software to take over mundane or well-structured tasks. Automation of repetitive tasks through ML can free up human analysts to focus on more complex problems. By automating data analysis, military personnel can concentrate on strategic execution rather than manual evaluation of information. This capability ensures that decision-makers have the most relevant, up-to-date information at their disposal, reducing the likelihood of errors and missed opportunities. The integration of AI into autonomous defense systems is revolutionizing military operations by enhancing accuracy, improving surveillance capabilities, and streamlining battlefield logistics.
- *Enhanced Decision-making:* Artificial intelligence (AI) and machine learning (ML) are transforming the landscape of military decision-making, equipping defense forces with cutting-edge tools that enhance intelligence gathering, automate processes, and improve battlefield strategies through AI systems. Military AI is revolutionizing decision-making processes by integrating artificial intelligence and machine learning into critical operations. ML algorithms can process vast datasets from the battlefield to help commanders make faster, more informed decisions.
- *Enhanced Situational Awareness:* By aggregating and interpreting intelligence systems from different military branches, AI enables a comprehensive, real-time operational picture that enhances military strategy and battlefield awareness. Drones, equipped with advanced sensors and computer vision technology, can identify enemy positions, track movements, and provide real-time situational awareness.
- *Predictive Analytics:* Machine learning algorithms analyze historical military engagements and current intelligence data to predict future enemy maneuvers and emerging threats, allowing military personnel to mitigate risks effectively. Using techniques like supervised learning, ML can forecast enemy movements based on historical and current intelligence, and estimate logistical requirements. AI's predictive capabilities extend beyond battlefield strategy to include risk assessment, crisis management, and tactical forecasting.

- *Cybersecurity:* As cyber warfare intensifies, military networks are increasingly vulnerable to attacks. AI driven cybersecurity system enhance military computer defenses through early detection, analysis, and neutralization of cyber threats. A cyber-attack on military facilities can result in the loss of highly sensitive data and cause damage to military bodies. By relying on established patterns, security systems can preempt attacks and develop countermeasures.
- *Maintenance:* Keeping track of the mechanical health of millions of pieces of equipment is a big job for the Army. To help with this data-intensive work, it is recruiting an AI assistant. ML models can predict part demands based on operational status, location, and other changing factors, improving maintenance scheduling.
- *Intelligence:* AI and ML are used for tasks like image recognition, electronic warfare, and communications. The incorporation of artificial intelligence into defense strategies has already begun to transform NATO's intelligence and surveillance capabilities in regard to the gathering and processing of data in order to effectively identify targets. AI/ML will enhance military decision-making and accelerate the acquisition of actionable intelligence.
- *Training:* ML can be used to create more realistic training simulations and analyze performance to adapt training for individual soldiers. This training plan will teach every marine the rudimentary skills necessary to implement simple solutions for themselves.
- *Improved Targeting:* Artificial intelligence and machine learning tools are already in use to help identify targets on the battlefield and they might soon power new types of cyber and autonomous weapons. These technologies could have profound implications for the role of humans in armed conflict and there will be important choices ahead. ML can significantly reduce the time it takes to identify a threat and determine if it is an enemy, speeding up the targeting sequence.

CHALLENGES

Although AI has the potential to impart a number of advantages in the military context, it may also introduce distinct challenges. While AI enhances military decision-making, its adoption brings significant ethical and security challenges that must be addressed to ensure responsible use. General concerns about the impacts of adversarial behavior on stability have been emphasized by recent demonstrations of attacks against these systems. AI-enabled systems can fail due to adversarial attacks intentionally designed to trick or fool algorithms into making a mistake. Other challenges include [16,17]:

- *Ethical Concerns:* The entire topic of robotics and machine automation can become controversial when people worry that these technologies might evolve to become better than human intelligence. Some people believe that AI eventually may pit humans and machines against each other in a battle of survival. Human operators must retain ultimate control over AI-driven systems to ensure that ethical considerations and strategic judgment are factored into decision-making.
- *Bias and Errors:* A clear disadvantage of learning AI is that it is only as good as the data it gets. A number of chatbots have developed undesirable sexist and racist. AI/ML systems are only as effective as the data they are trained on. If training data contains biases, whether historical, cultural, or systemic, the models may produce skewed threat assessments, leading to incorrect targeting or misidentification of hostile actions. Past incidents, such as defensive AI systems misidentifying friendly assets, highlight the potential for error and the need for careful validation.
- *Human Oversight:* Despite advancements, human oversight remains critical, especially in decisions involving the use of force. Human oversight remains an integral part of military operations and that responsibility for actions taken by AI-driven systems is clearly assigned. AI should function as an enhancement to human judgment rather than a replacement for military leadership. As AI technology progresses, military forces will need to balance automation with human oversight, ensuring that these advancements align with ethical principles, international regulations, and strategic objectives.
- *Trust in AI:* AI also can be a touchy subject when it comes to creating teams of humans and AI computers. The core issue: can humans really trust machine intelligence, and how can humans be sure that AI is making the best decisions? The entire topic of robotics and machine automation can become controversial when people worry that these technologies might evolve to become better than human intelligence.
- *Accountability:* The increasing deployment of AI-driven autonomous weapons raises concerns about accountability and decision-making authority. Unlike human-operated systems, autonomous weapons can make life-or-death

decisions without direct human intervention. These systems can fail when they encounter unexpected conditions and events.

- *Cybersecurity Threats:* AI-powered military applications are prime targets for cyberattacks. Adversaries may attempt to manipulate AI algorithms, deploy adversarial machine learning techniques, or exploit vulnerabilities to disrupt military systems.
- *Complexity:* The stochastic (randomness or chance) nature of AI/ML models makes it difficult to determine what impact they will have on Army organizations and processes. As such it will become increasingly important to maintain flexibility and adaptability in procuring AI/ML models.
- *Intermittent Demand:* This occurs when spare parts are needed only occasionally but historically has been a challenging element of the supply chain to forecast, leading to costly overages of excess spare parts. What makes spare parts problematic to forecast is that the sheer size and complexity of the military's supply chain can be daunting, with tens of thousands of unique parts for different vehicles, aircraft, and equipment to oversee. Using advanced forecasting methods, like machine learning, can help identify subtle patterns, such as seasonal changes, that might influence demand for these rarely needed parts. Machine learning is very effective at predicting intermittent demand even when an asset's operational status changes. AI/ML model can predict when a part breaks with a sensitivity of 90%.
- *Expertise:* Advancements in AI/ML technology is critically dependent upon having skilled workforce, and acquiring people with the right knowledge and skills to develop these technologies. While the commercial sector is able and willing to pay premium prices for such people, government and the defense sector are not in such a good a position to do this.

FUTURE OF MACHINE LEARNING IN THE MILITARY

Machine learning models can adapt to complex and changing patterns, which is especially valuable in dynamic environments like military operations. The US Department of Defense (DoD) is latching onto this revolutionary technology with the assumption it can provide the US military with an enduring decision advantage over its adversaries. The DoD and DARPA should continue to allocate as many resources as possible to improve machine learning due to the incalculably high cost an unprepared defense could incur [11].

As artificial intelligence and machine learning continue to advance, their role in military strategy is expected to grow, bringing about groundbreaking innovations in decision-making, predictive analytics, and battlefield automation. These advancements will enable armed forces to operate with increased efficiency, accuracy, and adaptability, allowing them to respond swiftly to evolving threats and complex combat scenarios. Rather than replacing human decision-makers, AI will serve as an intelligent assistant, providing data-driven insights and strategic alternatives while maintaining ethical oversight.

As governments and the defense industry project the expansion of AI/ML into new use areas in the next decade, their future applications may include multi-aircraft collaboration, precision targeting, and fully autonomous operations in denied communications environments. Future AI/ML advancements will further enhance cybersecurity defenses, using machine learning to detect, counteract, and neutralize cyber threats in real time [16].

CONCLUSION

Today, AI is perhaps the most transformative phenomenon that has happened in warfare in many centuries. US military forces utilize AI and ML to improve and streamline military operations and other national security initiatives. The US Air Force is using AI to keep track of when its planes need maintenance. It should be no surprise that the largest militaries in the world are focusing more on this technology than anything else, and the winner of this tech race will likely have more global leverage than the US had after developing the atom bomb.

As nations invest in AI-driven defense mechanisms, military organizations must leverage AI tools, generative AI, and autonomous weapon technologies to maintain strategic superiority in military operations. Governments that adopt machine learning in their military sectors will have an edge in warfare scenarios. China and the US are the most prominent of AI and machine learning for military use. More information on machine learning in the military is available in the books in [5,18,19].

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Figure 1 A symbol of machine learning [3].

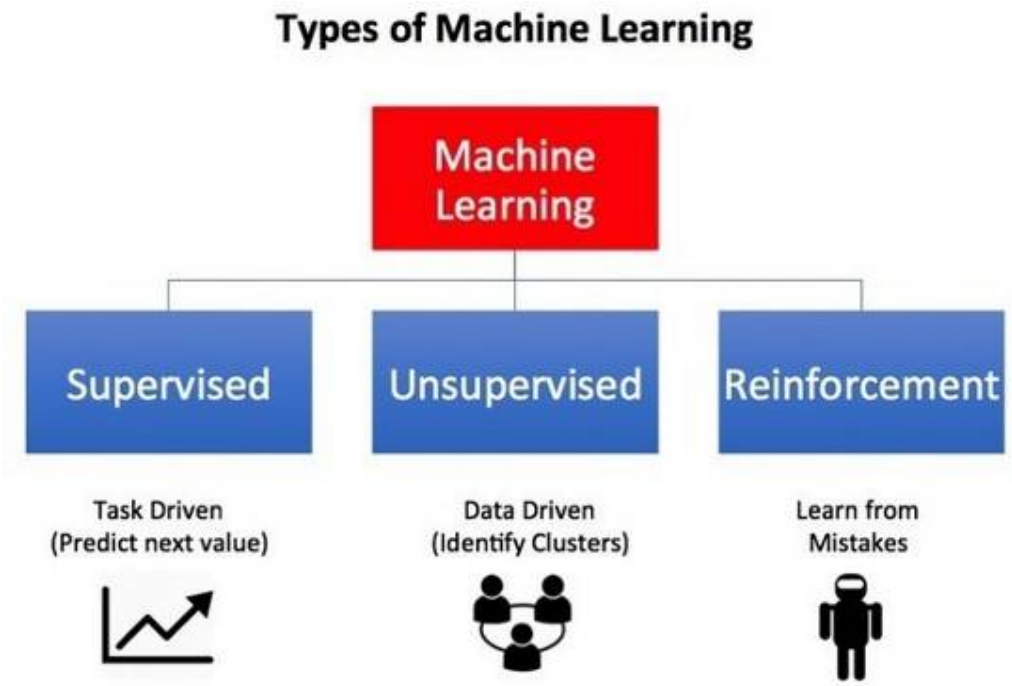

Figure 2 Different types of machine learning [7].

Figure 3 An example of combat training [11].

Figure 4 A typical war zone [12].

Figure 5 Air Force combat aircraft [13].

Figure 6 Drone in military use [14].

Figure 7 Soldiers conducting drone test flights and software troubleshooting [15].