Hellenic Institute for Advanced Studies

Robotics in the AI era: A vision for a Hellenic Robotics Initiative

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May 2021

About the Hellenic Institute of Advanced Study

The Hellenic Institute of Advanced Study (HIAS) is a non-profit, private foundation, established as a US 501 (c)(3), initiated by the Hellenic diaspora in order to:

- Create bridges and serve as a hub for scientific exchanges between the Hellenic diaspora and their peers in Greece;
- Foster the development of international, transdisciplinary collaborations on problems of societal relevance including Energy, Health, Education, AI, Environment, Transport, Maritime, Agrifood, Inequality.

HIAS is founded on scientific excellence, is inclusive, and represents the strengths of the entire Hellenic scientific community independent of any personal or political affiliation.

Abstract

In January 2021, the Hellenic Institute of Advanced Study (HIAS) assembled a panel including world leading roboticists from the Hellenic diaspora, who volunteered their scientific expertise to provide a vision for Robotics in Greece. This report, entitled "Robotics in the Artificial Intelligence (AI) era", is a whitepaper that we hope will trigger a dialogue towards the development of a national robotics strategy.

Our vision is that Robotics in the AI era will be an essential technology of the future for the safety and security of the Hellenic nation, its environment and its citizens, for modernizing its economy towards Industry 4.0, and for inspiring and educating the next generation workforce for the challenges of the 21st century.

To contribute towards making this vision a reality, after reviewing global trends in robotics and assessing the Greek robotics ecosystem, the panel has arrived at the following key findings and recommendations:

Hellenic Robotics Initiative: Greece should develop a national Hellenic Robotics Initiative that serves as the nation's long-term vision and strategy across the entire Greek robotics ecosystem.

Societal Drivers: Safety and security is an area of national importance necessitating a national initiative, while agrifood, maritime and logistics provide opportunities for internationally leading innovation.

Mission-driven research: We propose the establishment of a mission-driven, government-funded, organization advancing unmanned vehicles in societal drivers of national importance

Industrial Research and Innovation: Greece should leverage its unique geography and become a living testbed of robotics innovation turning Greece into a development site for exportable technologies.

Basic and Applied Research: Universities should create Centers of Excellence in robotics and AI as well as consider innovation-leading research institutes such as the Italian Institute of Technology.

Educating a Nation of Innovators: We recommend investing in robotics education using Maker Spaces in order to prepare the workforce with 21st century skills to become Industry 4.0 innovators.

Workforce Impact: The government should collect, measure, and analyze data on the robotics industry, robotics uses, labor shifts, and brain gain and promote awareness via a Hellenic Robotics Day.

Regulation, Legal, Ethics: The government should regulate robot safety without stifling innovation, provide safe experimentation areas and mechanisms for certifying safety of locally developed robots.

Our report has many additional suggestions that enhance the above main recommendations. We advocate bringing the robotics ecosystem together in order to sharpen and expand this report to an ambitious, long-term, and detailed national strategy and roadmap for robotics in the AI era.

Table of Contents

Executive Summary

In January 2021, the Hellenic Institute of Advanced Study (HIAS) assembled a panel including world leading roboticists and members of the Hellenic diaspora. Embracing the HIAS mission for promoting scientific exchanges between the Greek diaspora and their peers in Greece, our panelists volunteered their scientific expertise envisioning a future for Greek robotics. This report, entitled "Robotics in the Artificial Intelligence (AI) era," is a whitepaper that presents the panel's findings and recommendations. We hope this report will trigger a national dialogue across stakeholders in government, industry, and academia and contribute towards the development of a national robotics strategy (see Section 1).

Global economic and technological trends in robotics

Robots are divided into two main categories, industrial robots and service robots. Over the past sixty years, industrial robots have been heavily used globally in the automotive, semiconductor and manufacturing sectors. In Greece, the number of industrial robots is over-estimated at 600 robots total, resulting in a density of 17 robots per 10,000 people, significantly below the European average of 114 robots per 10,000 people. Clearly, industrial robotics has not arrived yet in Greece (Section2).

Contrary to industrial robotics which is very mature, the service robotics sector (unmanned aerial vehicles, healthcare, logistics and agrifood robotics) is in its infancy and fast-rising. Professional service robots is a $27 billion market worldwide and is growing at an annual rate of 30%. Furthermore, 20% of all service robot companies are young startups. This creates an exciting opportunity for aspiring Greek innovators to enter this young and fast-growing field and modernize the economy towards Industry 4.0.

Technologically, innovation in robotics is no longer about advances in robotic hardware, as many industrial robots or aerial vehicles have been commoditized, but rather about advances in robotic software making the hardware more intelligent (using AI), more connected (using 5G), safer for humans (collaborative robotics), and more valuable (using Robot-as-a-Service). The transition from hardware to software will drive robotic innovation and open new markets over the next decade (Section 3).

The Greek robotics ecosystem today

A holistic analysis of the entire robotics ecosystem in Greece today reveals numerous strengths, weaknesses, threats, but also opportunities for the future (detailed analysis in Section 4). Strengths include the excellent basic research community in Greece that has a very good international reputation, placing Greece in the top ten among EU countries in terms of funding and scholarly production. In addition, Greece has a plethora of well educated, English-speaking researchers in a relatively low-cost environment within Europe. In robotics, like several other scientific areas, there are many world-class scientists and innovators in the Hellenic diaspora, willing to contribute their expertise.

Unfortunately, scientific excellence in Greece does not translate to a significant impact on the nation's economy or safety. The low number of industrial robots, the lack of industrial research leaders in robotics or AI, and the limited technology transfer out of universities and research centers create a large valley of death in the robotics innovation cycle. This is the primary weakness in the whole ecosystem that results in very few innovation-leading technologies, limited high-end job opportunities accelerating brain drain. Limited national, defense, and industrial funding magnify this weakness.

Over the past ten years, there has been a rapidly growing threat due to the proliferation of low-cost, unmanned aerial, ground, surface and underwater vehicles in the region and the world. This is creating significant safety and economic risks to the Greek nation. As this is a threat that will grow over the next decade, it is critical that Greece avoids being technologically surprised in the future.

But there are also significant opportunities. Aspiring Greek industry and innovators can become regional leaders in the young but fast growing field of professional robotics (such as unmanned vehicles). There is an opportunity to modernize the economy towards Industry 4.0, while leveraging industrial leadership in maritime, tourism, and agri-food sectors. A growing innovation ecosystem in robotics, AI, and Industry 4.0 is very promising. Robotics researchers can pursue initiatives from the State (ΕΣΠΑ) or the EU (Horizon EUROPE) during 2021-2027. New international educational programs could prepare students for Industry 4.0, while there is excitement among secondary school students for robotics.

A vision for a Hellenic Robotics Initiative

Robotics in the era of artificial intelligence will transform every aspect of Greek society, security, and economy. Agricultural robots can assist Greek farmers in reducing exposure to dangerous spraying pesticides, while selective harvesting for increasing yield and quality operations. Robots with advanced perception can be used for automatic inventory inspection and management. Underwater vehicles can be used for inspecting ship hulls and pipelines or Greek ports, while aerial robots can ensure the delivery of urgent medical supplies in remote islands in the Aegean or mountainous rural regions. This is not science fiction. The technological revolution described above is starting to happen around the world, including Greece (Section 5). As we are still in early days in this revolution, this creates a historic opportunity for Greece to become a regional leader in this emerging yet critical future technology.

Our vision is that robotics empowered with artificial intelligence will be an essential technology of the future for the safety and security of the Hellenic nation, its environment and its citizens, for modernizing its economy towards Industry 4.0, and for inspiring and educating the next generation workforce for the challenges of the 21st century.

In making this vision a reality, the panel has arrived at the following recommendations:

Hellenic Robotics Initiative: Greece should develop a Hellenic Robotics Initiative that serves as the nation's long-term vision and strategy across the entire Greek robotics ecosystem. It should emphasize Greek national priorities, promote innovation leading programs, and prioritize efforts that will lead to demonstrable impact on the nation's security, economy, and prosperity. The first step is to assemble a Hellenic Robotics Council, bringing together the nation's leaders across the robotics ecosystem, initially tasked with developing a strategic roadmap. Once developed, it is critical that all future governments show long-term strategic and fiscal commitment in this initiative (see Section 5).

Societal Drivers: The national robotics strategy should start by identifying societal drivers where robotics technologies can have a demonstrable societal or economic impact. In the opinion of this panel, safety and security in the broadest sense (defense, civil protection, border protection, environment protection, emergency response) is an area of national importance that necessitates a national initiative in robotics. Additional societal drivers that exploit unique Greek differentiators (talent, geography, industrial areas of strength) include the maritime, logistics, and agrifood sectors, where there is an opportunity for innovation-leading efforts (see Section 5.1).

Mission-Driven Research Organization: Mission-driven research is defined as research that follows an impact-focused approach to address great challenges of national importance. In this spirit, we propose the establishment of a new Hellenic Center for Advanced Robotic Technologies, which will be a government-funded, mission-driven organization with the long term mission to advance, develop, and transfer innovative unmanned vehicle technologies in air, land, and sea in the service of national safety and security and other societal drivers of national importance. This panel proposes establishing a task force, tasked with a visioning and feasibility study for such an organization (see Section 5.2).

Industrial Research and Innovation: Thanks to her unique geography, Greece can become a living testbed of field robotics and applications in extreme environments. Instead of trying to find domestic markets, Greek innovators can turn Greece into a demonstration site of robotic technologies that then can be exported. Historically, many significant robotics technologies (self-driving vehicles, drones, warehouse robots, medical robots) were university spin-offs. Therefore, in addition to public-private investment partnerships (like Equifund) and angel investing, we recommend programs like Pittsburgh's Innovation Works. Such programs work closely with universities and research centers to identify ideas for commercialization and mentor researchers to launch startups. Lowering any barriers to mobility across academia, industry, and startups for faculty, researchers, and students is key for facilitating this process. Other ideas include bringing the ecosystem together in clusters and TechExpo (Section 5.3).

Basic and Applied Robotics Research: Given the interdisciplinary nature of robotics, it is critically important to establish Centers of Excellence in robotics and artificial intelligence, bringing together faculty and students in robotics, computer vision, control systems, automation, and machine learning, addressing scientific challenges in societal sectors of national importance. Basic science funding should ambitiously grow, while defense funding and joint funding mechanisms should be considered. Greece should also envision the creation of a research institute similar to the Italian Institute of Technology (IIT). What sets apart the Italian Institute of Technology from other research institutes is its emphasis on technology transfer and innovation without sacrificing research excellence. IIT was created in 2006 and has already received an impressive 50+ ERC grants among 80 principal investigators, 1,000+ patents, 24 existing startups with 50+ startups under development. This is precisely what Greece is lacking from its basic research institute portfolio. A similar Greek institute could strategically focus on future areas such as robotics, AI, Industry 4.0 among other areas of national importance (Section 5.4).

Educating a Nation of Innovators: We advocate investing in robotics education to prepare the future generations with 21st century skills not only for a career in robotics but also to become innovators in Industry 4.0. This is precisely the vision of the so-called maker movement which empowers intellectually diverse student-teams to innovate while addressing real-world challenges. Educating the nation to develop innovators in robotics means a cultural shift to become a nation of makers, builders, hackers, and tinkers. This requires a significant investment in Maker Space laboratories (one per university), but most importantly, requires a paradigm shift in educational goals. We also propose new undergraduate programs in robotics and AI, international masters programs, industrial competitions, improving diversity, and strengthening outreach in secondary education (Section 5.5)

Workforce Impact: In Greece it is expected that 23.4% of jobs face a very high probability of automation, with another 35.3% of the workforce facing the distinct possibility of changing the type of job they do. In response, we recommend that the government develops a framework for collecting, measuring, and analyzing data on the robotics industry, robotics uses, labor shifts, and brain gain. In order to help the mid-career workers, there is a need to provide funding and policy initiatives to support upskilling and retraining**.** The government should also declare an annual Hellenic Robotics Day with the goal of raising the public's awareness of new robotic technologies, economic and workforce impact, as well as inspiring the next generation about robotics, AI, and Industry 4.0. (Section 5.6).

Regulation, Legal, Ethics: Robots need to ensure the safety of humans at all times. But novel robots (e.g., self-driving cars) result in innovation that is ahead of safety regulation. It is critical to quickly embrace safety standards that ensure human safety but without stifling robotics innovation. Safe areas for experimentation as well as mechanisms for certifying robot safety developed by Greek companies will be important. Defining property rights over robot data will be very important both in protecting data owners and also in creating a new economy for data while incentives for proactively cyber-hardening infrastructure will be critical for secure and resilient robot operation. Universities should develop intellectual protection policies while robot programming should embrace ethical values and principles that are consistent with the Greek and European ethos (Section 5.7)

Our report has many additional suggestions that enhance the above main recommendations. We advocate bringing the robotics ecosystem together in order to sharpen and expand this report to an ambitious, long-term, and detailed national strategy and roadmap for robotics in the AI era.

1. Introduction

This year marks the 60th anniversary of the first industrial robot, the Unimate, a material handling robot, introduced in 1961 (see Figure 1). Over the past sixty years, industrial robots have had tremendous impact in the automotive, semiconductor, and manufacturing sectors. More recently, fueled by the rise of artificial intelligence, robotics is now poised to transform virtually every societal sector including national security and defense, agrifood, maritime, environment protection, infrastructure inspection, emergency response, logistics, transportation, healthcare, as well as entertainment and arts. Impressive recent advances, such as self-driving cars or walking robots (shown in Figure 1), have captured the attention of industry and the imagination of the broad public.

Figure 1: Unimate (left), Cruise self-driving car (middle), Boston Dynamics Atlas (right)

What is Greece's vision in this global technological landscape? What is our national strategy in robotics that results in demonstrable impact on the nation's security, prosperity, and the well-being of its citizens? What are the unique differentiators that should be leveraged so that Greece emerges as an innovation leader in targeted areas? What concrete actions will get us closer to realizing this vision?

Based on its mission to promote scientific exchanges between the Greek diaspora and their peers in Greece, in January 2021 the Hellenic Institute of Advanced Study (HIAS) assembled some of the leading Greek roboticists in the world. Many of them have significant experience in developing scientific roadmaps in the areas of robotics and artificial intelligence[1], and Industry 4.0[2]. All authors of this report have strong connections to Greece, volunteered their personal time for this effort, and have no conflict of interest with any proposed strategy or recommendations. Their goal is simply to offer their scientific expertise on issues pertaining to the welfare of Greek society. **This report, titled "Robotics in the AI era," is a whitepaper towards the development of a national strategy for robotics empowered with artificial intelligence over the next decade.** Robotics is an ideal topic for the HIAS inaugural study as it requires collaboration across disciplines and across international borders.

This whitepaper is a first step towards a broader community effort with the ultimate goal of developing a national roadmap for robotics in the era of artificial intelligence. It presents some preliminary findings and recommendations that can serve as the starting point for discussion with stakeholders across the robotics and artificial intelligence ecosystem within Greece. We advocate bringing together government, industry, startups, and academia through numerous workshops, discussion forums, collecting data, performing

[1] From Internet to Robotics: A Roadmap for US Robotics, 2020 Edition, September 2020
[2] A 21st century Cyber-Physical Systems Education, National Academies Press, 2016

market analysis, analyzing feasibility and cost in order to sharpen and expand this report to an ambitious, long-term and detailed national strategy, and roadmap with phased and actionable recommendations.

This report begins by presenting some global economic trends in the field, followed by some technological drivers that are currently transforming robotics. A brief assessment of robotics in Greece highlights some of the current strengths and challenges. We then present a holistic vision for a national robotics strategy, across all stakeholders of the Greek robotics ecosystem, which areas in robotics to invest in and why, followed by prioritized recommendations across the whole ecosystem for improving robotics research, education, innovation, and impact. We conclude with some recommendations for workforce impact as well as some regulatory, legal, and ethical considerations.

What is Robotics? Robots are physical machines that autonomously move within physical environments and can change the state of these physical environments. Defining robot characteristics are mobility (e.g., flying robots), interactivity (e.g., grasping objects), communication (e.g., human robot communication), and autonomy (e.g., robot vision). As a result, robotics is an interdisciplinary field that brings together mechanical design, hardware, computer vision, automatic control, and machine learning.

Robotics, artificial intelligence (AI), and Industry 4.0 are broad and overlapping areas causing occasional misunderstandings[3]. For example, there are robots without artificial intelligence (industrial robots) and robots with artificial intelligence (self-driving cars). Similarly, industrial robotics is critical to Industry 4.0 (emphasizing manufacturing), but non-industrial robotics will also have impact in other areas such as healthcare, transportation, or safety and security. In this report, we treat Robotics, AI, and Industry 4.0 as distinct from each other, but with the understanding that AI and Industry 4.0 will play a significant role for robotics innovation and vice versa. As a result, this report should be viewed as separate from, but synergetic with, other strategic roadmaps in artificial intelligence[4] or Industry 4.0[5].

[3] Artificial Intelligence-The revolution has not happened yet, Michael Jordan, Harvard Business Review, 2019
[4] https://knowledge4policy.ec.europa.eu/ai-watch/greece-ai-strategy-report_en
[5] Βιομηχανία 4.0, Μια ευκαιρία **π**ου δεν **π**ρέ**π**ει να χαθεί, ΣΕΒ, 2019

2. Global Economic Trends

The global robotics market was valued at $62 billion in 2019 and is projected to reach $189 billion in 2027, growing at a compound annual growth rate of 13.5%[6]. The market grows to $15.7 trillion by 2030 if artificial intelligence is considered[7]. Robots are divided into two main categories, industrial robots and service robots. Industrial robots are used primarily in the automotive, semiconductor, and manufacturing industry. Service robots are non-industrial and are further divided into personal service or professional service robots. Personal service robots include home robots and entertaining robots, while professional service robots include medical robots, self-driving vehicles, and unmanned aerial vehicles for monitoring infrastructure or the environment (see Figure 2).

Figure 2: Industrial robot (left), personal service robot (middle), DJI professional service robot (right)

During the past six decades, industrial robots have transformed the industry, improving productivity, enhancing safety, and lowering costs in the automotive, semiconductor, and manufacturing industry. Based on the International Federation of Robotics (IFR), in 2019 there were more than 2.7 million industrial robots, growing globally at an annual pace of 13%[8]. As seen in Table I, Asia is the major driver for industrial robotics while Singapore and Korea have the highest density of robots approaching one robot per ten people. In 2019, the European average was 114 robots per 10,000 people.

The number of industrial robots is not counted in Greece, but an earlier 2016 IFR study estimated it to be 600 robots total, resulting in a density of 17 robots per 10,000 people. This is significantly below the European average of 114 robots per 10,000 people or the global average of 113 robots per 10,000 people. Furthermore, this number is inflated[9], resulting in an estimate of 250 robots total in local industrial operation. Clearly, industrial robots have not arrived yet in Greece, placing industry in a competitive disadvantage in the upcoming Industry 4.0 revolution[5].

[6] Global Robotics Technology Market: Opportunities and Forecast 2020-2027, October 2020
[7] PwCs Global Artificial Intelligence Study: Sizing the Prize, 2016
[8] World Robotics 2000 Industrial Robots Report, International Federation on Robotics, September 2020
[9] Τα ρομπότ και η βιομηχανική παραγωγή έρχονται. Οι θέσεις εργασίας μένουν; Special Report: Ρομπότ και Απασχόληση, Σύνδεσμος Επιχειρήσεων και Βιομηχανιών (ΣΕΒ), Οκτώβριος 2019

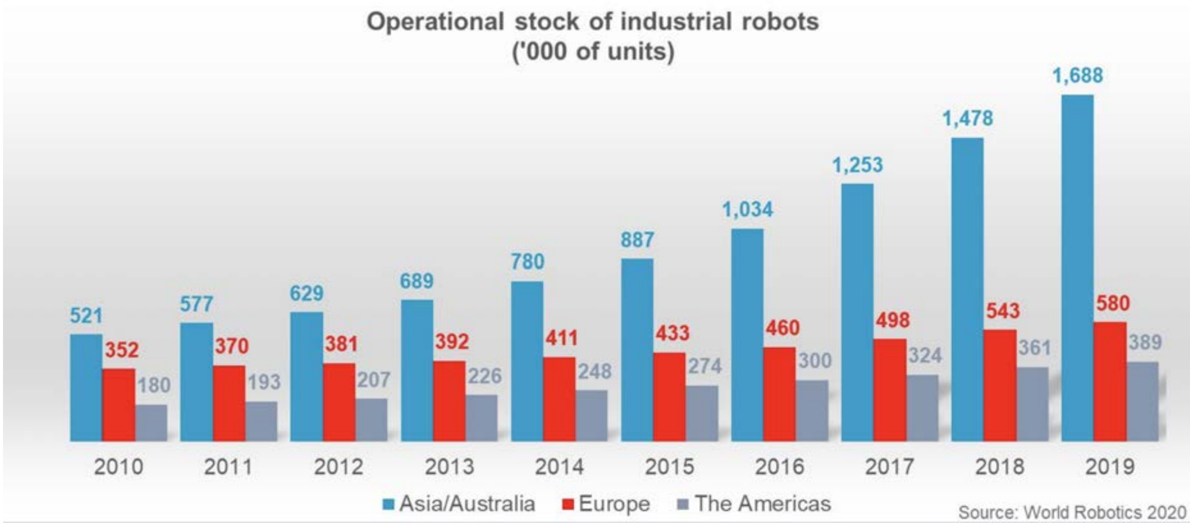

Table 1: Number of industrial robots across Asia/Australia, Europe, and the Americas

Contrary to the mature industrial robotics sector, led by companies like Kuka, ABB, Kawasaki, the service robotics sector is still in its infancy powered by very recent technological advances in robot navigation, perception, and artificial intelligence. In the personal service robotics area, IFR projects that 55.3 million service robots will be sold in 2023, growing at an annualized pace of 27% and resulting in sales value of $12.1 billion. Professional service robots are projected to grow to 537,000 units sold in 2023, resulting in an annualized growth of 31% for a value of sales estimated at $27 billion. The largest markets for professional service robots are logistics robots which are automating fulfillment and e-commerce centers, robots for public environments, and robots for safety and security applications.

We are at an inflection point where mature industrial robotics (also known as Industrial Automation) is giving way to the young, fast-rising professional service robots industry which includes healthcare robots, self-driving vehicles, and unmanned aerial vehicles. Furthermore, according to the IFR study[4], from the 889 global service robot companies, 183 are startups (launched after 2015, 94 in Europe), a measure of how young the field is. More specifically, for professional service robots, there are 155 startups out of 728 robot companies and few corporate heavyweights (mostly in self-driving cars). In other directions, such as unmanned aerial vehicles or artificial intelligence, the technological barrier-to-entry is relatively low. Therefore, **professional service robots is a $27 billion market worldwide that is growing at an annual rate of 30% and more than 20% of the robot companies are young startups! This creates an exciting opportunity for aspiring Greek industry and innovators to enter this young and fast-growing field and modernize the Greek economy towards Industry 4.0.**

3. Future Technology Drivers

Historically, progress in robotics was accelerated by dramatic advances in sensing, computation, and communication. Going forward, intelligent machines and systems, such as robots, will be core technologies in relevant Industry 4.0 domains, such as factories of the future[10]. At the same time, Industry 4.0 advances in IoT sensing, 5G networking, and artificial intelligence will drive future advances in robotics. Such advances in IoT, AI, and 5G will enable robots to go from structured, indoor industrial environments today to more challenging outdoor environments in the future. This results in a technological vision for agricultural robotics, as shown in Figure 3. Similar visions exist in every other societal domain (safety and security, logistics, transportation, manufacturing, healthcare, etc).

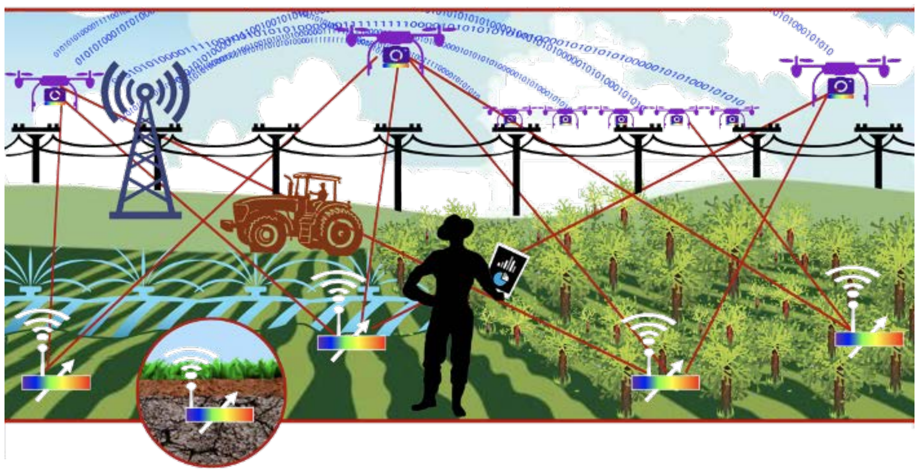

Figure 3: NSF Engineering Research Center for IoT for Agriculture (https://iot4ag.us/)

In order to realize such visions, innovations in robotics will leverage the following technological trends.

Robot Sensors and Actuators: Without sensors, robots would be blind. Sensing technologies are advancing dramatically and robotics is a direct beneficiary. Optical sensors, such as Light Detection and Ranging (LIDAR) have been essential in self-driving vehicles, as shown in Figure 4. Future optical sensors will have higher resolution, lower cost, and smaller size. Neuromorphic cameras, such as event-based cameras, are new dynamic vision sensors that can detect local image changes in high robot speeds. Aerial robots with modern hyperspectral imaging will be a critical sensing modality in the future of precision agriculture. Novel tactile and force sensors enable physical collaboration between humans and robots. Similar advances are happening not only in sensing but also in robot actuation resulting in micro-flying vehicles flying indoors or cell-sized nanorobots for medical purposes.

[10] The autonomous way to Industry 4.0, International Federation of Robotics, Case Study, March 2020

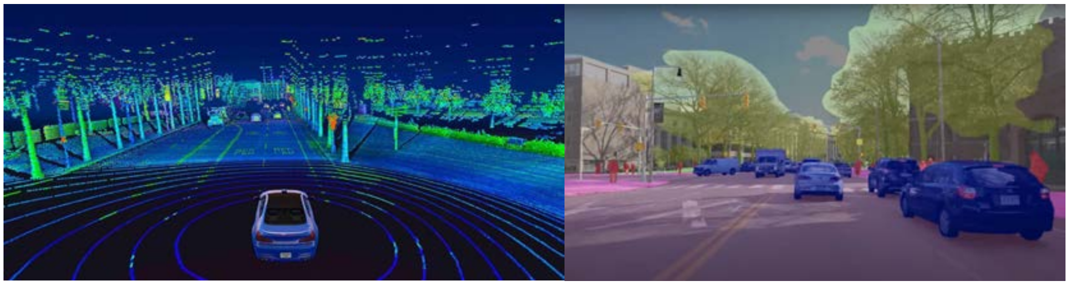

Figure 4: Velodyne LIDAR (left), MIT/Toyota DriveSeg (right)

AI-powered Robots: While sensors add eyes to robots, Artificial Intelligence (AI) provides an "artificial brain" for interpreting sensor data resulting in detailed understanding of the environment in the vicinity of the robot, as shown in Figure 4. In particular, deep learning (DL) is a revolutionary approach that enables robots to detect, identify, and classify objects from raw images or video. The implications of this technology are hard to fully comprehend yet, currently ranging from ensuring safety in driverless cars, to search and rescue, to cancer detection, etc. In the future, artificial intelligence breakthroughs may also be used in decision making in safety-critical situations such as taking over the steering wheel from the car in a busy intersection. This will require advances in making artificial intelligence trustworthy and safe.

Figure 5: Verge Aero drone show (left), Indian Army demo with 75 aerial vehicles (right)

5G-connected Robots: Previous network technologies focused primarily for connecting people, desktop computers, and mobile phones. In 5G and beyond, an emerging trend is in machine-to-machine connectivity such as robot-to-robot communication. Robot-to-robot communication needs to be ultra low-latency and of very high reliability. Increases in network bandwidth will allow robot teams to upload shared maps or information to the cloud. This will enable the collaboration of large numbers of inexpensive robots, as shown in Figure 5. Such teams of robots, empowered with AI and connected via 5G will be able to perform real-time search and rescue missions in disaster response, or coordinate surveillance of protected environmental areas. Furthermore, large teams of robots can also be used as communication relays in providing or improving communication coverage in underserved areas.

Figure 6: Kuka Collaborative Robot (left), Cobalt security robot-as-a-service (right)

Human-Robot Collaboration: A collaborative robot is a robot that physically interacts with humans in a shared workspace, as shown in Figure 6. Collaborative robots assist humans as opposed to replacing humans. The decreasing price of such robots, coupled with artificial intelligence, makes collaborative robots suitable for tasks in smart factory settings, warehouses, and logistics. The recent advances in easy and intuitive programming of such robots (e.g. learning by demonstration), have the potential to further reduce the associated costs and make these robots affordable even for SME. Challenges include collaborative manipulation, object grasp perception and learning, as well as ensuring human safety.

Robot-as-a-Service: Companies can save the upfront, capital investment of acquiring robots by leasing robot services. The Robot-as-a-Service (RaaS) business model offers robot rental services, add-on cloud-based data analytics services during rental, therefore lowering cost of entry and enabling companies to count RaaS costs as operational expenses. There are emerging RaaS services for industrial security robots (shown in Figure 6), delivery robots, factory robots, and agricultural robots. This new business model is accelerating robot adoption, especially in less mature markets, like agrifood.

As can be seen from this discussion, we are witnessing a technological inflection point in robotics. Innovation in robotics in the AI era is no longer about advances in robotic hardware, as many aerial or ground platforms have been commoditized, but rather about advances in robotic software making the hardware more intelligent, more connected, safer, and more valuable. This inflection point in robotics is reminiscent of the transition from IBM desktop hardware to Microsoft's MS-DOS operating software. The transition from hardware to software will drive robotic innovation and open new markets over the next decade.

4. Greek Robotics ecosystem, today

In this section, we provide a holistic view of the current Greek Robotics Ecosystem. We view the ecosystem as a composition of three main pillars as shown in Figure 7. The right pillar focuses on societal drivers, which are areas of Greek society and economy where robots are currently used. The middle pillar focuses on industrial research and innovation, where medium-term robotic innovation is converted to products of medium to high technology readiness levels (TRL) serving the needs of Greek society and economy. On the left pillar, basic research and education, typically performed in universities and research centers, focuses on long-term, low-TRL, disruptive, innovation in robotics and related areas while also educating the workforce for future careers in the ecosystem. Figure 7 shows how the pillars interact across stakeholders in government, end users, industry, startups, academia and research centers.

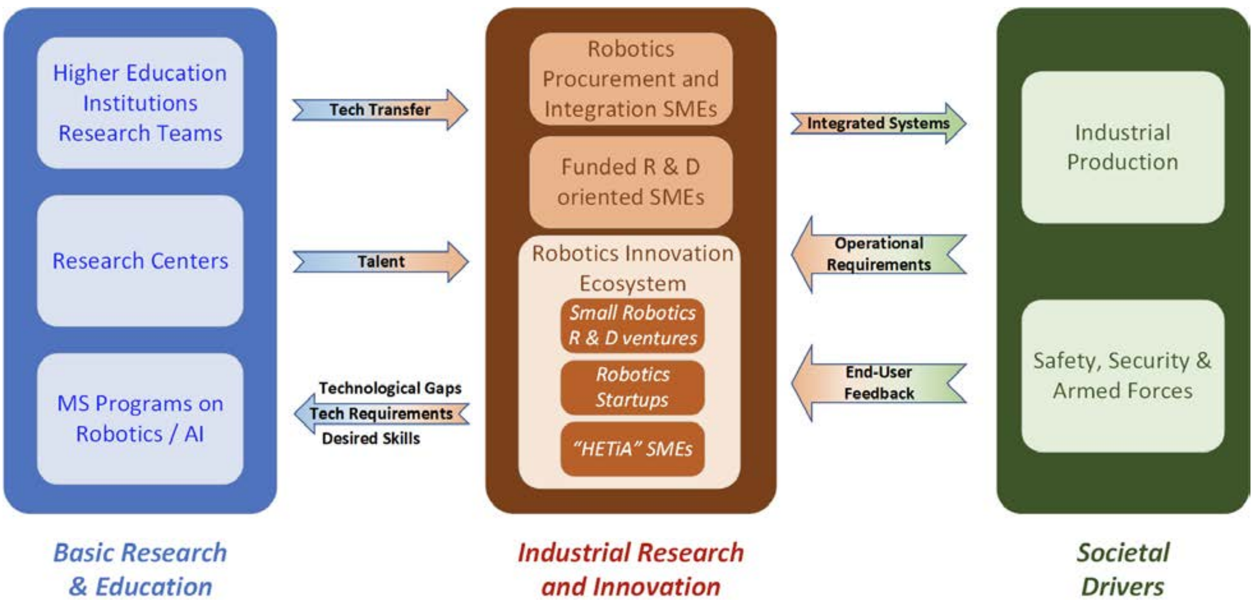

Figure 7: The current Greek robotics ecosystem

Societal Drivers

The Greek government utilizes robotic technologies in the safety, security, public order and civil protection activities of armed forces, coast guard, police, fire-fighters, first respondents, etc. Reports indicate this as a very small, fragmentary, but increasing activity over the last fifteen years, mainly focusing on ground vehicles (UGVs by bomb squads), underwater systems (ROVs in reconnaissance/searching), and aerial systems (UAVs). UAV technologies have very recently attracted government interest for a wider adoption and procurement effort. Procurement is the standard practice of Greek government organizations, and reflects a mentality to import "ready solutions" without any systematic efforts for national industrial development of such technologies.

When considering the Greek economic drivers (see Figure 8) we observe that for the agricultural and livestock farming sector of the Greek economy, although it represents a niche direction, no advanced automation solutions have been reported. Similarly, in services, a prevailing sector in Greece, only a limited number of applications have been reported (logistics, warehousing). The only business sector showing some activity of robotics utilization is industrial production. However, the Greek industry is falling behind in the adoption of robotic systems when compared to both developed (Israel) and developing (e.g., Slovakia, Portugal, Turkey) countries[11]. Although the Industrial Federation of Robotics (IFR) estimates that approximately 600 robots are operating in Greece, the real number is probably closer to 250, since the IFR number is based on robotic imports and thus includes a number of robots that are essentially exported by the Greek robotic integration SMEs[12]. Most industrial robots are used in the food industry (packaging/palletizing), few in manufacturing (welding, assembly), while all of them are of the fixed base manipulator type with no reported use of ground vehicles.

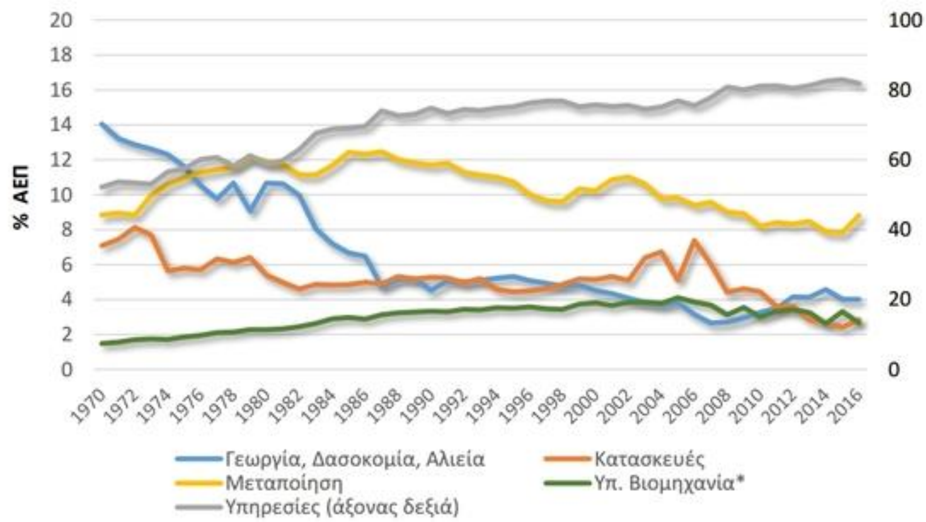

Figure 8: Main Sectors of the Greek Economy

Industrial Research and Innovation

Industrial research and development is motivated by market analyses about the end-user needs (societal drivers) and is technologically responding to the product or end-user operational requirements resulting in the development of robotic integrated systems and products. Within the Greek robotics ecosystem industrial research activities are performed by:

- Robotics Procurement and Integration SMEs: They provide added value to imported robotic systems through customised software and hardware. They serve both the local industry and international customers.
- Funded R&D oriented SMEs: They are mainly providing technical and management (including networking) services for international and national R&D calls. A segment of this category offers services of procurement and integration, while a smaller one is involved in innovation activities.

Within the pillar of "Industrial Research & Innovation," sector-oriented research and innovation centers are usually playing a crucial role. In the case of Greece, we highlight the absence of industrial research centers in robotics that could address key areas of economic or national priority13.

[11] Hellenic Industries Association (ΣΕΒ) – Special Report: *"Robotics and Employment"*, October 2019 (in Greek)
[12] Athens and Macedonian New Agency Report: "*Industrial Robotics in Greece*", June 2018 (in Greek)
[13] «Η Ελλάδα που Μαθαίνει, Ερευνά, Καινοτομεί και Επιχειρεί», DIANEOSIS group : https://www.dianeosis.org/wp-content/uploads/2021/02/RD_study_final.pdf

The lack of industrial research and development makes the middle pillar in Figure 7 the weakest across the Greek robotics ecosystem. The innovation-adopting philosophy, widely used in Greece, results in a major disconnect between basic research and societal and economic impact, eliminates the existence of sector leading companies in the startup ecosystem, accelerates brain drain, and sets unrealistic expectations for short-term innovation to basic research organizations.

Contrary to industrial research and development, the growing innovation ecosystem in Greek robotics and related areas (AI, IoT) offers more hope for the future. The Greek innovation ecosystem has three distinct components:

- Small R&D ventures of established international companies: They are located next to areas with strong and multifaceted academic/research presence, in order to capitalize on the existing talent of graduates. Currently, in areas related to robotics, these are very few (do not exceed 5).
- Startups: Although 140+ startups currently registered[14] address technologies related to robotics (such as AI, Data Analytics - Big Data, Hardware, IoT, Networks, Sensors, Software), currently twenty (20) essentially address robotic technologies (such as aerial and agricultural robotics).
- SMEs within the "Hellenic Emerging Technologies Industry Association - HETiA": Such SMEs provide services and products within the digital emerging technologies domain. A small number of them are involved in robotics (e.g., aerial defense systems, smart farming) or related technologies (e.g., IoT, Machine Learning, Remote Sensing, Sensors etc.)

The lack of a substantial commercial market within Greece usually leads to major "valley of death" issues of selected members of the last two categories.

Furthermore, and similarly to other emerging technological domains, certain successful startups are acquired by international ventures. This usually leads these startups to moving their activities abroad in countries offering more integrated high-tech ecosystems and a friendlier taxation system. Lately, there has been a visible national effort to address those factors.

Basic Research & Education

Basic and applied research in robotics is conducted across numerous Greek universities and research centers. In particular, robotics research is performed in Greece in

- Universities: Agricultural University of Athens, Aristotle University of Thessaloniki, Democritus University of Thrace, National Technical University of Athens, Technical University of Crete, University of Crete, University of Ioannina, University of Patras, University of Thessaly
- Research Centers: Center for Research and Technology Hellas, Foundation for Research and Technology Hellas, Institute of Communication and Computer System, and Athena Research Center

The average number of permanent research specialists (faculty, researchers, etc) per institution is two (2), usually of Electrical / Mechanical Engineering and Computer Science departments. Due to lack of hiring, a major concern is the age of senior / leading researchers which will result in 25% of them retiring by 2026. Furthermore, there is no recent ERC grant in this area. That said, the nature of performed research

[14] https://elevategreece.gov.gr/

extends from basic to applied and the quality is excellent in a world-wide sense[15]. Despite the very good international standing of many individual Greek researchers in robotics, we highlight the absence of basic research centers in this area (e.g., Center for Autonomous Robotics Systems) due to the fragmented nature of the current research landscape.

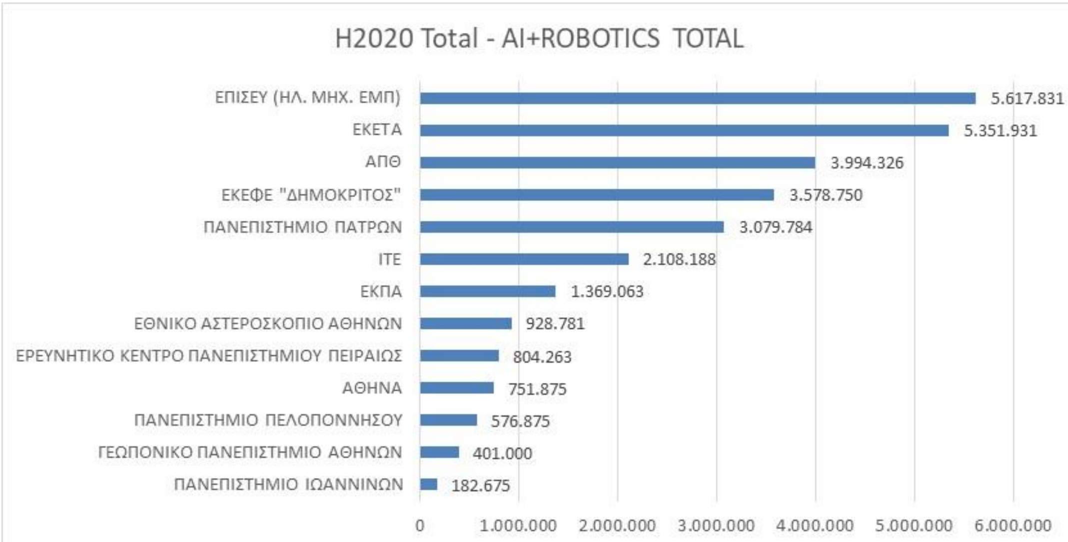

Figure 9: Levels of Robotics/AI funding of several research institutions within Horizon 2020

The research teams are mainly funded by national sources through competitive calls of the General Secretariat of Research and Innovation (multi-partner, applied research efforts), the Hellenic Foundation for Research and Innovation (single-partner efforts for basic research), and by international sources (e.g., European Commission, see Figure 9). Since international funding is considerably higher, the resulting research is fragmented and dispersed[16] and characterized by the following features:

- It follows international strategic mandates led by larger European objectives, or companies
- Inability of Greek basic and applied researchers to define and address Greek national needs
- Bottom-up tech innovation (i.e., "from conceptualization to prototype development") is very limited[17]
- Deep specialization is usually absent (researchers jumping from project-to-project)
- Experienced researchers leave for foreign robotics centers or industry, due to lack of continuity.

The most visible relationship between basic researchers and industrial R&D is through providing limited Technology Transfer and obtaining occasional feedback regarding technological gaps and requirements.

[15] During the last (i.e., 2019) physical occurrence of the *IEEE International Conference on Robotics & Automation*, the largest robotics conference, attracting 4000 participants from 70 countries with 1350 papers presented based on a 40% acceptance rate, Greek robotics represented by 13 papers by 5 institutions ranked 8th (based on population) and 14th (overall), outperforming countries like: UK, Israel, S. Korea, Finland, France, Italy, Belgium, etc.
[16] The group of 22 senior robotics specialists has been reported to address: computer vision, manipulator/interaction control, space robotics, underwater robotics, aerial robotics, ground robotics, healthcare robotics, entertainment robotics, grasping, human-robot interfaces, walking robots, planning and manufacturing
[17]«Η Ελλάδα που Μαθαίνει, Ερευνά, Καινοτομεί και Επιχειρεί», DIANEOSIS group : https://www.dianeosis.org/wp-content/uploads/2021/02/RD_study_final.pdf

International experience across Europe and the US has shown that government-funded research centers should have a much closer interaction with industry and innovation.

Robotics education is challenging as it requires coordination of courses across many departments. At the undergraduate level, individual Robotics and / or AI courses are offered in ten or so departments. At the postgraduate level, there is just a single program relevant to Robotics (National Technical University of Athens[18]), while there are several related Masters (MS) programs on AI and Data Science. Most MS programs, particularly tuition-free ones, have been progressively understaffed due to the retirement of senior personnel. State support for each postgraduate program is not enough to cover minimal requirements. Thus, similarly to undergraduate education, resources provided through externally funded research projects are used for education purposes. A basic and generic problem which concerns Greek postgraduate education is the lack of clear distinction of identity: Are MS programs meant to be "science oriented" preparing their graduates for the PhD level or "professional" with clear direction towards the market?

Robotics has been inspirational for many students at the primary and secondary education level. Current activities include the establishment of robotics student teams based on initiatives of individual teachers (usually the "Computing" teachers) – with no financial support from the state. Teachers try to relate the content with math and physics (+programming) since there is very limited guidance on robotics curriculum. There is overwhelming interest from the students, but due to limited resources, access is limited. The main form of support coming from the state is by providing information about possible EU-funded competition initiatives where the school might want to subscribe.

Strengths, Weakness, Opportunities, Threats (SWOT) Analysis

Below we summarize the previous discussion in a SWOT analysis.

Strengths:

- Basic research community in robotics has an excellent international reputation, but is small, individualistic, aging, and dispersed across many universities, departments, and research centers.
- Very good EU funding success, placing Greece in top ten EU countries in robotics research. Well-educated, English-speaking talent, relatively low-cost environment within Europe.
- World-class Greek scientists, engineers, and innovators in the Hellenic diaspora.

Weaknesses

- Lack of a national robotics strategy spreading national funding across many stakeholders diminishing the impact on society's safety, economy, and prosperity
- Lack of Innovation-adopting industry creates a very large valley of death in the innovation cycle
- Lack of industry leaders with R&D in robotics or AI, stifling local innovation
- Limited national funding addressing national priorities (i.e., safety and security)
- Limited technology transfer out of universities and research centers
- Very low number of robots and end-users across industry and government
- Limited high-end robotics jobs for high-end talent resulting in brain drain

[18] "Automation Systems": http://dpms-as.mech.ntua.gr/

Opportunities

- Aspiring Greek industry and innovators can become regional leaders in the relatively young, low-barrier to entry field of professional service robotics, such as unmanned vehicles.
- Leveraging industrial leadership in maritime, tourism, and some agricultural sectors. Modernizing the Greek economy towards Industry 4.0
- Capitalizing on the potential of robotics and related technologies in Industry 4.0 initiatives from the State (ESPA) or the EU (Horizon EUROPE) during the Programming Period 2021-2027
- Growing innovation ecosystem in robotics, AI, and related Industry 4.0 areas. Bringing the whole robotics ecosystem together (with AI, and Industry 4.0 ecosystem) housed in tech clusters
- Educational programs in robotics, despite understaffed and underfunded laboratories
- Growing excitement among secondary school students, but without career advice in robotics

Threats

- Over the past ten years, there has been a rapidly growing threat due to the proliferation of low-cost, unmanned aerial, ground, surface and underwater vehicles in the region and the world19. This creates new and significant national safety and security risks.
- Technological surprise due to upcoming robotics, AI, and Industry 4.0 technologies that creates new safety and security risks or dramatically reduces competitiveness of Greek industry

[19] China has made drone warfare global, Michael Horowitz et al, Foreign Affairs, November 2020

5. A vision for a Hellenic Robotics Initiative

Robotics in the era of artificial intelligence will transform every aspect of Greek society, security, and economy. Aerial, ground, sea and underwater robots empowered with artificial intelligence will be critical for ensuring safety and security as well as for environment protection, earthquake response, and disaster response. Agricultural robots can assist Greek farmers in harvesting operations or be used for precision agriculture, lowering costs, saving water, and maximizing yields. Underwater vehicles can be used for inspecting ship hulls, pipelines or Greek ports, as well as searching for precious archaeological sites. Aerial robots can ensure the delivery of urgent medical supplies in remote islands in the Aegean, disconnected mountainous regions in extreme weather events, or after earthquakes.

Figure 10: Top row: Zipline (left), Subsea Tech (middle), Greek startup Perceptual Robotics (right), Bottom row: Amazon Robotics (left), Augean Robotics (middle), Da Vinci surgical robot (right),

Robots with advanced artificial intelligence can support Industry 4.0 for automatic inventory inspection and management. Robots can be used for improving efficiency in logistics, warehouses, and fulfillment centers. AI-powered robots can assist in construction and real estate by building or mapping 3D structures. Remote robotic surgery across Greece can be enabled using low-latency and high-reliability 5G networks. Unmanned aerial vehicles can perform routine, low-cost inspections in wind farms or electric power lines. Robots can also be used as mobile communication hubs for providing or boosting network connectivity in rural areas or during emergencies.

This is not science fiction. The technological revolution described above is starting to happen around the world, including Greece, as shown in Figure 10. Furthermore, as articulated in Section 2, it is still very early in the days in this revolution. This creates a historic opportunity for Greece to become a regional leader in this emerging, yet critical future technology.

Hellenic Robotics Initiative: A vision for robotics in the AI era
Our vision is that robotics empowered with artificial intelligence will be an essential technology of the future for the safety and security of the Hellenic nation, its environment and its citizens, for modernizing its economy towards Industry 4.0, and for inspiring and educating the next generation workforce for the challenges of the 21st century.

It is time for leaders in government, industry, and academia to mobilize all relevant stakeholders across the robotics ecosystem in order to develop a national **Hellenic Robotics Initiative. The Hellenic Robotics Initiative should serve as the nation's long-term vision and strategy across the entire Greek robotics ecosystem.** It should be specific to the Greek national priorities, leverage unique differentiators for industrial innovation, and prioritize efforts that will lead to demonstrable, long-term impact on the security and prosperity of the nation. **Once developed, it is of critical importance that the Hellenic government shows long-term strategic and fiscal commitment to this initiative.**

The first step towards developing a national roadmap is to assemble a national **Hellenic Robotics Council,** that will bring together the nation's top experts and leaders, across government, industry, and academic sectors with the important goal of developing the inaugural Hellenic Robotics Initiative. Assembling a national council is arguably the most important recommendation of this report, as the ecosystem is currently fragmented. Over time, the Council should bring the robotics ecosystem together, fostering collaboration and cooperation, organizing events, enabling sharing of knowledge, skills, resources, and infrastructure, disseminating success stories, funding and employment opportunities, and providing educational and training opportunities. The Council could also consider developing a strong virtual organization that serves as the nation's gateway for the robotics ecosystem. The Council should coordinate with national councils (National Council for Research, Technology and Innovation) and international policy making bodies (such as European AI Experts).

The rest of the document provides some initial findings and recommendations that could contribute towards a national dialogue in developing such a Hellenic Robotics Initiative. The report starts by first examining why Greece should invest in robotics, followed by which strategic directions could be most impactful to the nation. Starting from these strategic directions, we then make recommendations for mission-driven research, industrial research and innovation, and basic and applied research. The report then focuses on how to best prepare the next generation to be innovators in this new technological landscape. The last part of this report discusses the impact of the adoption of robotics and AI technologies on the current and future workforce, and considers regulatory, ethical, and legal aspects of robotics in the artificial intelligence era.

5.1 Societal Drivers for Hellenic robotics

How can Greece best benefit from the global trends in robotics and AI outlined above? More importantly, how can the benefit be maximized through targeted interventions that either foster the adoption of existing robotic technologies, or foster innovation leading to novel technologies? The answer to these questions should take into account differentiating features of the Greek economy and society. These include:

Talent: Greece has a well-trained, sophisticated workforce, with relatively low labour costs compared to the rest of western Europe. Furthermore, a large and accomplished Hellenic diaspora has the means and the will to invest in Greece both in human and in financial capital.

Geography: Greece has extensive borders on land and in the sea. This includes rugged terrain, an extensive coastline, and numerous islands. Furthermore, natural hazards, especially earthquakes and wildfires are common. Greece is also a stabilizing nation that is centrally located in the sometimes volatile Eastern Mediterranean basin.

Industry: Greece's industrial base does not have much exposure in automotive, semiconductor or manufacturing, areas in which industrial robotics has had a significant impact in the past. On the other hand, Greece is a global leader in ocean shipping, tourism, and some agricultural sectors.

The well-trained workforce and the large diaspora are innovative forces that Greece should capitalize on. Being a stable country with good access to its neighbors' markets, means that Greek innovation may also attract independent foreign investment and become the basis for an export industry, reaching well beyond the country's borders. Robotics and AI are an ideal area for targeted innovation efforts. This is because robotics and AI require relatively limited financial capital investment, can take advantage of the excellent human capital, and can lead to customized solutions addressing particular Greek needs; indeed, Greek companies may well aspire to become global leaders in certain niche domains in robotics and AI.

A Societal Driver of National Importance: Robotics for Safety and Security

The particular features of the Greek geography, location and economy suggest areas where customized, innovative solutions may have a major impact. Greece's extensive borders in land and sea and the presence of natural hazards make **safety and security** applications a national priority. **Safety and security in the broadest sense (defense, civil protection, border protection, environment protection, disaster relief, emergency search and rescue) is an area of national importance that, in our view, necessitates a national initiative in robotics and AI.** Innovative solutions can address needs in autonomous surveillance of borders and critical infrastructures, monitoring of forests and natural resources, emergency and disaster response, search and rescue missions, and others. Innovation in aerial, land, sea and underwater robotics can lead to increased effectiveness in all of these areas, through automation or technologies for assisting human operators (Figure 11).

Figure 11: Safety and security, agrifood, maritime and logistics are key societal drivers for Greek robotics. Intracom Defense LOTUS UAV (left); Greek Startup Terra Robotics (middle); Bluefin Autonomous Underwater Vehicle AUV (right)

Economic Drivers with Innovation Potential: Agricultural, Maritime, and Logistics Robotics

In order for Greek robotics to be innovation leading, it should leverage differentiators, such as talent and geography, while also focusing on robotic innovations in industries that are internationally competitive. This results in strategically pursuing opportunities in areas such as agrifood and maritime.

Agriculture is an area where targeted innovation may lead to Greek global champions. The agricultural robotics market is expected to reach $20.3 billion growing at a cumulative annual rate of 34.5%[20]. The introduction of robotic technologies in agriculture and food industry is attracting attention internationally; however, many of those solutions are aimed at massive markets, such as Australia and the US, whose needs are very different from those of Greece. Off-the-shelf solutions developed for these markets are unlikely to be as effective as customized solutions targeted to the Greek geography and needs; these include small plots and rugged terrain. One can envision robotic solutions for monitoring as well as AI-based interventions to optimize yields or quality, supporting competitiveness of this major export industry, as well as food processing and food packaging.

The same applies to the globally leading **maritime** sector[21] where, for example, underwater robotics can be used for ship hull inspection, cleaning or maintenance as shown in Figure 10. Furthermore, robotics can be critical for marine fisheries and aquaculture, where one can envision robotic solutions for monitoring the inspection and repair of installations. Autonomous Underwater Vehicles (Figure 11) can also perform inspection of underwater gas pipelines or underwater electricity lines connecting islands, ocean floor monitoring, or even search for underwater archeological sites or shipwrecks.

The **logistics** sector is one of the leading sectors of the Greek economy due to the geographical positioning of Greece, providing about 200,000 employment positions[22] and 11b € before taxes (2019). The recent prospects of the Greek economy underline the need for investment in this sector emphasizing it's modernization via the introduction of information technologies[23] The adoption and integration of

[20] https://www.globenewswire.com/news-release/2020/10/07/2104754/0/en/Agricultural-Robots-Market-Global-Forecast-to-2025.html
[21] https://www.ecmar.eu/media/1813/ecmar-brochure-maritme-technology-challenges-2030.pdf
[22] "Sectors supporting the Greek GNP", Kathimerini, 1/11/2020 (in Greek)
[23] "The Digital Future of the Logistics Chain", ΣΕΒ (Hellenic Federation of Enterprises), 25/2/2021 (in Greek).

advanced automation, robotics, and AI technologies is of paramount importance to improve its competitiveness around the Mediterranean.

Some of the unique geography features that call for customized solutions are shared with other countries around the Mediterranean basin, but also niche sectors in larger global markets. This suggests that robotic and AI solutions developed in Greece for safety, security, agrifood, maritime, logistics can have a wider market potential leading to an export industry in their own right.

The potential for Greek innovation-leading technologies with global reach may be more limited in other sectors where robotics and AI are already having an impact internationally; however, there may still be considerable benefits from technology adoption to increase productivity and “opportunistic” innovation. For example, industrial robotics is an already mature field where Greek innovation may find it hard to make inroads, also due to the limited manufacturing base. Here, one can consider incentives to encourage adoption of available technologies by the Greek manufacturing sector; in the process, it may be possible to identify niches with innovation potential, such as tailored sensors and AI technologies in the context of Industry 4.0. Likewise, autonomous driving has seen massive investment in recent years internationally, from incumbents in the automotive industry, technology giants, and mobility-as-a-service providers; Greece will find it difficult to compete in this sector other than by seeking niches or investment from one of the international leaders.

5.2 Mission-Driven Research

Mission-driven research is classified as research that follows an impact-focused approach to address "great" challenges of strategic importance to the economy, society, or national security. Often, mission-driven research reflects current priorities (e.g., developing a COVID-19 vaccine), emerging needs (e.g., healthcare for aging population) or a push to advance long-term science and future technologies for national interest (e.g., space exploration, nuclear fusion).

In contrast to technology-push policies, mission-driven policies focus on the outcome for the society and the country as a whole. Achieving a mission therefore requires the concerted action of a wide array of players: not only scientists and technologists, but also manufacturers, users, public institutions, and policy makers at all levels[24]. Government plays a pivotal role for establishing mission-driven research priorities, by providing sustainable funding without the need to respond to market-driven factors or short-term, impulsive technology trends.

Mission-driven research does not mean applied research. Both applied and basic research could be mission driven. Instead, it is supported and evaluated on its ability to promote its mission and to meet verifiable objectives on a planned timescale. For example, NASA and JPL are mission-driven agencies that are funded and evaluated by the U.S. government on the basis of their mission (space exploration) and their impact on society.

Figure 12: Heron UAV developed by the Israel Aerospace Industries (left), Israeli desert farming (right).

Mission-driven research is more important for countries with unique challenges that cannot afford to wait for technology infusion from abroad. Because of their geography, history, ethnicity, or political system they are forced to develop long-term strategies of national interest. A prime example is Israel, which has developed an internationally well-recognized defense-related technology sector, as well as innovative agricultural technologies for arid areas that have been adopted around the world[25] (Figure 12).

Robotics and AI is a technology that will revolutionize the way we communicate and work with each other, the way we entertain and socialize with each other, and the way we fight with each other. There is no doubt that military and civilian AI systems will be absolutely critical for the security and prosperity of any nation. Recognizing this fact, and following the US model[26], the European Union has recently adopted

[24] "Mission-Oriented Research and Innovation Policy:A RISE Perspective", European Commissions, Brussels, January 2018

[25] https://www.israel21c.org/why-the-future-of-agriculture-lies-in-israels-desert/

[26] https://www.nscai.gov/2021-final-report/

mission-driven research as a model to achieve the level of coordination or the sense of purpose needed to have a transformative impact on Europe's economic and social goals[20].

Greece lacks a masterplan to create and nurture a fully functioning, harmonized advanced robotics ecosystem that can utilize the value, threats, and opportunities created by the development and deployment of AI technologies both in the civilian and, most importantly, the military sector. The current landscape is fragmented and lacks the integration between industry, research development, and national defense. A holistic analysis of the overall Greek robotics ecosystem reveals that there is a large "valley of death" between basic and applied research, on one hand, and societal and economic impact on the other. This gap is even larger in areas of national security/safety needs.

Paradigm shift: A Mission-Driven Research Institute on Advanced Robotics Technologies

It is a priority to understand the operational needs, end-user goals, and technological gaps for areas of importance to the country (e.g., safety and security). Recent initiatives (THORAX) are steps in the right direction, but in order to be successful and have a long-term sustainable impact, they have to be part of a broader agenda, which its end goal should be the development of indigenous technology that caters to the specific societal, economic, and security needs of the country.

In this spirit, having identified national security as the main societal driver for Greek robotics, we propose **the establishment of a new Hellenic Center for Advanced Robotic Technologies (HCART)** which will be a mission-driven organization with the mission to advance, develop, and transfer innovative unmanned vehicle technologies in air, land and sea in the service of national security (military, police, coast guard, fire service, first responders) and other areas of national importance.

Such a mission-driven organization should be government-funded in a sustainable manner enabling the organization to focus on long-term mission R&D rather than fundraising. The Center's board should include both leaders in technology innovation, and industry, as well as government leaders in national security. Although cutting-edge research, manifested through scientific publications may be a product of such a Center, it should be evaluated not on funding successes but rather on technological innovation and adoption and transfer of robotic technologies by the government and industry (e.g., operations, patents, spin-offs) in security, civil protection, environment protection etc. on a planned timescale.

Center operations should be to follow developments on the field, continuously assessing the country's needs and strengths, understand government uses and operational needs, identify technological gaps to avoid "technological surprises," perform market analysis for component technologies and map those to technological challenges and opportunities, transitioning technologies from prototype demonstration to integrated systems operational in the field. The proposed Center should reside organizationally outside any organization that has no provision for sensitive or classified research (i.e., universities), and should have continuous access, if not ownership, to infrastructure for deployment operations such as an airport or a port. Collaboration mechanisms with applied research may be pursued by issuing competition-based solicitations for proposals for collaboration with universities on basic or applied research, as long as they further advance the core mission of the Center.

The first step towards this direction is assembling a task force whose initial goal will be to provide an assessment of indigenous technology capabilities and opportunities in this area, map those to technology goals, and create a roadmap to reach these goals. The Task Force will also perform a market analysis to transition technologies from basic science prototypes to usable technologies in the field and recommend legislative and organizational actions to remedy current obstacles with patenting and licensing of technology in areas of national interest. A visioning and feasibility study for a Hellenic Center for Advanced Robotic Technologies (mission, governance, staffing, operations, budget) will be one of the initial tasks of this task force.

While the government needs to step up its funding efforts to support the establishment of HCART and related mission-driven activities, this should be done in a smart and efficient manner with the nation's interests in mind. Given the lack of previous similar efforts, there is a danger of creating unrealistic expectations that a single research effort or a single, short-term project will suffice to address this challenge. A mission-driven mindset should be promoted, by which funding decisions should be targeted towards innovation that has a demonstrable impact on the nations' long-term safety and security. In this spirit, we not only propose a new type of organization but **we also advocate for a change of funding philosophy from funding-driven research to mission-driven research**. **That change in philosophy conveys a sense of urgency and strategic purpose.**

5.3 Industrial Research & Innovation

The gap between research innovation and transition to market is a well-known problem for many technologies but is more pronounced for the robotics industry. Robotic technologies coming out of basic research centers on their way to innovative products, lose their cutting-edge appeal for curiosity-driven research, remain technologically risky for industrial funding, and are historically underfunded from the government. This leads to significant unrealized innovation potential and impact in both government and industry.

As summarized in Section 4, current robotics industrial activity in Greece is either in the area of national security and safety, or in industrial automation, mainly in the food industry and in manufacturing. This is complemented by a limited but increasing activity in integration solutions by SMEs[27], with a significant number of robotics startups. This section outlines our findings and recommendations for the growth of industrial R&D and its facilitation by technology transfer from academia and research centers, focusing on areas outside the national security and defense industry.

The ambitions for Greek industrial research and innovation in the area of robotics should go beyond the local market demands. An example that could serve as a role model here is the state of Pennsylvania in the US. The area around Pittsburgh emerged from high unemployment in the 1980's and 1990's to become one of the globally leading regions in robotics. In 2019, the Pittsburgh robotics ecosystem encompassed more than 50 robotics companies[28] with an investment of $2.9 billion in robotics startups. The two main reasons for this growth have been shown to be the existence of the Robotics Institute at Carnegie Mellon University and public-private partnerships[29].

To become such an international success story, Greece should capitalize on its unique features and strengths. These include the existing research and development efforts in robotics, a deep talent pool, and a particular geography. Greece already boasts excellent robotics research at academic labs (Section 4) and highly qualified graduates from all its Technical Universities and Computer Science Departments. Robotic technology is knowledge-intensive and requires a rigorous interdisciplinary education. Despite popular perceptions, innovation in robotics is not driven by teenagers fiddling in a garage. History shows that the bulk of innovation in this area (in driverless cars, rovers, manipulators, drones, warehouse robots) comes through spin-offs of universities founded by professors and recent PhD graduates; recent examples include Kiva, iRobot, DJI, Aurora, nuTonomy, and many others. Greece's rigorous engineering education and research performance offers a competitive advantage in this knowledge-intensive field. Moreover, Greece has a unique geography with a rare combination of a plethora of islands and inaccessible mountains. Unlike social media or software-as-a-service, robotics is first and foremost a technology that lives in the physical reality; any innovation in this area will have to deal with (and can take advantage of) the unique features of the Greek physical reality.

Combining these features, **Greece can aspire to become a living testbed for field robotics and their applications in extreme environments.** Instead of limiting the scope to domestic markets, Greece can become the main demonstration site of robotic technologies that can be exported

[27] https://www.amna.gr/home/article/265016/Ereuna-tou-APE-MPE-gia-ta-biomichanika-rompot-stin-Ellada
[28] The Pittsburgh Robotics Network https://robopgh.org/
[29] https://www.roboticsbusinessreview.com/manufacturing/pittsburgh-ideal-robotics-businesses/

and used in similar environments. There are examples of companies that are already exploring this path, such as the startup Perceptual Robotics specializing in wind turbine inspection, or Altus LSA that builds air and surface vehicles for security and fire protection applications (Figure 13). Other applications might include the automatic transport of critical health provisions like medication or blood supplies from island to island, the transfer of goods over difficult terrain to remote mountain villages, or fire detection in national parks. Last but not least, agricultural robotics, where global focus is shifting to precision agriculture and automatic quality monitoring at a level beyond the capabilities of human farmers. Here Greek robotics could offer a path forward for exclusive products like wine or olives where weather monitoring, quality monitoring, and precision manipulation are critical[30].

Figure 13: Perceptual Robotics Unmanned Air Vehicle inspecting a wind turbine (left). Altus LSA Unmanned Surface Vehicle for maritime perimeter patrol (right)

Having access to an internationally unique living testbed at a national scale can form a basis for a vibrant academia-startup ecosystem. This in turn can pave the way for foreign industrial actors to enter the Greek robotics innovation scene, for example through acquisitions. Many of the larger industrial research and development labs, including the Facebook Reality Labs, Qualcomm Research Robotics, and the Amazon Body Labs, were created through the acquisition of startups. Because of the strong talent in academic robotics, spin-offs will create a unique opportunity for an acqui-hire from one of the global industry leaders; focusing on niche areas with an international market as outlined above will make Greek robotics start-ups even more attractive targets for acquisition.

What would it take to turn Greece into such a living testbed for robotics technology? Necessary conditions include an appropriate legal framework that will facilitate innovation, enable easy and safe experimentation and provide a solid foundation for the ownership of data and intellectual property (Section 5.7). Lowering any barriers to mobility across academia, institutes, industry, and startups for faculty, researchers, and students would further facilitate the process: it should be possible for faculty to take innovation sabbaticals to start a company and for university students to obtain innovation fellowships to help them build prototypes, develop business cases, and raise capital. Community-building activities, such as an annual conference and technology exposition with an emphasis on technologies of the future, or common space like technology parks with a focus in robotics would also help. However, in our view a main catalyst in the process should be **public-private partnerships**.

[30] https://www.kathimerini.gr/economy/561130144/rompot-agrotis-made-in-greece-gia-tis-doyleies-sta-chorafia/

Greece's startup ecosystem[31] is already based on strong public-private investment partnerships like Equifund. Success in attracting funding from government or EU programs can be a double edged sword, however, indefinitely trapping robotics SMEs in the valley of death by disincentivizing them from seeking third party investment, or earning revenue. In addition to establishing commercialization criteria for public funding, what is needed is entrepreneurial education and mentoring of potential founders. Returning to the Pittsburgh example, several robotics companies there started with seed funds from the Technology Collaborative that evolved into what is now Innovation Works[32]. This entails a departure from the classic angel investing, by closely working with universities to identify ideas for commercialization and mentoring researchers on their way to becoming entrepreneurs. Robotics is a physical technology and investments have to address the costs of building actual hardware, deteriorating the valley of death. **A public-private partnership in seed funding could bridge the gap between discovery and first investment by appropriately training academic researchers**, similar to Innovation Works or the National Science Foundations' iCorps[33] program in the US.

[31] Startups in Greece 2020-21: Progressing against all odds https://thefoundation.gr/2020/12/17/startups-in-greece-2020-2021-report-progressing-against-all-odds/
[32] https://www.innovationworks.org/
[33] https://www.nsf.gov/news/special_reports/i-corps/

5.4 Basic and Applied Research

As described in Section 4, Greece has a very good international reputation in academic robotics research. However, this international standing is fragile and fragmented. This is owing to very limited faculty hiring over the past decade, resulting in excellent, but aging, faculty without new researchers that can bring new ideas (especially on the interface between robotics and artificial intelligence). Furthermore, Greek robotics research is fragmented, spread across many departments or universities with limited cooperation, limiting the competitiveness of individual investigators against organized team efforts from European research organizations.

University Centers of Research Excellence in Robotics and Artificial Intelligence
Given the interdisciplinary technological trends in robotics (as described in Section 3), it is critically important to **establish university Centers of Excellence in robotics and artificial intelligence, bringing together faculty and students with expertise in areas such as robotics (locomotion, manipulation, mobility, aerial, underwater, medical), computer vision and perception, control systems, automation, artificial intelligence, and machine learning, addressing scientific challenges motivated by needs in critical societal sectors (such as safety and security, agrifood, maritime, logistics, manufacturing).** Each center should have a critical mass of more than ten faculty members across departments, ideally physically collocating together existing faculty with numerous new faculty hires. This will rejuvenate research, improve cooperation and catapult basic research higher.

Centers of Research Excellence on Robotics and AI could be established through competitive calls among Universities, proposing a broad strategic vision, new faculty positions that can complement existing areas of excellence, space and infrastructure investments (startups, staff, robots, cloud). As articulated in the Education Section next, the centers could be responsible for developing international, industrially cutting-edge postgraduate programs in AI, Robotics, IoT including instructional labs. Each Center should contribute to the development of undergraduate programs in Robotics, AI as well as entrepreneurship training. Additional activities can include supporting robotic competitions, secondary education outreach, industrial partnerships, as well as hosting international conferences and summer schools. Centers should have strong relations with industrial and tech parks in related clusters. In robotics and AI it is very common in the US for university faculty to have joint appointments or industrial appointments (Amazon scholars) in industry. Furthermore, such centers should organize an annual Greek Robotics Conference & Expo (see Section 5.3) bringing the robotics ecosystem together.

Research Funding: Research funding has certainly improved over the years, particularly in public research funding. Despite these improvements, increasing basic research funding is one of the main recommendations of the Pissarides report[34]. This could include the following targeted initiatives:

Basic Research Funding: Basic funding should clearly increase but in targeted areas. An existing organization (e.g., HFRI-ΕΛΙΔΕΚ) should be strengthened while also improve its organizational structure and adopt best practices from other countries. A percentage of basic research funding (e.g., ~60%) should be directed towards priority areas set by the Greek government, while the rest should be more exploratory across all areas. In this regard, funding could be directed towards a national funding call in Robotics, AI, and

[34] https://government.gov.gr/wp-content/uploads/2020/08/GROWTH_PLAN_INTERIM.pdf

related Industry 4.0 areas. This should allow broader interdisciplinary efforts (i.e., faculty/researchers led proposals with emphasis on Postdocs and PhD researchers, options for inter-departmental, inter-university proposals could be adopted/promoted) on a regular basis (every 3-4 years to allow successful efforts capitalize on their performance and re-apply, instead of penalizing them by not permitting to re-apply). Graduate fellowships (IKY) programs for doctoral studies in AI and robotics in Greece should be expanded. Graduate fellowships should also adopt better monitoring and progress evaluation criteria, including publications to internationally leading conferences and journals.

Defense Funding: Different countries have different funding mechanisms, which indirectly affects the direction of robotics research. Japan's efforts in robotics have been funded by companies leading to humanoid and entertainment robotics. In Europe, national and European efforts have primarily targeted industrial robotics. In the US, a large fraction of robotics research is funded by the US military, leading to advances in autonomous aerial and ground vehicles for reconnaissance and combat missions. Given the recommended emphasis on robotics for safety and security, the US model for funding should complement the current European model when it comes to funding for robotics. In other words, the Ministry of Defense needs to play a much more prominent role in supporting basic and applied research in robotics and artificial intelligence. This can be performed by funding mission-driven institutes (as in Section 5.2) directly from its core budget. In addition, the Ministry of Defense could have its own research funding arm, or support joint funding calls with the European Defence Fund or the Greek General Secretariat for Research and Innovation. In fact, joint funding mechanisms should be considered by other ministries or industries as described next.

Joint Funding Mechanisms: Given the cross cutting nature of robotics, AI, or Industry 4.0 technologies, there will be an impact across various government and industrial sectors. In order to best harness the power of these technologies across various sectors of society, different ministries (Agrifood, Maritime affairs, Health, etc.) or organizations could provide additional funding for research activities that cater to their specific priorities. Leveraging resources from their own budget, ministries could initiate specific calls, jointly with the General Secretariat for Research and Innovation (GSRI) that has expertise in reviewing proposals. For example, this could enable specific calls across the Ministry of Agriculture and GSRI for agricultural robotics. Similar mechanisms could be considered in other sectors as well. On the corporate side, GSRI for applied research and innovation should emphasize risk-sharing between industry and the government for innovation, as opposed to cost-sharing projects for technology adoption. Joint funding mechanisms for international scientific cooperation with the US, Israel, S. Korea, Japan in areas of strategic alignment should be pursued using mechanisms such as the NSF-BSF Joint funding grants.

An aspirational research institute model: The Italian Institute of Technology

Over the past two decades, various new research institutes have emerged in Europe with the ultimate goal of improving research excellence. Some European efforts along this direction include the Alan Turing Institute in the UK, the Institute of Science and Technology in Austria, and the IMT School for Advanced Studies in Italy. The mission, objectives, and operations of these institutes differ slightly from each other but they all have had significant impact in their respective countries.

Greece should consider a similar model for basic and applied research for robotics and artificial intelligence. The primary strategic objectives should be to increase the density of research excellence, reversing brain drain, but, perhaps more crucially, have a demonstrable innovation impact on the Greek economy and society. Over the past fifteen years, there has been a European robotics research institute that was able to accomplish all these strategic goals in a country that is culturally similar to Greece.

The Italian Institute of Technology (IIT) was founded in 2006 with a mission to promote excellence in basic and applied research, but also to promote the development of the Italian economy. These two missions are equally important in measuring the impact of the Institute, justifying public investment. While publicly funded (with strong support over many governments) and supervised by both the Italian Ministry for Education and the Italian Ministry for the Economy and Finance, the institute operates outside the public legal framework giving the institute strategic and operational autonomy and flexibility. Independent monitoring bodies evaluate not only scientific excellence but also innovation impact on industry. In addition to robotics, IIT focuses on nanomaterials, life tech, and computational science.

Despite its relative young age as a research institute, the results generated by IIT have been, by any measure, outstanding. Competitive fundraising for the Institute has now grown to 350€ million where 250 million comes from competitive projects (national, European) while 100€+ millions comes from commercial, industrial and in-kind projects. Being able to offer higher salaries compared to other organizations, IIT aggressively pursued the recruitment of ERC winners across Europe and succeeded in bringing back outstanding Italian scientists from abroad. The Institute has received so far 50+ ERC grants for 80+ principal investigators, a tremendous measure not only of scientific excellence but also of international reputation. The Italian Institute of Technology is already currently ranked first among Italian public research institutions in the annual Italian ranking by ANVUR ranking (in IIT research areas).

Across all areas (not just robotics), IIT has now grown to 1,800 people (investigators, staff, technicians, postdocs, students, fellows and administration). The current composition consists of approximately 50% Italians (retaining local talent), 25% bringing back Italians from abroad, and 25% attracting international talent from 60 countries. Therefore, IIT was not only successful in bringing outstanding Italian scientists back to Italy, it was also successful in becoming an international magnet for European and global talent.

From its inception, technology transfer and economic impact was the fundamental differentiation between IIT and other Italian research institutes. On this front, IIT has over-delivered. IIT has a current portfolio of more than 1,000 active patents, which is more than ten patents per principal investigator on average. This is the highest patent filing rate in Italy's research system. IIT has also launched 24 startups while 50+ startups and business ideas are under development with a cumulative fundraising of 90€ million. Furthermore, the Technology Transfer Office of IIT has created an industrial ecosystem with joint IIT-industry labs through solid liaisons with more than 20 Italian and global companies. It is no surprise that IIT is also ranked first on tech transfer among Italian research institutes.

Greece should envision the creation of an institute similar to the Italian Institute of Technology. What sets apart the Italian Institute of Technology from other research institutes is its emphasi**s** on technology transfer and innovation without sacrificing research excellence. Despite the obvious differences between Greek and Italian economies (the presence of heavy industry in Italy being one of them), the overarching vision of performing world-class research, recruiting and retaining outstanding talent, and having an impact on the Greek economy is the same across both countries. Strategically, a similar Greek institute should focus on areas of importance to the future Greek economy, such as robotics, artificial intelligence, Industry 4.0 among others. Envisioning such an aspirational institute (mission, funding, strategy, research excellence, tech transfer) could be examined in greater detail in a future report, as the IIT research model also applies to areas outside robotics.

5.5 Educating A Nation of Innovators

Robotics education is one of the most inspirational ways to best prepare the next generation of Greek students for the technological revolution in Industry 4.0. Robotics brings together artificial intelligence (the mind) which is embodied in physical systems such as cars, planes, or manufacturing (the body), encapsulating many fundamental principles and technologies needed for Industry 4.0. Therefore, **we advocate investing in robotics education in order to inspire and prepare future students with 21st century skills not only for a career in robotics but also in Industry 4.0.**

Robotics education requires a departure from current educational philosophy that is primarily department-centric and with limited, individualistic laboratory exposure. Robotics requires hands-on, project-based, and team-oriented programs across traditional disciplines. This is precisely the vision of the so-called "maker movement" which empowers intellectually diverse student-teams to innovate while addressing real-world technical challenges[35]. **Robotics education in maker spaces is a cultural shift that will result in educating innovators in the era of Industry 4.0**.

A Nation of Makers: A Culture Shift

Educating the nation to develop innovators in robotics means a cultural shift to become a nation of makers, builders, hackers, and tinkers, where the mind and the hands are used to explore ways to conceive and implement ideas to put them to practice, as well as redesign devices; all as a systematic and pervasive educational endeavor. Greece is significantly below the European average in maker spaces per million citizens[36]. While a significant investment is required from all major technical universities in "Maker Space" laboratories, most importantly a paradigm shift in educational goals is needed.

Makerspaces: For every major technical university, we recommend the creation of Maker Spaces, which are student-centric laboratories including a blend of the following facilities:

<u>Machine shops</u> – that specialize in training, mentoring and making for the creation of both complex systems, as well as finely-detailed components. Staff consisting of skilled machinist educators is needed to provide the key element of inspiring students to build things.

<u>Hardware/Software Makerspaces</u>- where electronics, coding, design and fabrication come together. Educators/staff offer specialized training in hardware, software and safety techniques. Makers are free to move on their own timeline from ideas to innovations to potential startup assistance.

<u>Project-oriented Makerspaces for class instruction</u> – that support class projects, and contain resources that facilitate collaboration, such as open meeting spaces and multi-user shops. The goal of these spaces is to enable a programmed, curriculum-based learning of building systems.

<u>Open community Makerspaces</u> – that provide unrestricted access to the academic community fostering building and making as a community effort. The basic goal is to facilitate access to as many users as possible, targeting early and untrained users, educating them in safe practices.

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[35] M. Hatch, The Maker Movement Manifesto: Rules for Innovation in the New World of Crafters, Hackers, and Tinkerers, 2013

[36] Overview of the Maker Movement in the European Union, JRC Technical Report, 2017

Specialized laboratories with open access – these are laboratories such as micro- and nano-scale construction laboratories that are used for research but also provide open access to the students at reasonable cost that can be covered by departments and sponsored by industry.

Figure 14: MakerWorkshop innovation network across MIT

These Maker Space facilities are envisioned to form **one innovation network to serve the entire community of the University** (Figure 14). Facilities in Architecture, Mechanical Engineering, Electrical Engineering Computer Science, 3D printing facilities, machine shops, nano-fabrication and other laboratories, will be community-accessible facilities, encouraging students from all departments to use them with open access, rather than compartmentalized by department. Achieving this vision requires substantial investments in maker spaces and laboratory staff, and curricular reforms that leverage maker spaces. Maker spaces also provide an ideal industrial sponsorship opportunity.

New undergraduate programs: Robotics empowered with artificial intelligence as well as Industry 4.0 technologies do not align well with current academic structures[37]. Given the cross-disciplinary nature of robotics that brings together principles and skills from different disciplines, **we recommend that universities consider new divisions, departments or cross-disciplinary undergraduate programs in Robotics and Artificial Intelligence** and be equipped with Makerspace laboratories. This will be essential to educate students trained in the new technologies with an ingrained ability to implement ideas. Graduates of such programs will be immersed in a culture of learning through doing, discovering that innovation comes through a process of continuous

[37] A 21st century Cyber-Physical Systems Education, National Academies Press, 2016

experimentation and tinkering rather than a single inspiration moment, and that this is as important as the program curriculum. Universities should also increase entrepreneurial training across all engineering and computing programs, providing exposure in early years and leveraging industrially-relevant project-based courses closer to graduation.

International graduate programs. At the graduate level, there is a great opportunity for universities to create state-of-the-art Master of Science (MS) or Master of Engineering (ME) programs in Robotics and Artificial Intelligence that could be a magnet for talent in the region, while also impacting regional Industry 4.0, AI, and robotics industries. Programs utilizing a modern curriculum in AI and robotics, with hands-on training in a network of Makerspaces can attract international students and can generate funding for supporting the programs and serve for attracting top students from other nations.

The programs should be international and taught in English. They need to be competitively priced, targeting students that cannot afford the high-tuition of US, UK programs or the high-cost of living in other European countries. Close collaboration with local and European industry is needed, providing students with industrial internships, allowing them an entry point to the European market. Organizing seminars and short courses in collaboration with industry are effective ways to expose students to industrial experience and innovation in the marketplace.

National Competitions as Drivers for Student Innovation: Open competitions organized for undergraduate students (such as AI Driving Olympics, PennApps) and high school students (such as First Lego League) galvanize the imagination of students at all levels. Setting robotic challenges with tangible results is paramount to motivate students and create a spirit of open-ended hands-on experimentation. We recommend developing highly-engaging national robotic competitions for students across the nation. Funding for such programs and students should be provided by foundations and industrial sponsors.

Remote Lab Teaching: COVID-19 forced teaching to be online, placing particular challenges to laboratory teaching. The development of methods to teach laboratory courses remotely, opened new, digital ways to reach students in remote locations and at scale. Also, the development of remote teaching methods that include the replication of laboratories, color-coded to teach safe operation, offer enticing opportunities for providing instruction remotely in replicated Makerspace areas for access to a much wider pool of people, including students in other universities or high schools.

Pre-University Education and Outreach Programs: A national cultural change that places emphasis in making and building requires that efforts start from early ages, as by the age of entering higher education institutions it may be too late to attract a sufficient number of students to become builders and innovators. Secondary education, in particular, is crucial to providing the impetus for building and making, as education in mathematics and the sciences can be complemented and enhanced by doing and building.

Educating teachers in the maker mentality is central to establishing in middle and high schoolers a spirit of exploration through doing. The government should focus on supporting robotics training programs[38] for teacher mentors, which will catalyze and broaden the culture change nationally[39]. This could be performed by launching university outreach programs and by universities and Robotics/AI Industry offering short one-week courses for high school teachers and students. Emphasis should also be placed on gender,

[38] http://codeskills4robotics.eu/
[39] https://wrohellas.gr/

geographic, and socio-economic diversity of such programs ensuring equitable access and exposure for all students across the nation.

5.6 Workforce Impact

There is no doubt that Robotics and AI technologies will have an immense impact on society and economy globally in the 21st century. Bank of America Merrill Lynch predicts that by 2025 the "annual creative disruption impact" from Robotics and AI could amount to **$14 Trillion to $33 Trillion** including **$9 Trillion reduction in employment costs** due to AI-enabled automation of knowledge work[40]. Studies have shown that robots not only result in cost reduction, but they also contribute significantly to higher levels of productivity and efficiency. When integrated with other technologies (AI, 5G, data analytics, computer vision, etc.) the market impact from the use of robots is even greater.

While experts are divided on whether automated, artificial intelligence applications and robotic devices will displace more jobs than they will create, there is no argument about the disruption Robotics and AI will bring to the global job market. The argument is rather how the economies in each country are structured to absorb the coming changes in the current employment model. In the OECD countries it is expected that 14% of jobs face a very high probability of automation, while in Greece the number is 23.4%, with another 35.3% of the workforce facing the distinct possibility of changing the type of job they do[41]. This poses a great challenge to the Greek economy in the decade to come.

In the long term, the market will adjust to support the new production model. Human ingenuity will create new jobs, industries, and ways to make a living, just as it has been doing since the dawn of the industrial revolution[42]. The real challenge is what happens to existing mid-career workers caught in the middle of the transition. One of the challenges is that adjustment to Industry 4.0 will require a workforce having a new set of skills and knowledge. There is a growing consensus that industry should facilitate the development and growth of existing and new firms by focusing on employment opportunities, skills development and training for those new to the workforce of these fields, and establish reskilling and up-skilling opportunities for existing employees. The key to avoid both unemployment and unfilled jobs will be public/private life-time learning[43].

Measuring Impact of Robotics in Greek Industry and Workforce

In order to better support this effort of transitioning to the new economic landscape, we recommend that **the government develop a framework for collecting, measuring, analyzing data on robots across government and industry, number of robot end users, analyze market impact and labor shifts, and highlight opportunities for innovation**. Such data can be used to assess the impact of robotics on the national economy, identify opportunities in certain sectors and industries, update strategy and policies, and recommend funding priorities or funding adjustments.

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[40] "The Future Has Arrived: Integrating Transformative Technologies in the Workplace" Garry Mathiason, Kelly Lecture on Robots and Jobs, Institute for Robotics and Intelligent Machines, Georgia Institute of Technology, November 18, 2016.

[41] «Τα ρομπότ στη βιομηχανική παραγωγή έρχονται. Οι θέσεις εργασίας μένουν;» Special Report, ROBOT και Απασχόληση, ΣΕΒ, Οκτώβριος 2019.

[42] "AI, Robotics, and the Future of Jobs," Pew Research Center, 2014.

[43] "A Robotics Roadmap for Australia," Australian Centre for Robotic Vision, 2018.

Although the predictions about potential job losses in Greece due to automation are above the OECD average, the lack of heavy industry in Greece is an advantage in this case, as industrial automation technologies are better adapted for "industries of scale." On the other hand, with a focus on **service robots and the associated technologies** that support them, there is a great **potential for high-end job gain and reversal of the country's brain drain**. Given the prospects for global growth in robotics, and the demand for people with the relevant skills, the overall framework to support these industries should consider not only how to encourage skill retention, but also how to attract the best talent from Europe and other countries. This will require the active participation of top-notch academic and research institutions, as well as the close collaboration between universities, big companies, and highly skilled human capital.

In order to help the mid-career workers that are "caught in the middle" of the transition from traditional manual-intensive jobs to highly automated ones, there is a need for the government to provide funding and policy initiatives to **support upskilling and retraining.** If nothing else, the COVID-19 pandemic has taught us that it is possible to deliver educational content remotely. By investing in "reskilling" workshops or short courses and by utilizing new technologies (e-learning) it will be possible to instill a mentality of "life-long learning" to the Greek workforce.

Promote Awareness via Hellenic Robotic Day

There is a need to **improve awareness** in industry, government and the wider community of the positive benefits of the adoption of robotics technologies, including job creation, improved service delivery in remote areas, efficiency and productivity gains, and safety. Among other efforts, the government should declare and support a **Hellenic Robotics Day,** perhaps as part of a Greek Robotics Conference & Expo (Section 5.3) with the goal of raising the public's awareness on the positive benefits of new robotic and related AI technologies, as well as inspiring the next generation about the future of robotics. The Hellenic Robotics Day would include a Robotics Exhibition for the broader public, high profile technical seminars highlighting positive impact in Greek society and economy, public discussions about the social and economic impact of robotics, demonstrations of national or EU research projects, educational events, as well as secondary school robotics competitions. Finally, there is also a need to promote a **culture of entrepreneurship and risk taking** among the Greek workforce, **encouraging and facilitating worker mobility**. Both Greek citizens and government officials alike should take pride in their international renown for being "first" or innovative.

5.7 Regulations, Legal, Ethics

Robot Safety Standards: Robots need to ensure the safety of humans at all times. But how "safe" is safe and how do we regulate robot safety? Safety standards are developed and maintained by the International Organization for Standardization (ISO). In the context of industrial robotics, the ISO 10218-1:2011 standard basically states that humans should be at a prespecified safe distance while a robot is operating. But with the emergence of collaborative robotics in Industry 4.0 settings, humans and robots will collaborate together in physical proximity. This has resulted in a new safety standard (ISO/TS 15066:2016) for collaboration between humans and robots. In aerial robotics, there is a recent ISO standard[44] while the EU harmonized regulation across member states for drones in civilian airspace[45].

The pace of innovation is advancing faster than safety regulation. In the emerging area of self-driving vehicles, safety standards are a topic of discussion among policy makers, automotive companies, and scientists[46] [47]. Similar safety considerations are critical in low-latency vehicle-to-vehicle communications, where 5G standards are critical for safe distancing of autonomous vehicles at higher speeds. In more cutting-edge areas like artificial intelligence, robustness in AI is not well understood scientifically. As unmanned vehicles are empowered with artificial intelligence, safe and trustworthy AI is a scientific and policy imperative[48]. From a policy perspective it is important to avoid over-regulation by embracing robot safety standards that ensure human safety but without stifling innovation. In this spirit, the government should also consider safe areas for experimental deployment of autonomous vehicles as well as mechanisms for certifying the safety of robotic technologies developed by Greek companies.

Robot Technology Standards: Future robotic systems will require the integration of very different technologies ranging from new robot platforms, sensors, hardware, AI, 5G, cloud computing, and big data analytics. It is clear that no single research team and no single company can provide solutions for all components. This makes open architectures and standards across technologies critical for enabling cooperation and partnerships across industry and for fueling innovation. For example, the Robot Operating System (ROS) has fueled innovation across academia and industry. Embracing such international standards will maximize the interoperability, and exportability of Greek technologies.

Privacy & Cyber-Security: Defining data property rights over robot data will be very important both for protecting data owners and also for creating a new economy for data. If property rights could be defined then there is a possibility for them to be traded. For example, as we instrument our vehicles (not necessarily self-driving) with sensors and cameras, insurance companies may reduce insurance premiums for the right to have access to the recorded data in case of an accident. Similar issues arise in healthcare robotics in case of medical malpractice. Who owns the surgical robot data, the patient or the doctor? These challenges get more complicated when aerial drones are used for search operations. Well-defined property rights will protect not only rightful data owners but also the broader public.

New technologies bring many benefits but also new technological vulnerabilities. As robots increasingly rely on networking, GPS, AI hardware and software, malicious attackers may exploit vulnerabilities and

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[44] https://www.iso.org/obp/ui/#iso:std:iso:21384:-3:ed-1:v1:en
[45] https://www.easa.europa.eu/domains/civil-drones-rpas
[46] Preparing for the Future of Transportation: Automated Vehicles 3.0, US Department of Transportation, 2018
[47] Germany publishes draft law for the approval of fully autonomous vehicles, February 2021
[48] https://www.oecd.ai/dashboards/ai-principles/P14

disrupt industrial operations or remotely take over control of autonomous vehicles or aerial drones. This makes the issue of cybersecurity for robotics and Industry 4.0 a very important, yet relatively new, scientific field. While state-of-the-art cybersecurity could eliminate many security issues, cybersecurity is typically an afterthought in many industries. Incentives for proactively securing critical infrastructure across robotics, AI, and Industry 4.0 will be critical for ensuring their safe and resilient operation.

University IP policies: Most Greek universities do not have technology transfer offices even though this is changing soon[49]. This results in universities and research centers being viewed as institutions for research and education but not as innovation engines for the Greek society and economy. This is more pronounced in robotics, where industrial innovation has grown out of universities (Section 5.3). To reverse this trend we recommend that all universities and research centers be supported by an Innovation Office whose mission will be to strengthen connections to industry, foster startup creation, provide incubator space, connect innovators to capital, and support innovation legally and from a business standpoint. The Innovation Office should develop IP policies that facilitate technology transfer (as opposed to protectionist policies) that are suitable for the competitive world in robotics and AI.

Robot Ethics: Robotics, like many other technologies, lends itself to dual-use and is sometimes export controlled[50]. In addition, there are emerging challenges regarding the ethical use of robotics and autonomous systems operating in the real world, their impact on the workforce, and on the economic transition to Industry 4.0. It is important that we develop and use such technologies with the proper ethical values and principles[51]. The European Parliament has issued a resolution on robotics law and ethics[52]. In addition to articulating values and principles, the resolution focuses on research and innovation, education and training, liability, intellectual property, data, standardization, security, and safety. The panel encourages further study from social scientists, economists, political scientists and philosophers to understand ethical, social, economic, and cultural challenges that are specific to Greece.

[49] https://www.iefimerida.gr/ellada/dimas-xekinaei-grafeia-metaforas-tehnologias
[50] https://www.europarl.europa.eu/RegData/etudes/BRIE/2019/642230/EPRS_BRI(2019)642230_EN.pdf
[51] https://ethicsinaction.ieee.org/
[52] https://www.europarl.europa.eu/doceo/document/TA-8-2017-0051_EN.html#title1

6. Summary

The whitepaper provides numerous findings and recommendations towards a Hellenic Robotics Initiative. In order to better understand how the individual recommendations described in the previous sections form a holistic approach towards improving the overall Greek robotics ecosystem, one can capture the relationship between the main proposed recommendations in Figure 15.

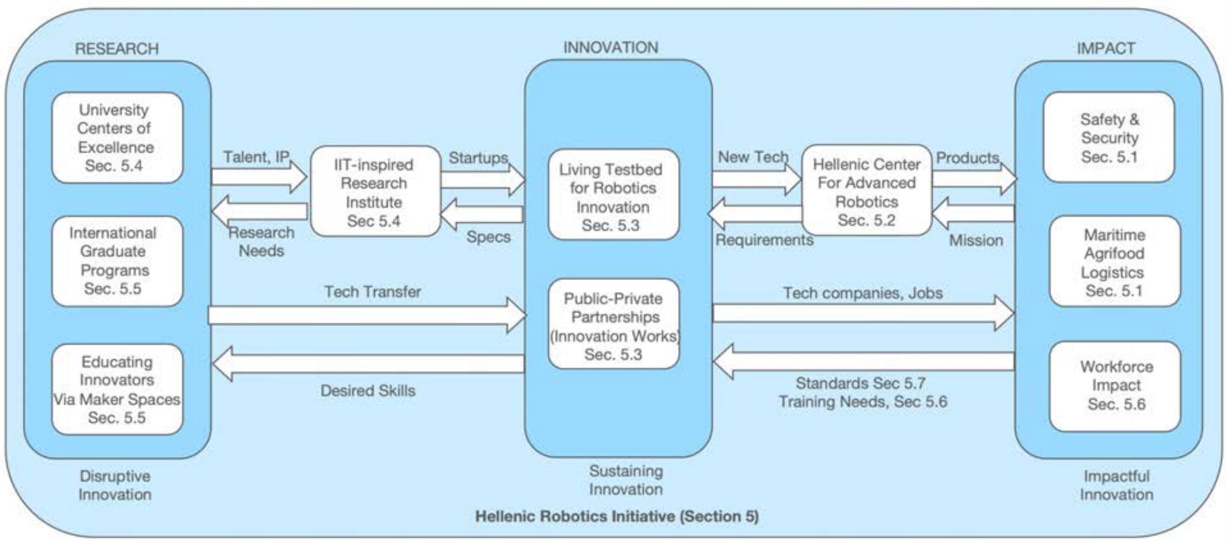

Figure 15: Summary of the Hellenic Robotics Initiative recommendations

From the perspective of the overall robotics ecosystem, our main recommendations aim at strengthening the relationships between the research, innovation, and societal impact pillars, in addition to strengthening the pillars themselves. In this sense, our goal is not only to strengthen the ecosystem as is but also to transform it by emphasizing impact-driven innovations as well as innovation-driven research. Taken together the proposed recommendations will pave the way for basic research to result in innovation growth as well as societal and economic impact. In reverse, anticipated workforce impact should lead to novel training programs as well as educational reform across all levels.

Given the numerous recommendations in this whitepaper, where does one start? Perhaps the most important recommendation in this whitepaper is to view the Greek robotics ecosystem as a whole. Therefore, the first step should be to assemble a Hellenic robotics council among leaders in Greek academia, research centers, industry, and government in order to sharpen, contextualize, and expand this report to a detailed national strategy with a phased implementation roadmap for robotics in the AI era. We hope that this whitepaper will be useful in their strategic discussions and we welcome the opportunity to continue this dialogue as the Hellenic Robotics Initiative becomes, hopefully, a reality.

Acknowledgements: We thank the HIAS members: Dimitris Bertsimas (MIT), Andreas Boudouvis (NTUA), Eleni Hatzi (ETH Zurich), Efthimios Kaxiras (Harvard), Daphne Manousaki (TU Crete), Demetri Psaltis (EPFL) for guidance, discussions, and comments on this whitepaper. We also thank Antonis Argyros (Crete), Spyros Fountas (AUA), Petros Maragos (NTUA), Pericles Mitkas (AUTH), Evangelos Papadopoulos (NTUA), Zoi Doulgeri (AUTH) for insightful and detailed comments on the document. We thank Antonio Bicchi (Pisa/IIT) and Nikolaos Tsagarakis (IIT) for inspiring discussions about the Italian Institute of Technology. Last, but not least, we are grateful to Dr. Christos Dimas (Deputy Minister of Research and Investments) and Michael Dritsas, (Ministry of Research and Investments) for their invaluable support during the preparation of this document.