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Impact of Emerging Technologies in Modern Warfare

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Abstract: ***The modernisation of defence infrastructure and the adoption of emerging technologies, such as artificial intelligence (AI), space technology, genetic engineering, radar technology, nanotechnology, 3D printing, the Internet of Military Things (IoMT), extended reality (XR), quantum computing, and cyber capabilities, are revolutionising military operations. Modern warfare is now fought across land, sea, air, cyber, space, and information domains. This paper analyses how emerging technologies are applied in military operations, identifies their capabilities, and explores the implications for current and future conflict. As new technologies emerge, they may lead to an arms race between countries. It is crucial to consider the erosion of ethical standards to manage future warfare. The weapons based on emerging technologies present significant dangers if used by terrorist groups, so global security should be a top priority.***

Keywords: Artificial Intelligence, Cyber Warfare, Quantum Computing, Genetic Engineering.

Nomenclature:
XR: Extended Reality
AI: Artificial intelligence
ISR: Intelligence, Surveillance, and Reconnaissance
IoMT: Internet of Military Things
AWS: Autonomous Weapon Systems
UAVs: Uncrewed Aerial Vehicles
GPS: Global Positioning System
HEL: High-Energy Laser
VR: Virtual Reality
AR: Augmented Reality
MR: Mixed Reality

I. INTRODUCTION

Modern warfare is shifting toward automation, hypersonic weapons, digital surveillance, precision-guided weapons, stealth aircraft, and space militarization. These shifts increase operational speed but create severe ethical, logistical, and global destabilisation risks. Artificial intelligence (AI) drives rapid innovation in robotics, aerospace engineering, cyber security, space technology, and early computer systems [1]. New techniques like additive manufacturing (3D printing) reduce production costs, making capabilities such as drones and surveillance technology widely available. Developed countries have launched satellites to improve communication, enhance target recognition, and enable accurate intelligence collection. Wars now extend into data centres, cloud infrastructure, semiconductor factories, and digital networks. War's impact on technology is increasingly visible across AI development, cybersecurity investments, and semiconductor manufacturing. Technology may even proceed beyond our imagination.

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II. EMERGING TECHNOLOGIES

Major global powers are competing for dominance in artificial intelligence, semiconductor manufacturing, cybersecurity infrastructure, and emerging technologies such as quantum computing, thereby compressing the timeline of warfare.

A. Artificial Intelligence

Modern warfare increasingly relies on artificial intelligence because it can analyse vast amounts of data, detect patterns in enemy behaviour, make predictions, identify potential threats, and recommend tactical responses. An AI-based Intelligence, Surveillance, and Reconnaissance (ISR) system can gather extraordinary information and completely remove the human interface in decision-making, command, and execution, almost in real time. AI systems are being employed to detect and identify wireless communications links and jam these signals using appropriate technology. The AI may lead to autonomous conflicts without human intervention, and it is important to recognise the dangers of AI's automated decision-making in conflict and combat situations. Therefore, it is recommended that proactive measures be taken to ensure the ethical use of AI-based weapons [2].

B. Autonomous Weapon Systems

Autonomous Weapon Systems (AWS) can locate and identify targets, then track and destroy them independently in electronic warfare environments without direct human intervention, and can make judgments on their own [3]. Uncrewed Aerial Vehicles (UAVs), also known as aerial drones, are equipped with high-resolution cameras and sensors to provide real-time data on enemy movements in hostile territories. The military-grade armed drone strikes from a safe distance may be very accurate and precise. Yet, the accuracy of drone strikes does not mean that the target was correctly identified as a military objective. With algorithms determining the functioning of autonomous systems, they can undoubtedly keep up with the rapidly evolving battlefield situations and make quick decisions. Autonomous Underwater Vehicles (AUVs), known as maritime drones, are being employed for hazardous

reconnaissance, mine detection, undersea surveillance, and combat missions to provide more detailed information on maritime security threats. Robots equipped with specialised tools are now commonly used to assist in mine clearing and explosive ordnance disposal safely. Autonomous systems are being used in search-and-rescue missions, providing critical support in combat zones and inaccessible environments.

C. Cyber Warfare

Cyber warfare has become a major part of modern conflicts. Nations are developing advanced cybersecurity tools to protect their infrastructure from cyberattacks. Cyber-attacks can disrupt critical infrastructure without conventional military engagement. This has accelerated improvements in data protection, encryption, and network security. The importance of cybersecurity during conflict has grown dramatically, as it protects financial systems, communication networks, and critical infrastructure. Security software detects unusual network activity, identifies threats, and prevents large-scale breaches. Modern conflicts are increasingly won through cyber-attacks against information manipulation, propaganda, and disinformation campaigns. Since ethics in cyber warfare is not well-defined, cybersecurity awareness is essential for global security [4].

D. Precision Weapons and Missile Technology

Advanced sensors and networking for long-range, precision hypersonic systems enable unprecedented accuracy and speed in striking a target. The hypersonic missiles are equipped with AI-enhanced guided systems that allow them to adjust their trajectory in real time, thereby compressing reaction times and enabling speeds exceeding Mach 5, making them extremely difficult to intercept using conventional defence systems. The increasing number and accuracy of ballistic and cruise missile systems will pose a significant threat to headquarters, communications facilities, airfields, logistic infrastructure, and other critical targets.

E. Space Technology

Space-based systems serve as early indicators of precision strikes, global surveillance, and reconnaissance, and provide real-time battlefield information for coordination and decision-making. Satellite imagery and signals play a crucial role in rapid communication, navigation, monitoring, intelligence, tracking enemy positions and activities, detecting and tracking missile launches, and monitoring compliance with arms control. The Global Positioning System (GPS) is used to determine the location of artillery and ballistic missiles on Earth in real time. Satellites are susceptible to various threats, including cyberattacks, communication disruptions, jamming, and maintenance issues.

F. Communication Systems

An advanced communication system that is not subject to adversary interception is critical during military operations. This has led to the development of secure, uninterrupted communication networks for military personnel. As a result of the development of highly advanced surveillance systems, advanced sensors, satellite systems, and high-speed connectivity, data analysis technology has improved situational awareness and decision-making, enabling real-time information collection.

G. High-Energy Laser (HEL) Technologies

High-Energy Laser (HEL) technologies are also being developed to engage a wide spectrum of aerial threats at the speed of light with precision. Pointing and tracking software and algorithms analyse data from integrated sensors to guide the laser beam to its target with extreme precision [5]. The software integrates with broader command and control networks, providing optimal power levels for different targets, determines the appropriate sequence and timing for engaging targets, and enhances overall situational awareness. A laser can be integrated with software for realistic battle simulations and training exercises.

H. Additive Manufacturing (3D Printing)

3D printing enables rapid on-demand production of replacement parts, such as damaged drone components, cruise and hypersonic missile components, and specialised equipment, in days or hours rather than months. 3D printing is revolutionising modern warfare by enabling on-site, low-cost production and delivery of weapons, modified drones, and spare parts using advanced metals and ceramics customised for specific battlefield requirements. 3D printing technology can digitally scan broken parts and produce exact replicas or improved versions, with minimal downtime. It enhances logistical agility by reducing dependence on a long supply chain while enabling quick design modifications for mission-specific needs. The future of 3D printing for arms manufacturing, in real time with greater precision and efficiency at decentralised locations, could be a more affordable and decisive factor in warfare [6]. Innovation in materials will enable the use of high-strength alloys and polymers to enhance the durability and performance of 3D-printed weapons.

I. Genetic Engineering and Biotechnology

Genetic engineering in modern warfare poses significant threats primarily through the creation of advanced biological weapons. Gene editing could be used to alter a soldier's DNA to increase physical strength, improve sensory perception, accelerate wound healing, and reduce susceptibility to fatigue. The delivery of engineered pathogens further increases the lethality and precision of these weapons. Genetically engineered technologies could create biological agents resistant to existing treatments.

J. Quantum Computing

Quantum computing enables ultra-sensitive surveillance, unhackable communications, and superior strategic logistics. Quantum sensors can detect, track, and locate submerged submarines or underground bunkers by measuring minute shifts in gravitational and magnetic fields. The sensor can also identify stealth aircraft, making them difficult to hide. Quantum technology provides precise navigation, allowing submarines, ships, and uncrewed vehicles to operate accurately in areas where GPS signals are blocked or jammed. Quantum-accelerated

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simulation enables rapid modelling of complex battle scenarios and weather patterns to support strategic decision-making. Quantum sensing enables unprecedented battlefield awareness by detecting signal movements and anomalies that were previously invisible [7]. The nation equipped with quantum-enhanced decryption capabilities could intercept and decrypt military communications, rendering secure operations.

K. Internet of Military Things (IoMT)

Internet of Military Things (IoMT) devices detect phenomena and events through sensors, collect data, and forward it to the cloud for further processing and analysis. IoMT applications include surveillance, target detection, threat localisation, data collection, and analysis. IoMT technology manages large numbers of devices and equipment to facilitate more efficient coordination of complex processes. The IoMT technology enables management in the air, on the ground, at sea, and in space through cyber interfaces, using intelligent command and control [8]. Through IoMT, data collection, processing, and distribution will enable more efficient management of flight safety. Timely information, management, or command is of crucial importance for pilots. IoMT technologies are used to surveil robotic uncrewed aircraft, underwater vehicles, and land vehicles for military purposes. Microelectromechanical Sensors (MEMS) with Global Positioning System (GPS) capabilities have played a significant role in the fields of surveillance and soldier control. The blockchain technology exchange collects data from IoT devices and securely and reliably sends it to a cloud server.

L. Nano Technology

Nanotechnology focuses on developing stronger, lighter armour, advanced stealth material, and enhanced sensors. Nano sensors can detect chemical, biological, or radiological agents in the environment. Nano-scale explosives can be used to create more powerful and efficient explosives. Materials such as carbon nanotubes and graphene enable lighter, stronger body armour that offers better protection. Nano composites allow for the creation of durable, lightweight vehicles. Nanoparticles can be used for targeted drug delivery, accelerate wound healing, and open new possibilities for treating injuries and diseases. Nanoscale coatings can be applied to weapons to enhance their durability, corrosion resistance, and stealth. Military clothing using nanotechnology is durable, crack-resistant, and waterproof, protecting the environment from flames, heat, insects, and chemicals [9].

M. Extended Reality (XR)

Emerging technologies, including simulators and extended reality (XR) tools such as virtual reality (VR), augmented reality (AR), and mixed reality (MR), are used to train military forces for military operations [10]. AR equips soldiers with wearable glasses or headsets to provide mapping information. XR tools enable the visualisation and analysis of strategic warfare scenarios during immersive training for operators, mission planners, and controllers to better understand spacecraft operations. XR tools are typically used for motivation and knowledge training to protect civilians in armed conflict. AR provides real-time information during operations, enhancing situational awareness and decision-making capabilities.

III. ETHICAL CHALLENGES

The ethical implications of the use of military technology in modern warfare are imperative for ensuring responsible and principled conduct on the battlefield. The deployment of autonomous weapons raises concerns about the accountability for actions taken without direct human control, which is a potential violation of human rights and international law [11]. Since these systems operate independently, it will be very difficult to determine who is responsible for any mistakes or malfunctions. The increasing use of cyber warfare poses challenges regarding ethical guidelines and legal frameworks. It is important to ensure that technological advancements are used ethically and responsibly, protecting human rights during times of war. The potential for autonomous robots to make kill decisions without human intervention raises deep ethical, moral, and legal concerns because it is increasingly difficult to distinguish between military and civilian targets. It is the moral responsibility of individuals and entities involved in the design and fabrication of 3D printed weapons of mass destruction, such as chemical and biological weapons, which are unethical in war. The speed of AI–driven decision–making can be compressed from minutes to seconds, increasing the risk of accidental escalation and limiting time for human judgment. The unethical accumulation of nanoparticles in the environment will lead to ecological damage and adverse health effects. Future wars could involve targeting vital trade routes, leading to massive disruptions to the global industrial base.

IV. CONCLUSION

The integration of emerging technologies is revolutionising military operations and shaping the future of war. Countries are pursuing these technologies with the sole aim of weaponising and deploying them as quickly as possible to enhance the effectiveness and efficiency of military operations. Developments in imaging, remote sensing, night vision, sensors, precision-guided munitions, stealth technology, and, above all, digital communications and computer networks are compelling us to adopt new war-fighting techniques. The study recognises the ethical implications and potential challenges associated with integrating emerging technologies into warfare.

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AUTHOR'S PROFILE

Prof. (Dr.) Shailaj Kumar Shrivastava is a distinguished academic, administrator, and author holding a first-class Master's Degree (second topper) in Physics (advanced electronics) from Patna University. He has worked as a Research Fellow at the National Physical Laboratory, New Delhi, and obtained his PhD in Physical Sciences from Delhi University. He was selected for the post of lecturer on the recommendation of the Bihar State University Service Commission, Patna, and secured first rank in the Merit list of Magadh University, Bodh Gaya. He completed different courses, such as the Orientation Course (one from Jawaharlal Nehru University, New Delhi), refresher courses (two, from Jawaharlal Nehru University, New Delhi and Himachal Pradesh University, Shimla, respectively) and the Principal Workshop(one) from Jawaharlal Nehru University, New Delhi) and awarded grade 'A' in all. He was appointed as Principal through the Selection Committee and secured the first rank in the Merit List of Magadh University, Bodh Gaya. He possesses outstanding educational skills and has effectively incorporated innovative teaching methods in college, enhancing social and cultural activities. Prof. Shrivastava excels in Physics teaching and has demonstrated strong administrative skills as Principal. His research interests are in superconductivity, thin films, and devices. With more than 28 years of distinguished teaching experience, he has published 78 research papers in leading national and international journals. He participated in more than 125 national and international conferences and seminars in India and abroad. He presented his papers on superconductivity and higher education issues. He is the editor-in-chief and an editorial board member of journals. Three Scholars have been awarded PhD degrees under his supervision. Besides being a member of several academic bodies (Academic Council, Senate, Syndicate, Resource person, Expert, Observer, and Centre Superintendent, etc.) at the university, he has over 15 years of experience as a principal in constituent colleges of L.N. Mithila University and Magadh University. Currently, he is the Principal at Kanhai Lal Sahu College, Nawada, Bihar (A constituent unit of Magadh University, Bodh Gaya). He has also written two books, entitled "Superconductivity: Materials and Applications" and "Reforms in Indian Higher Education". He got several awards from different organisations, including the 'Young Research Award' at IUMRS-ICA-98 held at IISc Bangalore. Despite his busy administrative schedule, Prof. Shrivastava remains active in his academic pursuits.

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