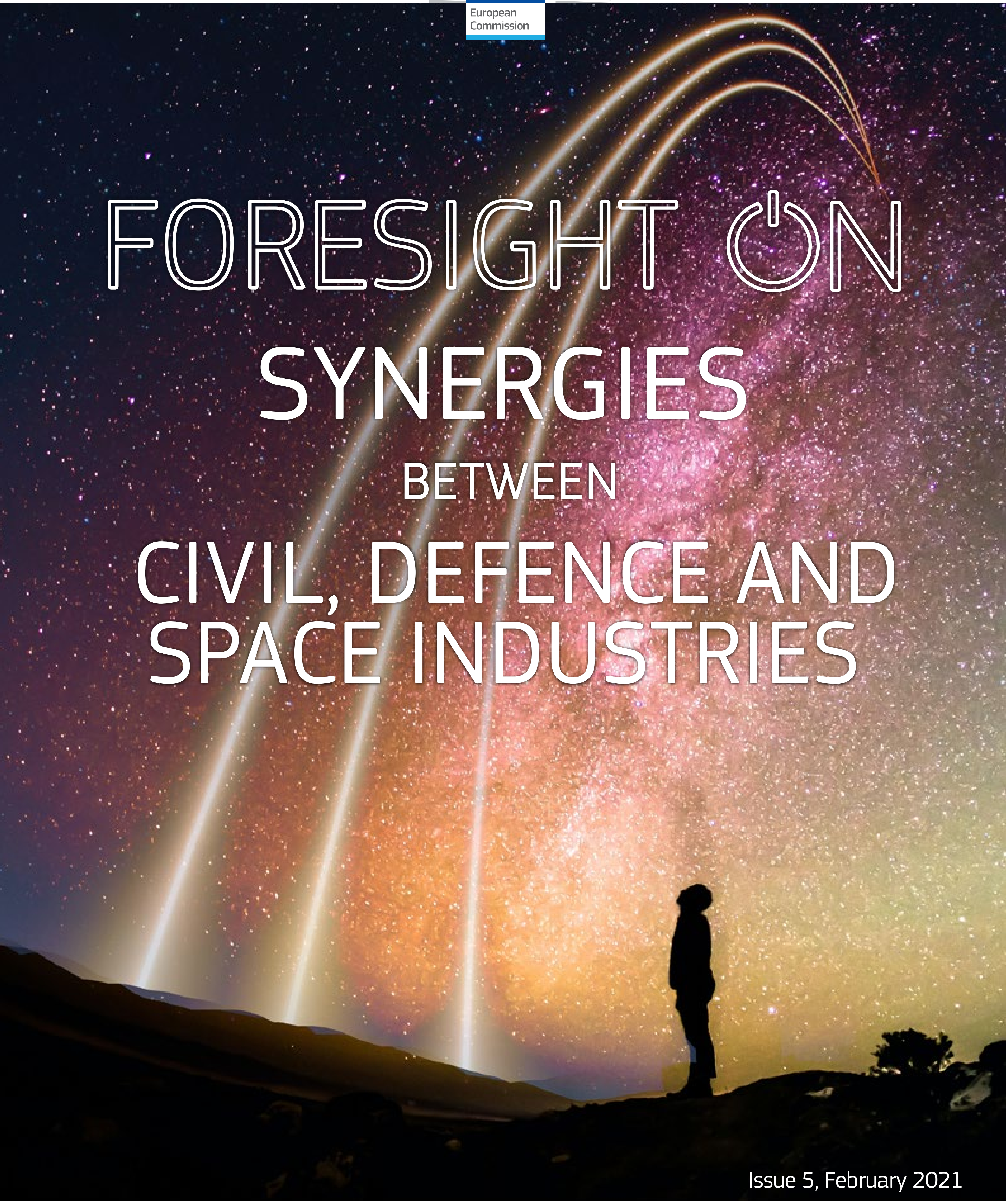
European Commission



FORESIGHT ON

SYNERGIES BETWEEN CIVIL, DEFENCE AND SPACE INDUSTRIES

Issue 5, February 2021

Joint research centre

WHY A FORESIGHT NEWSLETTER?

The objectives of the newsletter 'FORESIGHT ON' are to raise awareness and stimulate debate on trends, important emerging issues and potential implications, as well as to support future thinking (timeline 3-10 years) among policymakers, to trigger reactions and inspire strategies and long-term policies. The primary audience is the College of Commissioners and the senior management of Directorates-General.

This foresight newsletter looks forward at key challenges and opportunities that the synergies between civil, defence and space industries might need to address. The intention of the newsletter is to enlarge the discussions by highlighting forward-looking questions backed by recent facts and figures, related to the Action Plan on 'Synergies between Civil, Defence and Space Industries'. The objective is not to be comprehensive but to shed light on relevant issues for European policymaking.

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Greg Rakozy - Unsplash.com

Other images:
Convergences of Emerging and Disruptive Technologies (EDTs):
DLR Institute of Robotics and Mechatronics.

Global Green Intelligence: Earth observation data-informed negotiations: Coperinicus

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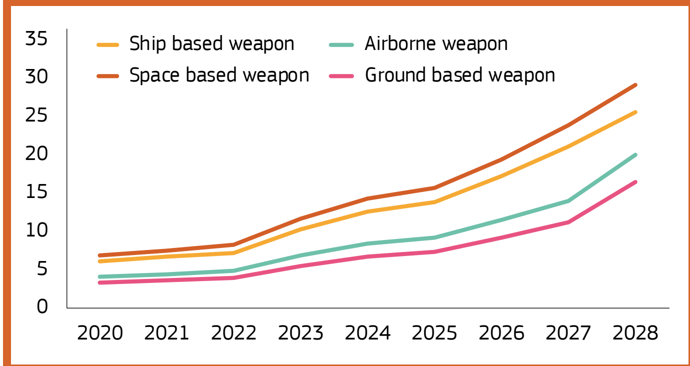
DIRECTED ENERGY WEAPONS

Directed Energy (DE) technology is a future strategic capacity in both a military and economic sense. Economically, DE can be used for propulsion and energy transport in space. DE is also considered to be a method to defend the Earth from the impact of meteorites[1].

Militarily it can be used for advanced weapons. DE Weapons (DEWs) aim laser, microwave or particle beams at a target to hinder it, to temporarily incapacitate it, or to destroy it[2]. DEWs could bring a solution to a number of upcoming and serious threats[3] that have no good solution currently, such as hypersonic missiles, drone swarms, and some types of anti-satellite weapons. Conventional defences are not fast enough to deal with these. DEWs could therefore alter the military strategic balance.

Figure: Global DEWs market forecast in US$Billion.



Source: Market Forecast Amsterdam

Because the use of DEWs by adversaries is expected to increase, new defences are needed for the future. The US is leading in the technology's development and use[4]. European industry should be able to produce DE systems, as a tool in the space exploitation arsenal, as well as for defence use. Fostering Research and Development will be needed to build up capabilities in DE and DEW production and protection.

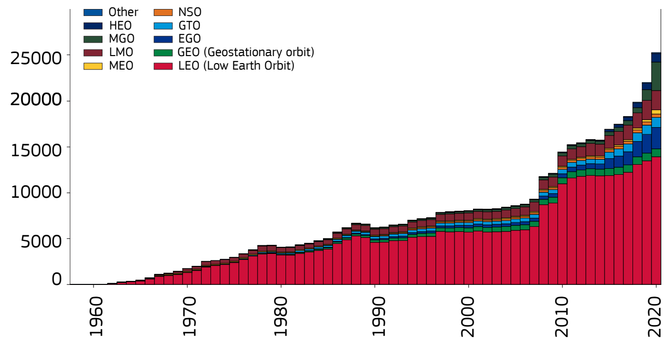
SPACE TRAFFIC MANAGEMENT AND CONTROL

Space, once completely empty, is becoming congested and contested. We are seeing over 80 spacefaring nations (some adversarial), a growing host of private companies, a proliferating number of satellites and a saturating radiofrequency spectrum. Our military and economic reliance on space-based services (navigation, communication, observation) is creating growing vulnerabilities.

To ensure a sustainable use of space for the future[5], better *Space Traffic Management* (STM) is needed. STM encompasses measures, rules, capabilities, organisations, governance and cooperation for the safe use of space[6]. Beyond just Space Surveillance and Tracking that is already in the Space Programme to detect and track objects and help prevent collisions, we need the deeper contextual understanding called *Space Domain Awareness* (SDA), to be conscious of threats to space infrastructure and to deter unattributable attacks, the hallmark of hybrid warfare[7,8].

New international (UN[9]) rules are needed to give private space enterprise long-term regulatory clarity for their investments, and to establish a global level playing field with clear rules for sustainable use. The EU should not leave all the initiative to the US[10], but take an active role in STM, to create a position from which to enter into strategic partnerships for STM and SDA.

Figure: Number of objects in orbit (satellites and debris) over the years.



Source: European Space Agency's Space Environment Report, 2020.

TECHNOLOGICAL SOVEREIGNTY: CHIPS, ECHOES FROM THE PAST AND MULTI-DIMENSIONAL RIPPLES

Chipsets are a set of electrical components that control data flow between processors and other key components in a system, such as the 5G infrastructure (network, consumer mobile devices and Internet of Things devices). These are all important for the future of our civil, space and defence industries.

The overall global chipset landscape is quite varied, but in the crucial 5G sector the EU is weak. It was well-placed in the design and production of chipsets for the 2G market[11], but became more dependent on foreign companies with reduced production costs. Recently, strategic alliances have been made, e.g. Nokia with Intel, Marvell and Broadcom[12], to address this dependence.

Against this background, we need to urgently rethink and redesign the supply chain risk management (SCRM) strategy to achieve mastery of the supply chains of these critical technologies. They are key for our future well-being (e.g. chipsets are present in health monitors) and our competitiveness (chipsets enable other technologies). Effective strategic foresight and targeted investments, e.g. to re-build EU capability to manufacture chipsets, must be made to increase awareness and reach socio-economic resilience against disruptions and external shocks. The launch of a European alliance on microelectronics would significantly give a boost to this endeavour.

Table 1 – Chipset types vs. top chipset manufacturers

5G Chipset Type	Huawei Technologies	Samsung Electronics	Nokia	Ericsson	Fujitsu Limited	ZTE Corporation
Application Specific Integrated Circuit	■	■				
Radio Frequency Integrated Circuit	■	■				
Millimeter Wave Technology Chips	■	■	■			
Field Programmable Gate Array					■	■

Source: Oliveri et al., 2019

1. DE-STAR Directed Energy Planetary Defense, https://www.deepspace.ucsb.edu/projects/directed-energy-planetary-defense
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3. China's Advanced Weapons Systems, 12 May 2018, U.S.-China Economic and Security Review Commission, https://www.uscc.gov/research/chinas-advanced-weapons-systems
4. Global market share by 2028: U.S. 31 %, EU 17 %, China 6 %, Russia 2 %. Global Directed Energy Weapons – Market and Technology Forecast to 2028, October 2020, MF201025, Market Forecast BV, Amsterdam.
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12. https://www.allaboutcircuits.com/news/nokia-taps-three-major-chip-vendors-customized-5g-chipset/

GAME-CHANGING WEARABLE SENSORS

Across the military sector, sensors have the potential to improve productivity, efficiency and reduce costs, and when associated with an Internet of Things (IoT) ecosystem they will change military economics. Increases in military spending, a rise in terrorism and asymmetric warfare are expected to be the major drivers of IoT and the sensor market. Sensors are expected to dominate the market in 2028 with an estimated revenue of around €27.3 billion[1]. This will be a game changer for soldiers who can expect to be enhanced with three types of sensors.[2]

Table: Real-time monitoring sensor

Sensor Type	Use	Measurement
Physiological	to spot injuries, trauma and stress	heartrate, blood pressure
Kinetic	stress and injury, generate electricity and offer tactical coordination between ground troops and command centers	steps, location
Agent detection	to detect and avert dangers in environment	radiation, chemical

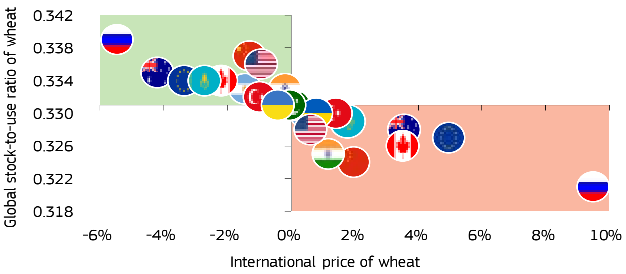
Source: PEI-Genesis

Key challenges remain for this technology, such as the cost of its lifecycle and cybersecurity. There are large ethical, privacy, data governance and fundamental human rights issues to be addressed too.

CLIMATE EXTREMES AND AGRICULTURAL SHOCKS HIT GLOBAL MARKET

Severe climate events such as drought, heat stress and water excess are traceable thanks to Earth Observation-based information and modelling. When they occur in several food producing regions of the world, within a relatively short period of time (concurrent extremes), they can cause large crop yield losses, shock the global markets and have serious socio-economic impacts. This may have implications in the civil and defence sectors when triggering food security issues and socio-economic instabilities, especially in certain regions of the world.

Figure: Impacts of climate extremes on wheat price and supply



Source: Chatzopoulos et al., 2020[3].

For example, wheat is mainly produced in eight regions of the world and is one of the most important crops. Climate extremes distort wheat supply, demand and trade, and may induce price variability and spikes. Unfavourable conditions for production in Russia would lead wheat's world price to rise by 10% and the stock-to-use ratio to drop to 0.320. Evidence shows that drought and heat-stress events occurring in the EU and Australia depend and influence each other. And it is the same for the US and Canada. This is particularly important given the current changing climate, characterised by an intensification of extremes and rapid population growth. Global high-resolution, advanced integrated systems and services are needed. They will build on integrated data (from different EO sources) and modelling (e.g. stochastic agro-climate economic models) while exploiting recent and expected progress in seasonal-to-decadal climate predictions.

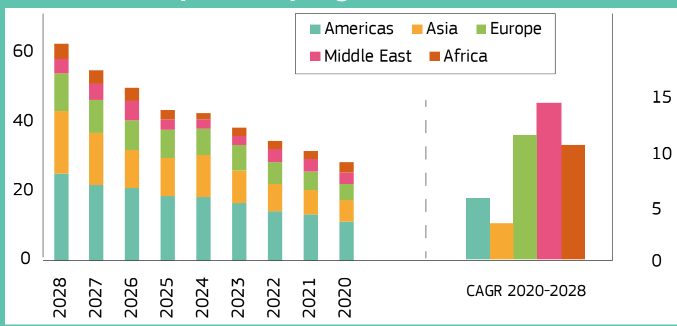
DUAL-USE TECHNOLOGIES DRIVEN BY THE MARKET

The market for military robots (including wearables) and autonomous systems (collectively called MRAS) is driven by new technologies (Artificial Intelligence [AI], self-learning machines, edge computing, etc.). The sector is also driven by an increase in terrorist activities, geopolitical tensions and other armed conflicts. Conversely, the market may be restrained by the high cost of robots, or the decline in defence budgets in developed economies.

In the military domain, the growing trend of synergising humans and robots on the battlefield is expected to accelerate unmanned military systems. The use of MRAS is expected to rise globally[4] with Europe among the top three regions, after the Americas and Asia. In Europe, the highest rise is expected in Russia, followed by the UK and France.

Looking at the current trends, robots are expected to complement humans rather than replace them, leading to changes in the nature of work. The future impact will depend on what the required skills are. Understanding the evolution of the future workplace is crucial to being able to prepare for it[5].

Figure. Market forecast - military robots and autonomous systems by region (€ billion).



Source: Market Forecast Amsterdam (converted to Euro). **CAGR (Compound Annual Growth Rate)

FUTURE SKILLS FOR SPACE AND DEFENCE

Recovery from COVID-19 and the green and digital transitions will affect the technical skills needed in the space and defence sectors (e.g. quantum computing, AI) and transversal skills such as resilience, teamwork and critical thinking.

An integrated foresight approach involving diverse stakeholders will be necessary to address skill gaps and mismatches, to anticipate needs and accelerate knowledge-sharing and training - which can address today and the future's skills gaps - for space and defence[6,7,8].

This anticipatory approach is also necessary to correctly mobilise private and public investments in order to keep a competitive edge. Under the Pact for Skills there is a plan to upskill 6% annually (200 000 people) and reskill 300 000 to enter the sector, with €1 billion invested over the next ten years[9]. The European Defence Fund and European Structural and Investment Funds are setting up the capacities to provide the training. Strategic foresight can help to map the future needs, taking into account the existing heterogeneity across countries and ensure coordination between industry and public authorities.

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8. https://eu-ems.com/event_images/Downloads/1%20Main%20report.pdf
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SOCIETY

ETHICS AND HUMAN ENHANCEMENT

'Augmenting' our mind and body with technology could enhance human physical and mental capabilities. Computer-based augmentation, prosthetics and genetic interventions are only some of the techniques. Although human enhancement offers a variety of benefits, it also raises questions about safety, justice, responsibility and ethical issues. How could it affect human dignity, diversity, privacy and autonomy? Its use would need close monitoring.

The existence of states with enhanced soldiers requires a rethinking of international laws of war and human ethics. Freedom of choice and safety of personnel will be a key question, as well as accountability and responsibility for actions. Applications for military purposes carry dual-use risks, as they could be misused and/or used to facilitate criminal activities[1].

Scientific uncertainty and a lack of impact data create challenges for regulation. But an absence of international standards may lead to substantial differences between domestic legislations. The EU could show leadership by developing standards at an international level, taking into account EU values and priorities.

DRONE 2.0 – NEW CHALLENGES AND THREATS

The market for drones in Europe is expected to double in the coming five years[2]. Higher payload capacity, increased speed and the use of AI is boosting new services and opportunities in security and defence. Researchers expect that autonomous weapons will be available within the next ten years[3]. 3D-printed weapons optimized for drones, or minimized-shaped charges[4] are both capable of killing designated targets. Alongside this, a single pilot has the ability to operate dozens of drones from a safe distance, allowing for 'clean' interventions, while breaking down conventional defences and obscuring the line between battlefields and civilian zones.

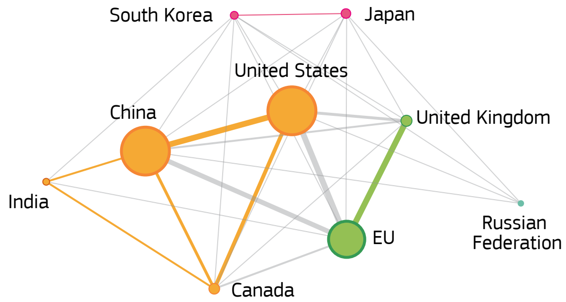
Combining drones in an AI-controlled swarm could result in warfare of algorithms. Who is responsible for such an event and how does one fight back against a 'black box' algorithm? This challenges military conventions and the existing legal framework[5]. Measures to mitigate the emerging drone threat by malicious actors must be developed[6] in a proactive manner, taking into consideration foresight scenarios, thorough risk management procedures and legal issues.

GYROSCOPES

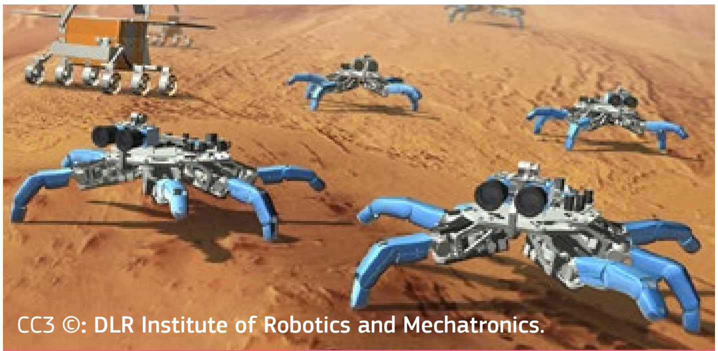
A gyroscope is a device used for measuring orientation and angular velocity. It is fundamental for precision navigation, stabilisation, guidance and control. Some applications are land, sea and sky navigation, medical (e.g. magnetic resonance), telecommunications, energy production and entertainment (e.g. game controllers). In the aerospace and military sectors, high performance gyroscopes are fundamental, hemispheric resonating gyroscopes (HRG) are currently the game changer. For the future, micro-electro-mechanical system (MEMS) gyros could be the next disruptive technology, along with the emerging quantum gyroscopes. MEMS are currently in an advanced stage of development and within 10-15 years, they may be used for the accurate orientation of cruise missiles, and air, land and sea navigation systems. Integration of MEMS production methods with ICT devices, offer a large potential for cost reduction and performance improvement.

The EU research community is among the top three players of future gyro technologies in the world. It has strong connections with the UK and good connections with the US research networks[7,8,9].

Figure: Network graph of publications on 'future gyro technologies' (Scopus)



EC JRC 2020 (Tools for Innovation Monitoring)



CC3 ©: DLR Institute of Robotics and Mechatronics.

CONVERGENCES OF EMERGING AND DISRUPTIVE TECHNOLOGIES (EDTS)

Emerging and Disruptive Technologies (EDTs) are the enablers of competitive advantage, both in business and in warfare. In the intelligent, interconnected, distributed and digital (I2D2) environment of the future, fast developments in AI, data, IoT, robotics, autonomy, space, quantum, biotechnology and sustainable materials by design, will only accelerate. As developments in these separate areas are mutually reinforcing, it is in their convergences that true revolutions can be found.

Recent studies have analysed such convergences and their potential impacts[10,11]. For example, data and AI will enable the design of advanced materials (nanoscale, smart, self-sensing, self-healing) for use in robots and drones. Data and AI will also enable them to act autonomously, individually or in groups. Their deployment can be in remote, harsh or hostile locations, including in space or on the battlefield, where 3D/4D printing will enable repairs on the fly.

While the technology may go ahead driven by competition, regulatory support will be needed, e.g. in product liability and intellectual property[12]. The technology's accessibility will result in many competitors/adversaries, who might surprise us with unexpected solutions.

1. Jensen, S. R. (2020). SIENNA D3.4: Ethical Analysis of Human Enhancement Technologies (Version V1.1). Zenodo. https://zenodo.org/record/4068071#.YAbO-Od7lPY
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4. A 'shaped charge' is an explosive object, shaped to focus the effect of the explosive's energy.
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12. The Future Today Institute, 2019 Tech Trends Report, https://futuretodayinstitute.com/2019-tech-trends/

GLOBAL GREEN INTELLIGENCE: EARTH OBSERVATION DATA-INFORMED NEGOTIATIONS

Earth Observation (EO) data[1] combined with modelling, have the potential to be a game changer in how we define, implement and assess policies. EO data enable a common understanding of events and trends which are then justifiable and traceable in political negotiations (e.g. water scarcity in conflict risk areas, with implications for civil and defence). The monitoring of environmental and climate performance and compliance in the context of trade and climate agreements (for food security, cocoa, deforestation, MERCOSUR, Greenhouse Gas emission monitoring etc.), is only possible through the unique perspective afforded by EO data. These data can also provide input into due diligence needed to report on responsibility and sustainability of global value chains.

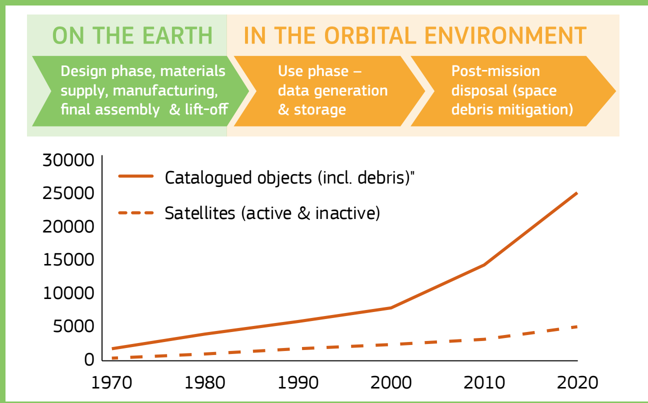
Europe's investments in EO Infrastructure, through Copernicus[2] and modelling, have laid a strong foundation. The opportunity for the future is to transform this into more actionable and targeted information, providing a global knowledge base underpinning decision-making in policy and supporting trade negotiations, transboundary resource limitation issues, and, increasingly, environmental and climate-aggravated conflicts. The EU should seize this opportunity and equip the EU with a 'strategic autonomy on global data and information' – to strengthen its technological sovereignty and provide an advantage in dialogue with international partners.

Figure : Satellite image of water in the Nile basin (incl Grand Renaissance Dam), for water issue negotiations.[3]

IMPACTS AND BENEFITS OF SPACE APPLICATIONS THROUGH LIFE CYCLE ASSESSMENT

Space applications could help to protect the environment and support the Green Deal. At the same time, space activities generate increasing pressure on the environment due to the growing number of rocket launches and private and public players in the field.

Figure: New environmental impacts, assessed through the Life Cycle Assessment (LCA) of space missions and programmes[9].



Source: adapted from Maury et al., 2019

Intense scientific developments will be needed to adapt the LCA framework[10] to the particularities of space activities, to assess the impacts of space applications and to balance them with expected benefits. Sector representative and robust life cycle inventory data are acutely needed.

Beyond 'classical' environmental impacts, it will be important to characterise, simulate and monitor the contributions of the sector to relevant earth impacts (e.g. ozone depletion[11], climate change[12]). Those that occur in Outer Space[13] between, e.g. the 'use phase' and 'post-mission disposal' should be captured. The generation of debris in the orbital environment can be considered an environmental stressor that is increasingly damaging the quality of the resource. This 'pollution' needs to be urgently tackled as the number of satellites (alone) is expected to grow by an order of magnitude[14]. New environmental impacts related to space activities beyond the near-Earth orbits (e.g. Moon or Mars missions[15], including resource extraction, exploration) will have to be characterised and monitored too.

GREEN DEFENCE: SYNERGIES OF THE GREENING AND DIGITAL TRANSFORMATIONS

The US-Military spends around $12 billion a year on fuel, heat and electricity, while the EU militaries have a combined energy consumption of ~40 GWh per year - 75% of it from fossil fuels[4]. This energy consumption equals a small EU member state. A switch to renewable sources and decreased dependence on non-EU resources (fossil fuels), benefits the EU's Open Strategic Autonomy, while opening up potential benefits in sustained operational capability and unit autonomy.

AI and data-driven applications, such as smart meters and grids, intelligent measurement, and electric and autonomous vehicles, can assist the military to limit its energy consumption and increase efficiencies.[5] It is estimated that efficiency matters could save the US military over $1 billion annually, though access to data on emissions and energy usage in militaries worldwide is fractured, or not available.[6]

Future hydrogen applications could provide off-grid auxiliary power and alternative fuel for land, sea and air vehicles. Linked with solar power generation in the field, this could largely decrease fuel consumption and increase cost-efficiency of off-grid operations. Slovenia and the EU fund a project called RESilience Hub Network in Europe (RESHUB) - which aims to develop a local renewable hub for energy harvesting, with hydrogen energy storage capabilities for the defence and transportation sectors.[7] The key for a successful transformation towards a green and digital military is to foster synergies. Incentives and projects that favour the symbiosis of green and digital technologies[8] must be balanced with measures to mitigate related risks for the future.

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3. The EC's JRC global water surface explorer at https://global-surface-water.appspot.com/ ; Feyen L. et al, 2020. Climate change impacts and adaptation in Europe. doi:10.2760/171121, JRC119178.
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8. https://www.eda.europa.eu/info-hub/press-centre/latest-news/2020/03/10/first-energy-consultation-forum-project-to-receive-eu-funding
9. https://www.e3g.org/news/recasting-the-twin-green-and-digital-transitions-as-one-integrated-challeng/
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12. Recently, the EC published an updated analysis of the non-CO2 effects of aviation on climate change (caused by high altitude emissions): https://ec.europa.eu/clima/news/updated-analysis-non-co2-effects-aviation_en
13. The outer space is considered by the United Nations' treaties as a 'Global Common' of the humankind. (UN COPUOS, 2017.).
14. Peterson, G., Sorge, M., Ailor, W., 2018. Space Traffic Management in the age of New Space.
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16. Figure adapted from Maury et al., 2019. https://doi.org/10.1016/j.scitotenv.2019.02.438 and based on data published by Steffen et al., 2015 and ESA Space Debris Office, 2021

Nuclear Thermal Rocket concept - © USNC-Tech

FASTER SPACECRAFT PROPULSION CONCEPTS

In the context of a revitalised Space Race[1], the White House has given an executive order to promote the development of small nuclear reactors for space and defence applications[2]. Nuclear Thermal Propulsion (NTP) experts defend its potential to carry astronauts to Mars twice as fast as the most powerful chemical engines.

DARPA[3] aims to demonstrate the feasibility of NTP for cislunar missions[4] by 2025[5] while Ultra Safe Nuclear Technologies (USNC-Tech) delivered another NTP rocket concept to NASA using the same low enriched uranium microcapsules of their micro modular reactor (MMR)[6] to reduce development costs and regulatory concerns[7].

Whether or not NTP brings crewed missions to Mars by the 2030s[8], similar nuclear technology will be used on Earth before the end of the decade for remote or strategic deployment of electricity, industrial process heating and maritime transport[9]. However, in Europe only the UK has announced a partnership with Rolls-Royce to study the potential of NTP[10]. Whenever the algorithms of data businesses, or the Internet itself[11], start migrating from 'the cloud' to Space looking for cheaper energy[12] or mining becomes more profitable in asteroids than down here, it will be already too late for seeking European strategic autonomy.

TIME WILL MATTER EVEN MORE: THE FUTURE OF ATOMIC CLOCKS

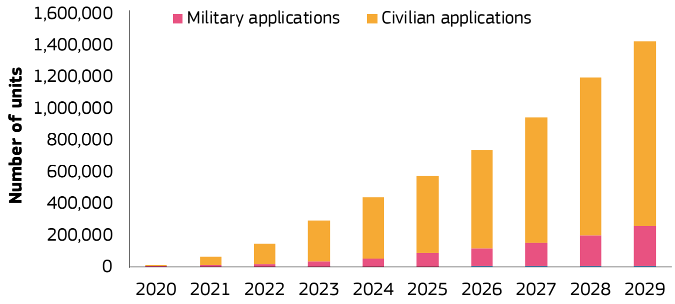
Atomic clocks are the most accurate time devices. They are used as primary standards for international time determination (caesium atomic clocks), for high-speed electronic communications (including financial transactions), for controlling the wave frequency of television broadcasts and in satellite navigation systems such as GPS (US), Galileo (EU), GLONASS (RU) and BeiDou (CN).

The exponential growth of new applications requiring precise time measurement will boost investment in research[14] and manufacturing of various types of atomic clocks. The value of the market is expected to grow significantly to reach around US$ 1B in ten years.

Recently, Chip Scale Atomic Clocks (CSAC) were introduced into the market. CSAC are of low size, weight and power and of low cost (around €500). In the next decade, millions of CSAC units will be produced for use in autonomous vehicles, drones, tactical navigation devices and Low Earth Orbit satellites[13].

The future game changers include on the one hand, massive employment of less-precise and lightweight CSAC, and on the other hand, a redefinition of international time standards by the replacement of the currently used caesium clocks (precision of 10^{-16}s) with much more precise and stable optical lattice atomic clocks (precision of 10^{-19}s)[15].

Figure: Predicted number of atomic clocks in the current decade



Source: Inside Quantum Technology

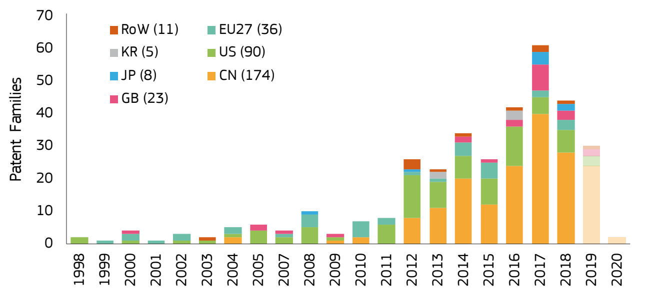
QUANTUM TECHNOLOGIES FOR AEROSPACE AND DEFENCE

Emerging information and sensing technologies which exploit quantum physics can execute tasks, or achieve performance levels, which are otherwise impossible. International competition is fierce, with large public research & technology investments, including by the EU[16]. Understandable excitement must be tempered with realism. What practical advantages over non-quantum alternatives can be achieved, and by when?

If challenging scalability problems are overcome, quantum computers could defeat even high security military cryptography in 10-15 years[17]. Algorithms resistant to quantum crypto-analysis are being developed, as well as quantum optics techniques that reveal eavesdropping, the relative merits of these two approaches being controversial. The EU and European Space Agency are planning a quantum communications infrastructure[18], with space and terrestrial segments, in combination with the Connectivity initiative.

Other quantum technologies with military potential include cold atom sensors for inertial navigation, entanglement-enhanced radar to defeat stealth technology, and quantum computers for space mission planning, processing of Earth images and aircraft design. All are far, or very far, from being defence-ready. Conversely, field-deployable chip-scale atomic optical clocks, with increased precision and spoofing/jamming resistance, for position, navigation and timing, might appear in just 10 years[19].

Figure: Patent applications related to cold atom interferometry



Source: JRC analysis, 2020 based on European Patent Office GPI database[20].

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