AI: A Key Enabler for Sustainable Development Goals, Part 2

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The United Nations (UN) 2030 Agenda for Sustainable Development defines a plan of action to address critical areas for humanity and the planet. It focuses on

- eradicating poverty and hunger and ensuring that all human beings can fulfill their potential with dignity and equality
- protecting the planet from degradation to support the needs of current and future generations
- ensuring that every person can enjoy a prosperous life
- fostering peaceful, just, and inclusive societies
- mobilizing the global community to implement the agenda.

The agenda's core is composed of 17 sustainable development goals (SDGs) that were approved in 2015 by the UN General Assembly. These include

1) no poverty
2) zero hunger
3) good health and well-being
4) quality education
5) gender equality
6) clean water and sanitation
7) affordable and clean energy
8) decent jobs and economic growth
9) industry, innovation, and infrastructure
10) reducing inequality
11) sustainable cities and communities
12) responsible consumption and production
13) climate action
14) life below water
15) life on land
16) peace, justice, and strong institutions
17) partnerships to achieve results.

The SDGs and their 169 subdivided targets are interdependent and interlinked. Those connections are illustrated in Figure 1, which was proposed by Rockström and Sukhdev [1]. The SDGs are organized into three groups: 1) the biosphere, 2) society, and 3) the economy. The first addresses the protection of the biosphere as an essential precondition for social justice and economic development, while the society-related goals address issues such as eradicating poverty, improving social justice, promoting peace, and fostering good health. Finally, the economy-related goals focus on industry, innovation, infrastructure, reducing inequalities, responsible consumption and production, and decent employment and economic growth.

In Part 1 of this article [2], we discussed artificial intelligence (AI) as an enabler of the SDGs. In this part, our focus is on the role of robotics and automation (R&A) in achieving the SDGs. Since automation has been a core component of technology development for a long time and is the driving factor behind the advances discussed in Part 1, we primarily focus here on robotics and robotic systems. Attending flagship conferences, such as the IEEE/Robotics Society of Japan International Conference on Intelligent Robots and Systems and IEEE International Conference on Robotics and Automation, enables us to foresee how R&A will affect our lives in the near future. It is clear that R&A has a wide-ranging impact on many areas of people's lives in developed and developing countries. The anticipated outcomes include improving work conditions; increasing rapidity, precision, repeatability, reliability, flexibility, productivity, and competitiveness; and tackling serious problems in humanitarian, economic, and environmental dimensions, such as agriculture, health-care services in isolated areas, mining in dangerous environments, and managing natural and human-made disasters. The following sections shed light on the role that R&A will play in achieving the biosphere-, society-, and economy-related SDGs.

R&A for the Biosphere-Related SDGs

The biosphere-related SDGs address the protection of the natural ecosystem as an essential precondition for building a fair society based on sustainable economic development. SDG 6 focuses on ensuring access to water and sanitation for everybody. Water monitoring and cleaning systems mounted on autonomous and teleoperated surface vehicles could overcome the limitations of stationary systems since they can take samples at different locations, exchange information with other sensing/acting agents, and collaboratively achieve the required tasks. Examples include fish-like robots developed to patrol waters for pollutants [3], the autonomous surface vehicle [4] developed by the Institute of Intelligent Machines, and the Center for

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Autonomous Systems float for automatic cleaning, oil removal, and in situ water measurements. SDG 13 emphasizes the need to take urgent action to combat climate change and its impacts. Robots can help through precision manufacturing and production on demand (within the context of Industry 4.0 [29]) to increase flexibility and reduce waste and energy consumption. They can monitor the environment, remotely inspect and maintain renewable-energy plants and power lines, and improve deforestation-tracking methods and fighting wild fires, among others.

SDG 14 aims to conserve and sustainably use the oceans, seas, and marine resources. Seas and oceans can be explored with submarine robots, such as Stanford University's OceaNOne [5]. Marine resources can be monitored through smart stationary and mobile sensors. Illegal fishing activities and marine-life migration can be tracked through pattern recognition. Thanks to underwater robots, we have a better understanding of the ocean and the creatures living there [30]. The information gathered by underwater robots can be used to better protect life below water and manage floating waste [31].

Regarding SDG 15 for life on land, sustainable forest management requires information gathering, rigorous planning, and proper policy making. Robotics and AI can collect data and analyze those data as well as perform dull and dangerous tasks in the wild, such as firefighting [32]. The world's industrial activity and global warming are threatening one fifth of plant species. Robotics has provided new means to monitor biodiversity [33]. Robotic technologies are used to measure the light reflected from plants, which enables scientists to sample the vegetation's functional diversity and evolutionary history. Land degradation affects many countries, and robotics could be used to slow it down. Various robots have been developed that are capable of digging, seeding and watering plants, and monitoring the environment [34].

Robotics for the Society-Related SDGs

The society-related SDGs address issues such as eradicating poverty, improving social justice, promoting peace, and fostering good health. The elimination of poverty worldwide is the first SDG. Upgrading local manufacturing in developing countries through R&A technologies for better and faster productivity and stronger local and international competitiveness will have a positive impact on the gross domestic product of many nations [35]. However, the widespread use of R&A in poor countries faces many obstacles. Apart from high initial adoption costs and the macroeconomic situation of most developing countries, there are challenges such as the overproduction-underemployment dilemma. There are common misconceptions about R&A

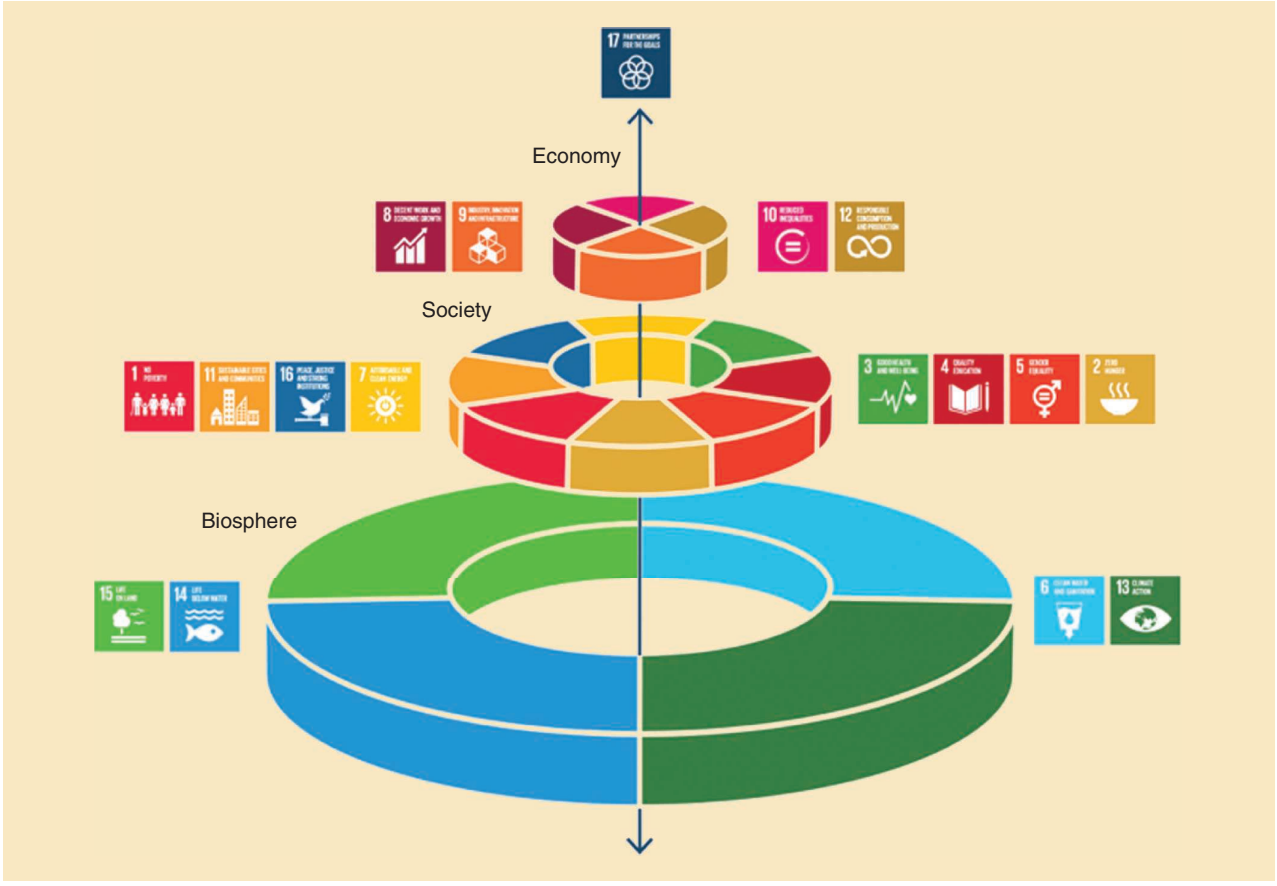

Figure 1. The UN's SDGs. (Source: Azote for Stockholm Resilience Center, Stockholm University.)

and a lack of highly qualified personnel [36]. In most developing countries, there is a common belief that modernizing factories through advanced automation technologies will negatively affect the employment rate and exacerbate the overproduction-underemployment problem. In developed countries, too, there are serious concerns about AI's impact on employment [38]. Many analysts expect a wave of structural unemployment to spring from AI during the medium term.

However, R&A has the potential to create new businesses and innovate existing ones, resulting in higher productivity and a better quality of services. That would create a strong demand for highly skilled workers, such as algorithm developers, programmers, data analysts, machine-learning specialists, robotics engineers, technologists, drone pilots, system engineers, market analysts, business developers, and marketing and services staff. Business innovation and the ability to start new companies were highlighted as personal technology's most positive impact, according to a Microsoft study [6]. To ensure a higher level of acceptance and adoption of R&A, especially in developing countries, people must be properly educated. Education is a key driver of economic growth and a main catalyst for poverty eradication and sustainable development [7].

SDG 2 represents ending hunger, achieving food security, and improving nutrition while promoting sustainable agriculture; precision methods (smart farming) can help to achieve these goals. However, agriculture varies widely in field and weather conditions, soil types, diseases, seed, fertilizers and pesticides and their effects, ambient conditions, and so forth [38]. Modern robotics technologies can revolutionize farming. Applications of outdoor agriculture robotics include aerial imaging, spraying/weeding, fruit harvesting, and self-steering equipment. Indoor robots are used for harvesting and material handling. A further application for robotic systems concerns the management of farmed animals, such as dairy cattle, pigs, and chickens, where intervention via the provision of appropriate and timely data can help to reduce waste and pollution as well as improve animal welfare and farm productivity [8].

Rehabilitation and medical robotics, personal assistant robots for the elderly and physically challenged, and aging in place play crucial roles in achieving SDG 3, which addresses good health and well-being [39]. Aging in place refers to the idea that people can remain in their homes rather than moving to institutional settings, such as nursing and care homes and residential living centers. Enabling people to age in place would not only improve their quality of life but also provide a cost-effective solution to the problems of an expanding population of very old people [9]. Emerging assistive technologies, including domotics and cognitive robotics, have a considerable potential to enhance the lives of many older people throughout the world [40]. They could enable frail seniors and people with disabilities to function more independently and, thus, gain self-respect and more acceptance in mainstream society. Moreover, novel surgical robots and micro/nanoscale medical robots have the potential to radically change the standard of care for many diseases [41].

Aligned with SDG 4, R&A is highly interdisciplinary and provides an excellent education platform for constructionism and experiential and challenged-based learning [42]. Constructionism is an active learning process in which students build things that are personally meaningful to themselves and others around them [10]. Instead of being served information in the traditional one-way setting, learners develop their own knowledge and understanding of a subject through physical construction and the implementation of their ideas [11]. Constructionism as an educational theory is inspired by constructivism and experiential learning. Constructivism argues that humans generate knowledge and meaning from interactions between their experiences and ideas [12], [13]. Experiential learning, or learning by doing, is a teaching strategy that focuses on the learner's subjective experience. The role of the educator is to design direct experiences that include preparatory and reflective exercises. Challenge-based learning through robotic competitions provides motivational platforms for students, researchers, and laypeople to present their work to a wider forum and achieve extensive media coverage. The technical challenges improve participants' hard and soft skills, such as engineering design, mechanical engineering, electrical engineering, computer science, sensors, systems engineering, project management, teamwork, and creative problem solving [14].

SDG 7 focuses on ensuring access to affordable, reliable, sustainable, and modern energy. Power is crucial to almost all of the challenges and opportunities the world faces. R&A is making an impact on major aspects of wind and hydroelectric turbine manufacturing [15]. Robots are used in wind power-blade cleaning [16] and transmission-line inspection [17]. Water and water-free autonomous robots clean solar panels to improve their efficiency. Electric autonomous vehicles and personal transporters and e-bikes are enablers of a future with zero emissions.

SDG 11 aims for sustainable cities and communities. According to the UN, the number of people living in cities will increase from 3.6 to 6.3 billion between 2010 and 2050. Urban population growth is a major driver of sustainable cities and communities. A city can be defined as "smart" when social capital and traditional (transport) and modern (information and communication technologies) infrastructure fuel sustainable economic development and a high quality of life [18]. Robots and autonomous vehicles play various roles in smart cities, including environmental maintenance (trash removal, recycling, and monitoring), smart living (medical care and personal assistance), intelligent mobility (robocars, autonomous air taxis, and automated people movers), and the economy (Industry 4.0) [43].

Aligned with SDG 16, R&A helps to develop technologies for law enforcement, homeland security, surveillance, reconnaissance, demining,

and countering improvised explosive devices to assure citizen safety [44]. Natural/human-made disaster management can be improved through smart prevention, better preparedness, effective responses, and fast recoveries [45]. For example, landmines and unexploded ordnances (UXOs) are victim-operated weapons of mass destruction that make no distinction between friends and enemies and children and animals [46]. While basic detection and neutralizing technologies remain practically unchanged, landmine technology has improved dramatically, resulting in more than 2,000 kinds of buried weapons; among them, there are more than 650 types of antipersonnel landmines. Conventional methods for landmine detection rely on a close-in method where the deminer inspects the field through hand-probing techniques, such as metal detectors, magnetometers, and ground penetrating radar; manned armored vehicles; and biological techniques, resulting in a high risk of potential detonations. In addition, the conventional approaches make the procedure of removing great numbers of landmines tedious, slow, inefficient, and costly. One deminer is killed and two are injured for every 5,000 successfully removed landmines. During some missions, only 12% of the target landmines are detected. Moreover, with manual probing, no digital data are recorded, and the success depends upon the deminer's skill, resulting in inconsistent results. Consequently, more efficient ways to detect and locate landmines and UXOs are needed. Humanitarian R&A technologies can provide a more efficient, reliable, adaptive, and safe solution to the problem of landmine and UXO contamination compared to traditional detection and disposal methods [19].

Robotics for the Economy-Related SDGs

The economy-related SDGs focus on industry, innovation, infrastructure, reducing inequalities, responsible consumption and production, and decent work and economic growth. Service robotics will be major driver of economic growth over the next several years, with a market that is expected to reach US$34.7 billion by 2022, representing a compound annual growth rate (CAGR) of 15.18% from 2016 to 2022, according to a report from Markets and Markets [47]. Service robots assist human beings, typically by performing jobs that are dirty, dull, distant, and dangerous. Service robots for professionals are commonly employed for applications such as defense, intelligence, surveillance, reconnaissance, search and rescue, firefighting, health care, construction, logistics, smart factories and farming, hazardous-environment monitoring, and space exploration. Applications of service robots for personal use include home automation, personal assistance for the elderly and physically challenged, entertainment, and automated cleaning devices.

Considering SDG 8, which concerns decent work opportunities and economic growth, the application of robotics and AI in industry will lead to significant growth. Robotics and AI have been identified as core technologies to enable the fourth industrial revolution. Through automation and productivity improvements, robotics will create more high-paying jobs. Economic growth will result through technological advances and the workforce's improving skills. A more productive workforce will lead to a stronger economy. When robotic technologies are used, more goods will be manufactured in less time, which is vital to economic growth.

Following a similar line, SDG 9 focuses on industry, innovation, and infrastructure. Industry has witnessed three revolutions that resulted in significantly higher productivity and tighter quality control. The first improved efficiency through the use of hydropower and steam and the development of machine tools. The second brought electricity and mass production (assembly lines), and the third accelerated automation through electronics and IT. The fourth is already on its way. Industry 4.0, or smart industry, is based on new and radically changed processes. It connects embedded system production technologies and smart production processes to pave the way to a new technological age that will drastically transform value chains and business models. Smart factories represent a paradigm shift from centralized to decentralized production, made possible by technological advances that reverse conventional production process logic. The ultimate goal for this technology is to improve work conditions and increase productivity, rapidity, precision, repeatability, reliability, flexibility, and competitiveness. During the coming years, the technologies will become a viable alternative to current manufacturing processes, enabling make-to-individual manufacturing, manufacturing on demand, and mass customization to become a reality. According to Markets and Markets, the smart-factory sector is expected to reach US$153.7 billion in 2019, with a CAGR of 9.76% between 2019 and 2024.

The preceding SDGs align with SDG 10, reducing inequality. R&A has become an integral part of everyday life. Like the invention of modern computers, robotic applications save many people from doing dull, dirty, and tedious work. The robotics industry has created millions of higher-paying jobs in all sectors. Advances in R&A free workers for new tasks with higher wages, thus reducing inequality. Thanks to working with robots, humans will have greater levels of productivity and enjoy better lifestyles. Rather than laboring at repetitive and low-paying jobs, humans can align with robots on more creative and innovative solutions.

Finally, SDG 12 focuses on responsible consumption and production. Earth's finite resources and energy require more sustainable production and consumption. Robotics provides an energy-efficient production model. The cost of robotic operation essentially equates to the cost of the energy to power the machines. Robots require less power than manually operated equipment and ensure quality through precision, strength, and endurance. Higher quality will lead to less changeover, production, and waste. Designing robots for sustainable production and consumption is an exciting challenge for

academicia, industry, and government. Robotics technologies need to be developed to discover new resources, recycle materials, reduce waste and pollution, increase food production, and efficiently manage energy consumption.

Ethical Aspects

Despite their clear benefits, R&A and AI have the potential to negatively affect our rights as humans. It is not difficult to find examples of systems violating our privacy [20] and, consequently, our right to a private life; providing unequal opportunities based on gender [21]; infringing on the right to gender equality; degrading or potentially degrading the environment [22]; breaching the right to a decent standard of living; discriminating against minorities [23]; denying access to justice and the right to a fair trial; and so forth [24]. Mapping examples from an AI-based system to an R&A-based one is straightforward. Fortunately, our community has been working hard to discuss the ethical aspects of the development of autonomous and intelligent systems (AISs). The IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems is a good example [48]. Recently, it published the document "Ethically Aligned Design" [25], which discusses issues in the different domains impacted by AISs and proposes recommendations for addressing them. In addition, the IEEE has a program called *IEEE TechEthics* that provides a platform to discuss new technologies' ethical and societal implications.

The need to broaden the discourse and delineate strategies to mitigate the potential impact of digital technologies on global society caught the attention of UN Secretary General Antonio Guterrez, who established the UN Secretary General's High-Level Panel on Digital Cooperation in 2018. On 10 June 2019, the panel issued a report, "The Age of Digital Interdependence" [26], that discusses methods to strengthen global cooperation to ensure a safe and inclusive digital future for everyone. The report touched on the impact of AI and R&A on global society. In particular, it proposed recommendations for applying existing international human rights accords and standards to new and emerging digital technologies. It recommended that new digital technologies include accountability, responsibility, and transparency. In addition, the report stressed that life and death decisions should not be delegated to machines, including autonomous lethal weapons as well as systems such as end-of-life devices. On 24 June 2019, the UN High Commissioner for Human Rights, Michelle Bachelet, reaffirmed the report's importance [30] and said that her office would engage multiple sectors and geographies to develop guidance for applying the UN Guiding Principles on Business and Human Rights to digital technologies.

Conclusions

In this article, we discussed how R&A, and particularly robotic systems, can help to attain the SDGs set out by the UN. We firmly believe that technology based on R&A can bring many benefits to humanity in terms of the biosphere, society, and the economy. However, reaping the benefits while mitigating potential negative outcomes requires the strong involvement of all members of society, including governments, nongovernmental organizations, industry, academia, and individuals. Because technology does not have frontiers, a multilateral effort should be made. Fortunately, at a global scale, we can see initiatives in that direction, such as those conducted by the IEEE and UN.

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