NATO OTAN
Science & Technology Organization (STO)

Robotics and Autonomous Systems

Briefing paper

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Autonomous systems are an integral part of today’s conflicts, being used for operations including intelligence gathering and offensive strike. As enabling technologies evolve and military operations become more complex, the options for use of semi- and fully autonomous platforms will also increase. Much of the autonomous systems research and innovation is being driven by the commercial sector and is therefore dual-use.

Implications

Economic Implications – Increased automation will prompt economic transformation in many sectors. In transport, autonomous vehicles could drastically reduce labour costs, increase efficiency, transform logistics, and deter accidents. In manufacturing, production speeds could improve, and errors and operational costs could decrease. In agriculture, seed-planting robots and autonomous farming equipment promise higher crop yields with reduced labour and environmental impact. These advancements may cause economic disruption, particularly in the labour market. Many jobs could be displaced, necessitating significant workforce retraining.

Military Implications – Growth in robotics and autonomous systems (RAS) use has been concentrated in the air domain, but the land and maritime domains' use in logistics, sustainment, and manufacturing are growing increasingly important. Intelligent autonomous systems will enable novel capabilities, including long-duration under-water operations or operations in extreme or GNSS (Global Navigation Satellite System)-denied environments. Autonomous systems could also increase the impact of cyber-attacks while offering new ways to defend against them. However, in the near-term, semi–autonomous, rather than fully autonomous, systems will be of greater interest to NATO.

Societal Implications – How societies balance technological innovation with social and employment needs will determine the benefits of autonomous systems. Trust, reliability, safety and transparency are crucial for widespread adoption. 'Explainability' (systems' ability to provide understandable reasons for their decisions), as well as training and education, will be key to building trust. Clear regulations, ethical guidelines and security measures are required to address concerns about autonomy and accountability. However, semi-autonomous systems will continue to develop long before safe full autonomy is realised.

Key Technology Areas

Counter-RAS – Research on combatting uncrewed threats through kinetic and directed non-kinetic effectors is growing. Rapid detection, classification and tracking require advanced sensors and software to enable cost-effective RAS-on-RAS engagements, as vehicles may be too fast for direct human control. In particular, research is advancing in AI-enabled swarm-on-swarm engagement, advanced detection sensors and electromagnetic counter-RAS capabilities. High-powered radio-frequency-directed energy weapons are a promising area of non-kinetic counter-RAS.

Levels of Autonomy – Despite their adaptability and advanced decision-making capabilities, autonomous systems will likely involve humans in a supervisory role, while reducing the need for human brain power. For example, the 'warfighter as a system' concept foresees human-machine systems that allow every soldier to act as a squad. In the cyber domain, autonomous software agents will increasingly undertake offensive/defensive operations. Notably, NATO Allies have committed to ethical use during military operations.

Human-RAS Teaming – Research exploring the interaction between humans and machines in future semi- and fully autonomous systems is plentiful. This research recognises that humans cannot fully synthesise and act on the volume of information presented, nor control the autonomous collection of data. Therefore, more effective interaction between AI, RAS and humans will enhance operations. It is important to consider the need for human control, and AI's ability to assess the trustworthiness of a human operator's input.

Technology Convergence

Biomimetics, Energy and Propulsion – Nature inspires functional and behavioural aspects of robotics. Examples include the mimicry of animal swarming, or of insect neurons (which could enable real-time spatial tracking of multiple moving objects). Reduced energy requirements facilitate low-power control systems, improving size, weight, power and cost and drastically reducing the trade-offs between these factors.

Artificial Intelligence and Quantum – AI will be increasingly embedded in warfare platforms, systems and weapons across land, sea, air, space and cyber domains. AI-enabled systems can process vast data in real time, improving awareness and response times. Machine learning enables systems to learn from experience and adapt to situations. In autonomous systems, AI improves coordination between units, enabling swarming behaviour and complex collaborative missions. Advances in quantum computing and quantum sensors enhance the secure processing speed of AI and associated sensors, facilitating improved autonomous systems.