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Artificial Intelligence in Industry 4.0: The future that comes true: AI

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Trend Innovation of Artificial Intelligence and Robotic Technology: Implementation in Advanced Robotic Systems

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Abstract: *In the last ten years, the development and research of advanced technologies, as well as their application in all segments of society, have led to major changes and reshaping of the new world. New innovations are occurring on a daily basis, but their application is not going fast enough due to the rigid infrastructure. However, in order to secure an optimal future, we all have to adapt to the changes that are coming. The developed countries have adopted the strict implementation of advanced technologies of Industry 4.0, some of which include: Internet of Things (IoT), Big Data, Cloud Computing, smart sensors, Radio Frequency Identification (RFID), 3D printing, advanced security systems, Virtual and Augmented Reality (VAR), etc. Robotics is the basic and first technology that has been implemented since the 60s of the last century, with artificial intelligence coming in the spotlight in the last ten years. Artificial intelligence is becoming a key to the development of advanced robots, as it enables them to adapt to unpredictable situations, to learn from experience and make intelligent decisions.Robots use AI to process sensor data, navigate, recognize objects, plan paths and interact with the environment. In short, artificial intelligence enables robots to be smart, whereas robotics uses AI to create autonomous and useful devices. This symbiosis contributes to progress in many industries, including healthcare, manufacturing and transportation. Artificial intelligence (AI) and robotics are two key fields that complement each other. The paper presents the trend of applied and approved patents in artificial intelligence and robotics, as well as an example of the use of artificial intelligence in advanced robots to perform certain tasks. Artificial intelligence (AI) is having an increasing impact on robotics, opening up many possibilities.*

Keywords: *artificial intelligence, advanced robots, patents, application, Industry 4.0*

1. Introduction

Artificial intelligence (AI) and robotic technology are currently in the center of interest of researchers throughout the world. Artificial intelligence is broadly defined and deals with intelligent behavior, perception, reasoning, learning as well as navigating and acting in a complex environment. By using artificial intelligence in robotic technology, we aim for all robots involved in all segments

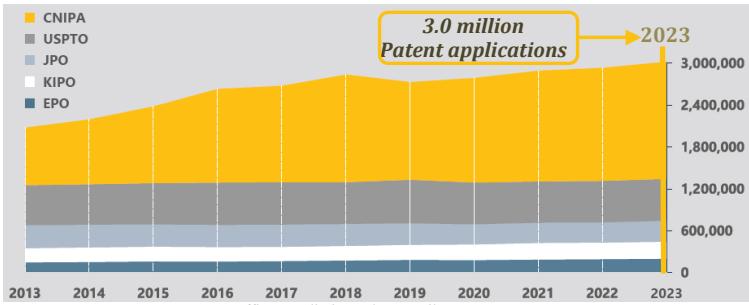
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around us to be intelligent, to have perception, to learn, to reason and navigate in a very complex environment, and to make decisions independently. The very implementation of industrial robots in production processes began in the 1960s, when the idea of automating appeared, primarily in the automotive industry. The roots of the formalization of human thinking and reasoning come from ancient Greek times. For example, Aristotle defined three basic laws of thought and syllogism, and later many important minds tried to create formal systems based on a combination of symbols. In 1950, Alain Turing (Turing's test - which requires the ability to process natural language, knowledge representation, reasoning and learning) laid the foundations of the philosophy of artificial intelligence. In 1955 Allen Newell and Herbert A. Simon created the first framework of artificial intelligence called Logic Theorist, while the authors Alfred N. Whitehead and Bertrand Russell demonstrated the use of this framework through 40 hypotheses *Principia Mathematica* [1-3]. At the conference in Dartmouth, a group of researchers defined the field called ''artificial intelligence'', which marks the beginning of research in this field. As a scientific field, like all other fields, it has been developing until today. However, with the development of the basic technologies of Industry 4.0 such as: Things (IoT), Big Data, Cloud Computing, Smart Sensors, Radio Frequency Identification (RFID), computers with increased processing power encourage its research and growth with a large amount of digitized data. Artificial intelligence is moving from theoretical research to the global market using a large amount of data based on which it conveys a revolutionary effect [4,5].Its implementation can improve productivity in industry, and can make significant changes in medicine, agriculture, meteorology and other segments of our environment. Even though AI is becoming a part of our lives today, we are still at the very beginning and we must discover what impact it will have on society, culture and business. Artificial intelligence is currently the light of transformation in various industrial branches and sectors, because it changes the way we work, buy, communicate with each other, travel, etc. With the emergence of Big Data technology, i.e., vast amount of information and artificial intelligence, both industrial and service robots are becoming more and more reliable, and their application in expanding the tasks they perform increases with human supervision. In other words, they are introduced to the tasks that were previously performed by workers [6,7]. Artificial intelligence is very interesting for robotic technology because of intelligent automation in production processes, which aims to make production processes intelligent.

2. Trend of Registered and Approved Patents in the World

The global competition of companies worldwide depends on investments in the development and research of new technologies. This is best shown in the trends

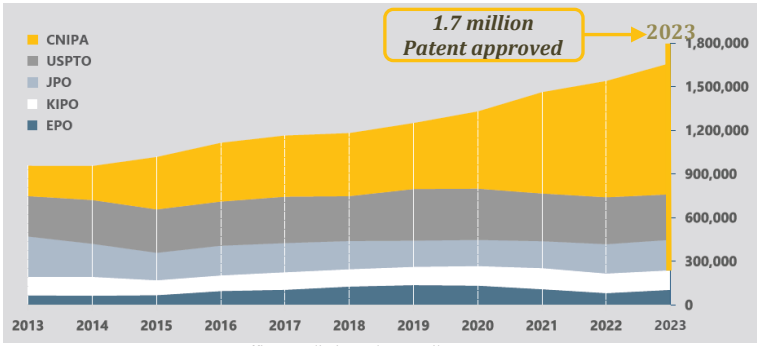
of registered and approved technological innovations, i.e., patents submitted in the offices in charge of filing and approving patents. The most important offices for the application and approval of patents in the world are: EPO – European Patent Office, USPTO – United States Patent and Trademark Office, JOP – Japan Patent Office, KIPO – Korean Intellectual Property Office, and CNIPA – China National Intellectual Property Administration. The annual trend of registered patents in the world for the period 2013-2023 in the aforementioned patent offices is shown in Figure 1 [8, 9].



Source: IP5 Offices, Preliminary data, April 2024

Figure 1. Trend of annually applied patents in the world for the period 2013-2023 in five patent offices in the countries of USA, EU, Japan, Republic of Korea and China [8, 9]

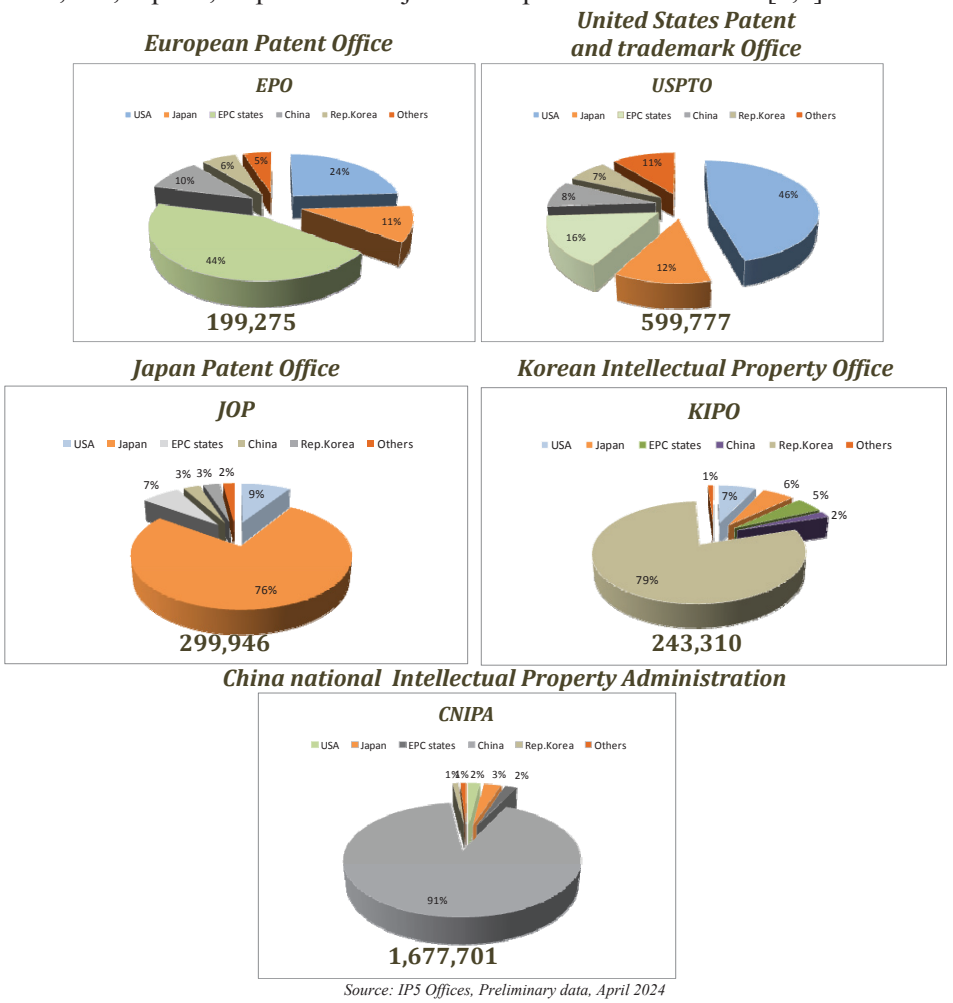
Based on Figure 1 we can conclude that the trend of patent applications in the world in the period 2013-2023 is continuously increasing. The number of applied patents in the world reached a value of about 3 million in 2023, as shown in Figure 1. Given that not all applied patents in patent offices were approved, Figure 2 shows the trend of approved patents in the world.



Source: IP5 Offices, Preliminary data, April 2024

Figure 2. Trend of annually approved patents in the world for the period 2013 - 2023 in five patent offices in the USA, EU, Japan, Republic of Korea and China [8, 9]

Likewise, as shown by the annual trend of approved patents in the world for the period 2013-2023, five patent offices are continuously increasing their work, so that in 2023 the number of approved patents amounted to about 1.7 million. We come to the conclusion that out of 3 million registered patents in the world, around 1.7 million patents have been approved. The number of approved patents compared to those applied for is around 57%. The real state of the number of registered patents in the world will be obtained if we look at the number of registered patents in five patent offices located in the countries: USA, EU, Japan, Republic of Korea and China, as shown in Figure 3 [8,9].
USA, EU, Japanu, Republici Koreji i Kini a prikani su na slici 3. [8,9].



Source: IP5 Offices, Preliminary data, April 2024

Figure 3. Annual applications of patents in the world in 2023 by application of origin in five patent offices in the USA, EU, Japan, Republic of Korea and China [8,9]

The diagrams shown in Figure 3 illustrate the trend of registered patents in the world in five patent offices: EPO – European Patent Office, USPTO – United States Patent and Trademark Office, JOP – Japan Patent Office, KIPO – Korean Intellectual Property Office, and CNIPA – China National Intellectual Property Administration, based on which we can conclude that companies from one country apply for patents in other countries because they have their own companies that work and operate in those countries. If we examine Figure 3, we can see that if we rank the patent application offices by the number of most filed patents, we will get the following arrangement from highest to lowest:

- 1.677.701 registered patents in CNIPA – China National Intellectual Property Administration,
- 599.777 registered patents in the USPTO – United States Patent and Trademark Office,
- 299.946 registered patents in JOP – Japan Patent Office,
- 243.310 registered patents in KIPO – Korean Intellectual Property Office, and
- 199.275 registered patents in: EPO - European Patent Office.

We come to the conclusion that the highest number of registered patents in the world is located on the continent of Asia because it includes three patent application offices, namely CNIPA, JOP and KIPO.

The current state of research, the most represented scientific research in artificial intelligence and robotic technology, as well as the identification of research directions in the future will be obtained based on the biometric analysis of the trends of registered and approved patents in artificial intelligence and robotic technology. In the last ten years, the interest of the academic community, research institutes, and companies that strive to implement these two technologies in their production processes has been growing. The paper provides an analysis of the trend of registered and approved patents in artificial intelligence and robotic technology in the last ten years.

3. Trend of Applied and Approved Patents in Artificial Intelligence

Extensive research is being conducted all over the world when it comes to artificial intelligence. Huge amount of money is being invested in this research with the aim of creating an environment in which productivity can be increased for the purpose of reducing the production time that can be provided by the individual. The development and research of artificial intelligence reveals its application in every field, whether it is the production process in companies, logistics, accounting, assembly companies, agriculture or medicine. There is no segment of human life where AI cannot be used. The advantage of using artificial intelligence is that it can analyze a large amount of information which usually does not fit into any of the ordinary computer, much better than any

human. In recent years, there has been a sudden interest in artificial intelligence research, which is shown by the trend of approved patents in artificial intelligence shown in Figure 4.

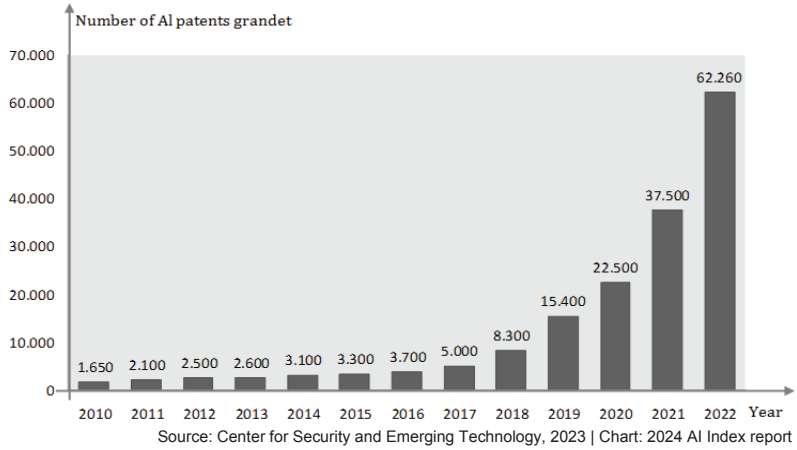


Figure 4. Diagram of the number of approved Al patents in the world for the period 2010-2022 [9-11]

The analysis of the diagram of the number of approved artificial intelligence patents shown in Figure 4 for the period 2010-2022, provides us with the conclusion that the number of approved patents in artificial intelligence has been growing rapidly since 2016. For example, between 2010 and 2015, the growth of registered patents in artificial intelligence was 2 times higher, whereas in the next five years in the period 2015-2020, the growth of registered patents in artificial intelligence was 6.8 times higher. In just one year, in the period 2021-2022, the trend of approved patents was 1.7 times higher. In twelve years, during the period between 2010 and 2022, the number of approved patents increased enormously by 37.7 times. Based on Figure 4, we come to the conclusion the trend of approved patents in artificial intelligence in the world had a sudden growthsince 2015. In order to get more complete information about the number of patents in artificial intelligence, Figure 5 shows the trend of approved and unapproved patents in artificial intelligence.

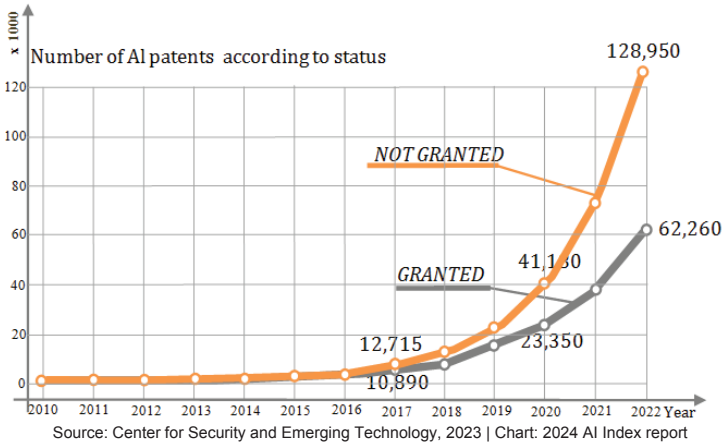


Figure 5. Diagram of the number of unapproved and approved Al patents in the world for the period 2010-2022 [9-11]

The diagram shown in Figure 5 gives us an insight into the trend of approved and unapproved patents in artificial intelligence in the period 2010-2022. As the diagrams in Figure 5 show, the number of approved patents has been increasing since 2016, so that in 2017, 10.890 artificial intelligence patents were approved, whereas 12.715 patents were not approved. In 2020, the number of approved artificial intelligence patents was 23.350, while far more patents in artificial intelligence were not approved, i.e., 41.130. In just one year, the number of patents that were not accepted in 2022 amounted to 128.950 patents, whereas 62.260 patents were approved.It can be seen that the number of unapproved patents is 2 times higher than the number of approved patents in artificial intelligence. We come to the conclusion that since 2016, the trend of the number of applied patents has followed an exponential function, including the number of approved and unapproved patents in artificial intelligence.

The gap between approved and unapproved artificial intelligence patents has been continuously increasing since 2016, as shown in Figure 5. To get a more complete insight in the number of approved and unapproved artificial intelligence patents, Figure 6 shows the trend of approved and unapproved artificial intelligence patents in countries that invest in its development and research.

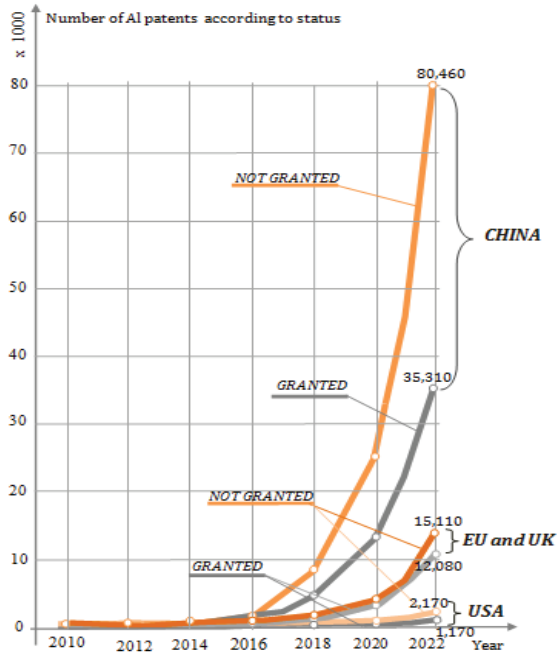


Figure 6. Diagram of the number of unapproved and approved patents in artificial intelligence in China, EU and UK, USA for the period 2010-2022 [9-11]

Figure 6 shows the trends of unapproved and approved artificial intelligence patents in China, European Union, Great Britain and USA in the period 2010-2022. Through the analysis, we can conclude that China ranks first in the world in terms of the number of approved and unapproved patents in artificial intelligence. As of 2015, the number of approved and unapproved patents in artificial intelligence has been continuously increasing in China. However the gap between approved and unapproved patents was also increasing. We can see that in 2022, China had 35.310 approved patents, but also 80.460 unapproved patents. The second place in terms of the number of approved and unapproved patents in artificial intelligence is held by the European Union and Great Britain. These countries have a small difference between approved and unapproved patents in artificial intelligence, so that in 2022 the number of approved patents amounted to 12.080, while there were 15.310 unapproved patents. The third place is occupied by the USA, with a large discrepancy between approved and unapproved patents in artificial intelligence in 2022. They had 1.170 approved patents and twice as many unapproved ones, that is, 2.170. In order to describe the actual situation of the countries that are investing in and developing artificial intelligence, we have shown the percentage of approved patents in relation to the

total number of approved patents in the world. The analysis includes the countries: China, EU, UK, USA, India and the rest of the world in the period from 2010 to 2022, as shown in diagrams in Figure 7.

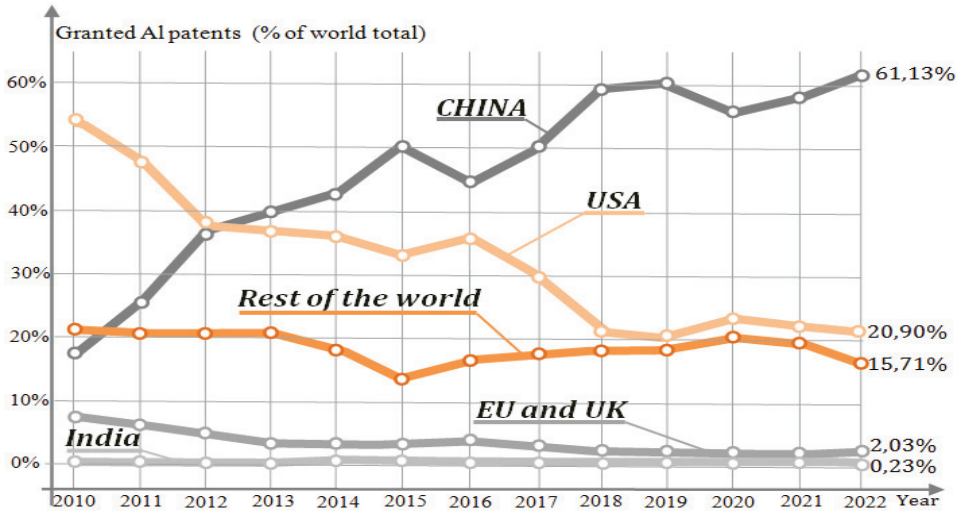
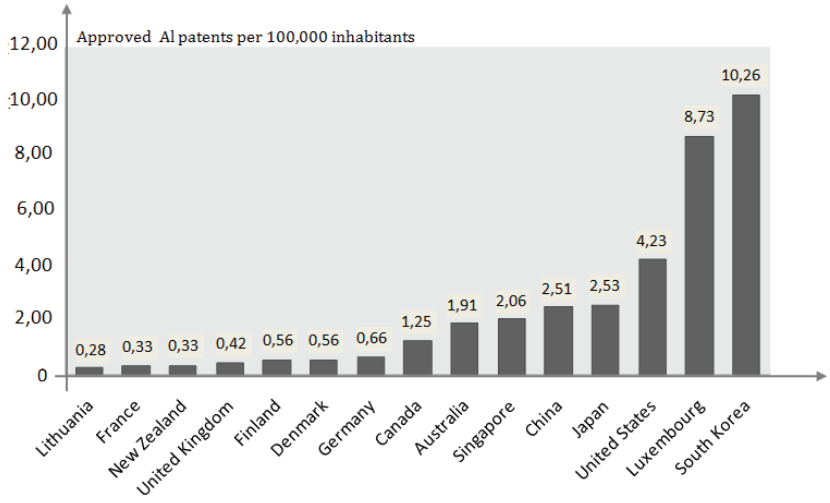


Figure 7. Diagram of approved patents in artificial intelligence in China, USA, EU and UK, India and the rest of the world in the period 2010-2022 [9-11]

By analyzing the diagram in Figure 7, we can conclude that up to 2012, the USA was the world leader whose percentage of approved patents in relation to the total number of approved patents in the world was the highest, so that in 2010 it amounted to about 54 %. In the same year, namely 2012, China had about 18 % of approved patents, followed by EU and UK with about 8.85 % of approved patents, India with about 0.15 % of approved patents, while other countries of the world had about 21 % of approved patents in relation to the total number of patents in artificial intelligence. The trend of approved patents was constantly changing in the period 2010-2022, as shown in Figure 7, so that the trend of approved patents in China was continuously increasing, while in the USA, as well as in the EU and the UK, it was continuously decreasing. As of 2012, China has taken the lead in terms of the percentage of approved patents in artificial intelligence in relation to the total number of approved patents in the world until today. In 2022 China had 61.13 %, followed by the USA with 20.90 %, the EU and the UK with 2.03 %, India with 0.23 % and rest of the world countries 15.71 % of approved patents.The USA, EU and UK recorded a decline in approved patents in the period from 2010 to 2022. We can note that the largest share of the world's approved patents in artificial intelligence originates from Asia, where

China is the leading country. Figure 8 shows which countries in the world are the leaders in the number of patents per capita.



Source: Center for Security and Emerging Technology, 2023 | Chart: 2024 AI Index report

Figure 8. Diagram of the number of approved patents in fifteen leading countries in the world per 100.000 inhabitants in 2022 [9-11]

Based on the diagram shown in Figure 8, we see that out of fifteen countries in the world in 2022, five countries are leading in terms of the number of approved patents per capita, namely the Republic of Korea, Luxemburg, the USA, Japan and China. The first place is held by the Republic of Korea with 10.26 approved patents per 100.000 inhabitants, followed by Luxembourg with 8.73, the USA with 4.23, Japan with 2.53 and China with 2.51 approved artificial intelligence patents per 100.000 inhabitants. The other countries ranked by the number of approved patents per capita are: Singapore, Australia, Canada, Germany, Denmark, Finland, the United Kingdom, New Zealand, France and Lithuania, with the values shown in the diagram. We come to the conclusion that the largest number of approved patents in artificial intelligence in the first five countries is coming from Asia, mostly owing to the Republic of Korea, Japan and China. It is expected that this trend of approved artificial intelligence patents will continue in the coming years, and that China will join the leading country in the world, namely the Republic of Korea. China is implementing its National Program for research, development and implementation of high technologies named *''863 Program''* which is implementing both specific goalsandthe long-term goals in order to transform China into a global leader in future production.

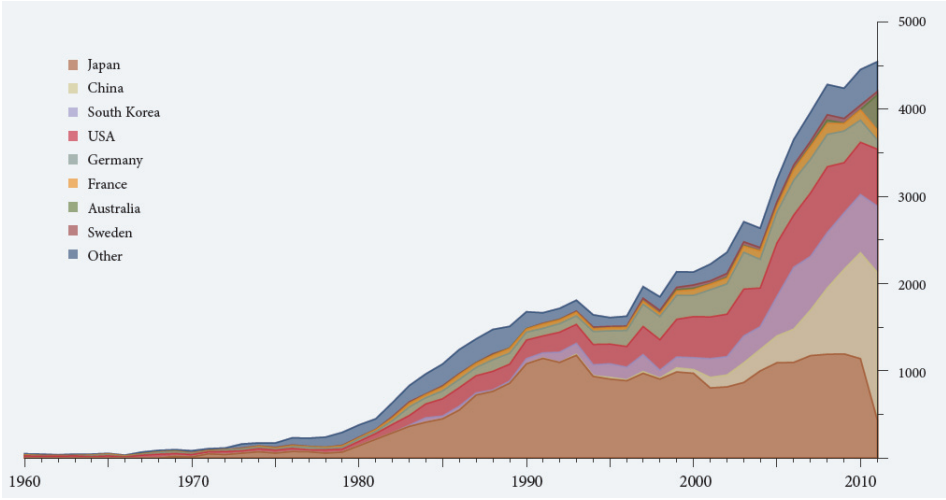
4. The Trend of Applied and Approved Patents in Robotics

Robotic technology, one of the basic technologies of Industry 4.0, leads us in the direction of intelligent automation, even though its research and development has potential impacts in other areas, such as healthcare, agriculture to security. Advanced robotics refers to specific design characteristics as well as the ability to:

- be autonomous to work in an unstructured or unsafe environment,
- be mobile and cooperate with other workers in the production process,
- be designed to manipulate or physically interact with their environment,
- be trained to achieve the desired results without the need for reprogramming,
- safely perform tasks in intimate operations with people or in extremely dangerous environments.

In order to provide all these characteristics of advanced robotics, it is necessary to continuously work on research and development of robotic technology, as well as technologies that represent support for robotic technology. In the last fifteen years, the demand for robotic technology has been increasing, as companies are hastily implementing it in their production processes in order to be competitive on the global market. The advancements in development and research in autonomous navigation, smart sensors, computer vision, and machine learning technology help create more mobile robots, which are more agile and collaborative, as their awareness of the environment in which they operate increases their implementation. In order to have an insight in the research and development of robotic technology, we must follow the trend of applied and approved patents in robotic technology. Figure 9 shows the trend of first patent applications in the field of robotics by origin and type of applicant in the period 1960–2011 [10,11].

The analysis of the trend of approved patents since the very beginning of the application of the first robotics patent in the 1960shas shown that the number of applications for robotics patents has been continuously increasing until today. We must note that since 2000, the number of patents began to increase not only in Japan, but also the Republic of Korea and China, which can clearly be seen from the diagram shown in Figure 9.



Note: Only the first filings with at least one patent granted within the patent family are counted.
Source: WIPO based on the PATSTAT database

Figure 9. Trend of patent applications in robotic technology in the period 1960-2010 in countries that focus on research and development of robotic technology in the world [10, 11]

The basis for applying patents in robotic technology is the development of the automotive and electrical/electronic industry, because in order for companies to be competitive on the market, they must invest in research and developmentdue to the increase in quality and productivity by implementing robots in their production processes. In recent years, increasing number of Internet companies are entering the field of robotics, employing experts in robotic technology and entering the market with new robotic systems.

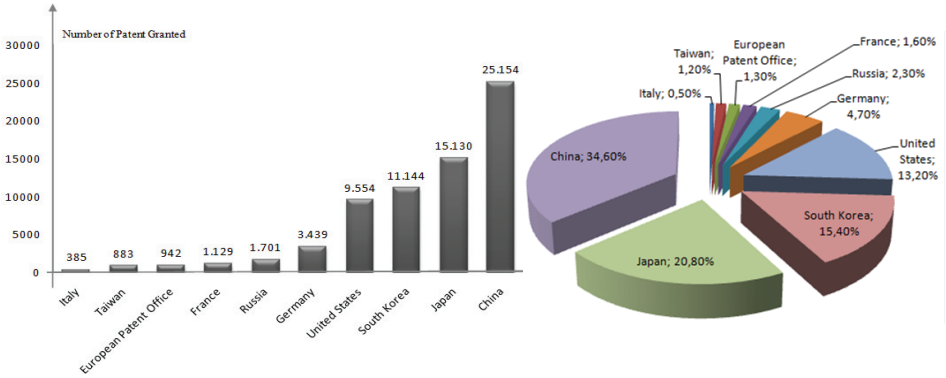


Figure 10. Approved patents in robotic technology in ten countries in the world in the period 2005-2019 [12-15]

Likewise, as of 2010, the percentages and numbers of registered patents change from country to country depending on the national strategy of that country. The real insight into the development and research in robotic technology in the world can be seen in the analysis of patent applications in the top ten countries in the world, as shown in Figure 10 [9,10-12]. When applying for robotics patent, a patent can be an underwater robotics patent, a manufacturing robotics patent, a mobile robotics patent, a military robotics patent, robotics with artificial intelligence, or a patent involving the physical components of the robot and control system characteristics. Figure 10 includes all the approved patents in robotic technology previously listed in the top ten countries in the world.

The top ten countries in the world include those countries that have companies for the development, research and production of robots, and have developed automotive and electrical/electronic industries, since it is known that these two technologies implement more than 50 % of all robots produced in one year. These countries are the following: China, Japan, USA, Italy, Taiwan, France, Russia, Germany, and Republic of Korea. If we examine the number of approved patents in robotic technology for the period 2005-2019, we can see that China holds the first place with 25.154 approved patents, which represents 34.6 % of the total number of approved patents, followed by Japan with 15.130 approved patents or 20.8 %, South Korea with 11.144 approved patents or 15,4 %, United States with 9.554 approved patents or 13.2 % and finally Germany with 3.439 or 4.7 % f approved patents in robotic technology. The following top five countries in terms of the number of approved patents in robotic technology, ordered by size, are the following: Russia (1.701), France (1.129), European Patent Office (943), Taiwan (883) and Italy (385). The analysis of approved patents in robotic technology in 2019 gives a clearer picture of research, development and improvement of advanced technology in countries that develop robotics. The analysis is shown in Figure 11 [12-15].

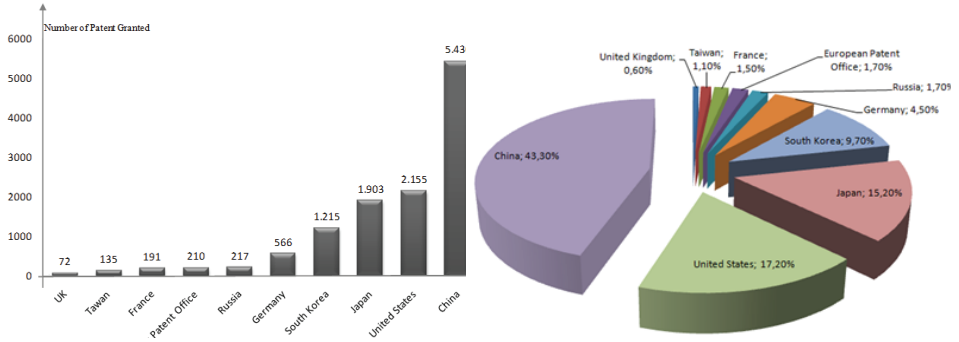


Figure 11. Approved patents in robotic technology in 2019 in ten top countries in the world [12-15]

The leading country in terms of the number of approved patents in 2019 was China with 5.410 patents in robotics, followed by the USA with 2.155 approved patents. Next in the line are: Japan with 1.903, Republic of Korea with 1.215 and Germany with 566 approved patents in robotic technologies. In terms of percentage, the ranking goes as follows: China 43.3%, USA 17.2%, Japan 15.3%, Republic of Korea 9.7% and Germany 4.5% of approved patents in robot technology. The trend of approved patents in robotic technology in these countries in the period 2005-2019 is shown in Figure 12 [12-15,16]. As we have already mentioned by analyzing Figure 9, as of 2000, in addition to Japan from Asia, the increasing trend of approved patents originates from China and the Republic of Korea, and continues to grow until today. China has become the leader when it comes to the number of applied and approved patents in robotics technology in the world and remains so until today. China is also the leader in development and research in robotic technology,as shown in Figure 12 [9-11]. Nowadays, many companies face global competition. However, the solution to competitiveness on the global market is based on new technologies that offer answers. Only those technologies that deal with the growth of production and productivity are able to significantly improve the quality of production and enable the company to achieve an improvement in its competitive advantage, in other words to make the company successful

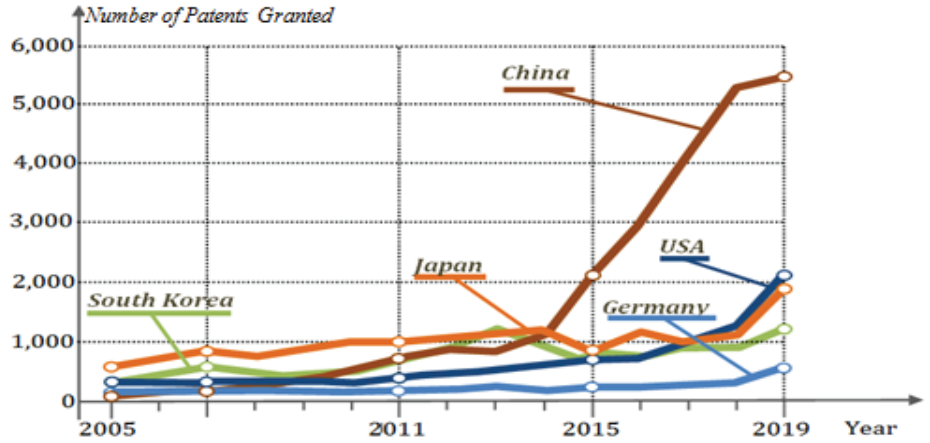


Figure 12. Approved patents in robotic technology in China, Japan, Republic of Korea, USA and Germany in the period 2005-2019

The company can achieve all of the above by implementing Industry 4.0 technologies, which include: Internet of Things (IoT), Big Data, Cloud Computing, smart sensors, Radio Frequency Identification (RFID), 3D printing, advanced security systems, virtual and augmented reality (AR), etc. In addition to the above-mentioned technologies, the basic technology is robotic technology,

without which there is no flexible automation, reduction of production costs, higher quality, increased productivity and other steps, from the delivery of raw materials to the transportation of products to the customer, and recently, the successful implementation of artificial intelligence. By implementing all the mentioned Industry 4.0 technologies, the company should be competitive with other companies on the global market. To analyze the role of advanced robotics in industry, it is necessary to explain the difference between conventional robots, that is, robots of the first generation in relation to advanced robots, that is, robots of the second generation. The first-generation robots are surrounded by fences from workers so as not to injure them, and the best example is industrial robot that serves to perform certain operations. The second-generation robots, or advanced robots, are a combination of powerful hardware and sophisticated programming, using smart sensor technology (including ultrasonic, touch, and light sensors) that interact with their real-world environment to perform real-world tasks.

Advanced robotics is the robotics of the future, because advanced robots are becoming flexible, smart, intelligent, autonomous and efficient. The implementation of advanced robotics in industry will transform production processes. Advanced robots are equipped with new technologies so that they have programmed abilities to make decisions on their own, which allows them to make decisions independently and function and navigate in any new environment. By implementing advanced robots with the basic technologies of Industry 4.0, we transform the rigid automation of production processes into flexible production processes that are simplified, increase productivity, reduce errors, increase product accuracy and ensure the efficiency of the production process. With its implementation in industry, advanced robotics has a number of benefits, some of which are the following:

- increased productivity,
- increased speed,
- quality improvement,
- increased security,
- increased accuracy,
- increased agility.

The implementation of advanced robotics in production processes will enable it to understands the production process faster, become more intelligent, and busier. At the same time, manufacturers can use it in the configuration of new production processes that meet the growing demand for more product variations, customized products and redesigns. Currently, advanced robotics is in the focus of research because its capabilities have not yet been utilized, as its complexity and the depth of its implementation need to be understood. There are many technologies that will contribute to its greater use in all segments of society, and

one such technology is material technology, which has great potential because it is possible to find materials that will create soft grippers that are flexible and have the ability to grip a wider selection of objects. This technology is also known as soft robotics. Soft robotics is in the research trend and smart solutions are expected in the coming years in different technologies such as material technology, so that materials and design can be carefully studied and evaluated. Other technologies that will contribute to the advancement of advanced robotics are robotic hardware-smart sensors, machine learning and quantum computers.

5. Implementation of Artificial Intelligence in Advanced Robotics

Trend of approved patents in artificial intelligence and robotic technology in relation to other technologies in the period 2011-2019 is shown in Figure 13 [13, 14, 16].
By analyzing the diagrams shown in Figure 13, we conclude that the trend of artificial intelligence patents is experiencing significant growth since 2016 until today and is far greater than that of robotics technology. In 2019,it made an increase of about 140% compared to the previous year, while at the same robotic technology had an increase of about 32%.

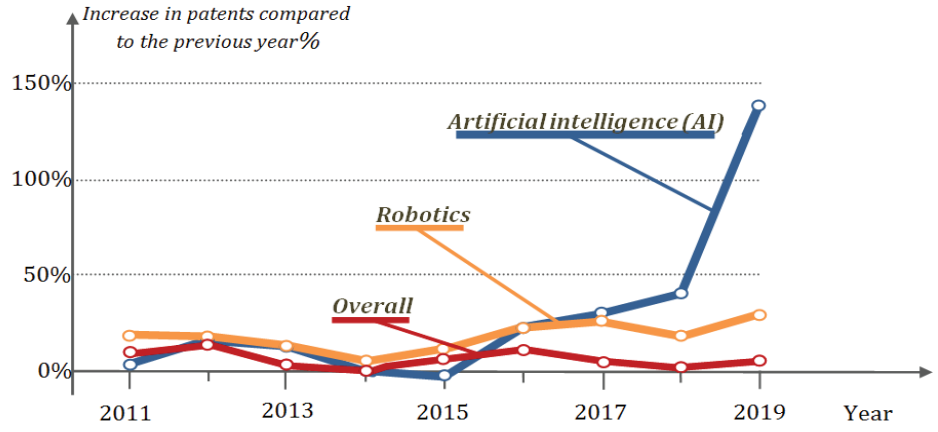


Figure 13. Comparative analysis of the percentage increase in patents from robotic technology and artificial intelligence compared to other technologies in the period 2011-2019

In recent years, artificial intelligence (AI) and computer vision have experienced an increase in patents compared to other technologies. The reason is that this is a newly emerging field of research, even though it had a lower number of patents than robotic technology until 2016. This trend of patent growth will continue in the years to come. The overall representation of approved patents in robotics

technology in the world is obtained by analyzing the patents of five top countries in the world in this technology, as shown in Figure 13 [13-14, 16].

The implementation of advanced robotics and artificial intelligence is the future, because advanced robots with artificial intelligence become flexible, smart, intelligent, autonomous and efficient. The implementation of advanced robotics and artificial intelligence in industry will transform production processes. Using artificial intelligence, advanced robots can have programmed abilities that allow them to make decisions independently because it enables them to function in any type of environment and navigate within that environment. By implementing advanced robots and artificial intelligence with the basic technologies of Industry 4.0, we transform the rigid automation of production processes into flexible production processes that are simplified, increase productivity, reduce errors, increase product accuracy and ensure the efficiency of the production process. As we mentioned, advanced robotics includes the entire spectrum of advanced technologies, all of which contribute to the improvement of industrial processes in all industrial branches. Processing, precision and speed are key characteristics in the field of robotics. High precision sensors, computer vision systems and advanced control algorithms are integral components [17]. Computer-aided design (CAD) models allow robots to be controlled with high precision, whereas force feedback sensors allow them to adjust their actions in real time to ensure optimal material removal rates and achieve results close to specialized CNC machines [18,19,21].

Let us mention one example of the use of advanced robotics and artificial intelligence, which was discussed by the authors [20]. This is the system architecture and communication between multiple devices, as shown in Figure 14. In the processing cell, an industrial robot with six DoF (FAUNC-M20iD/35) is used for the automatic grinding process, and a motor-driven gripper is installed at the end of the robot for accepting workpieces. In their paper, the authors [20,21], show the grinding, deburring and polishing processes that also benefit from robotization, especially through the use of modern end effectors. Force and torque sensors integrated into the end effectors provide feedback to the robot so that it can adapt its force application to material properties and surface conditions.

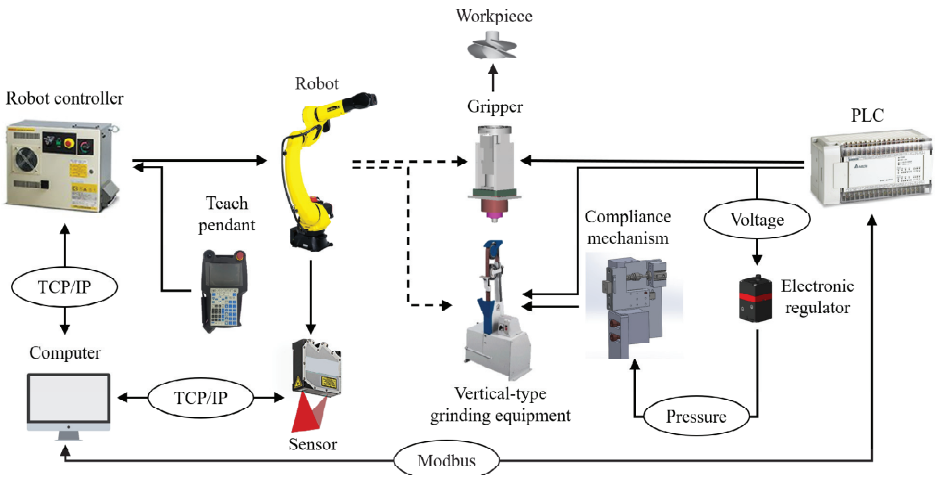


Figure 14. Schematic representation of the architecture and communication of an industrial robot with multiple devices – an example of grinding, deburring and polishing (obtained from [20,21]

Machine vision systems are used in quality control to check surfaces for defects and ensure that the product meets the required specifications. These technologies not only improve the efficiency of the machining process, but also contribute to the overall quality of the manufactured components.

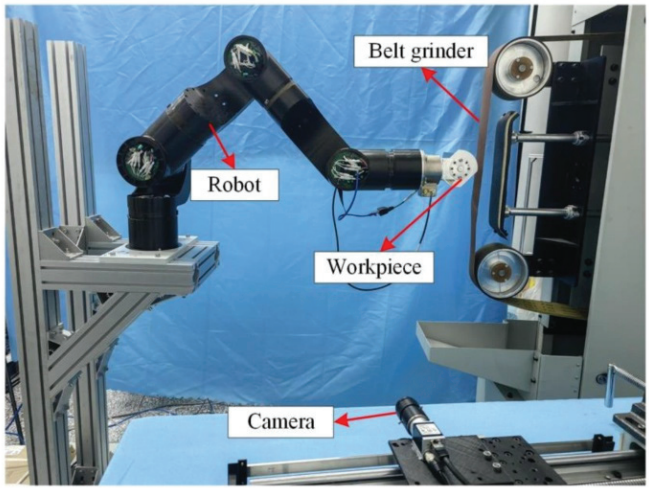


Figure 14. An example of controlling the roughness of the product surface with the use of an advanced robotic system and artificial intelligence during grinding of workpieces (obtained from [22])

When talking about the interaction between a human and a robot, the use of artificial intelligence (AI) offers innovative approaches to improve collaboration. One important capability is intelligent task assignment, where artificial intelligence algorithms evaluate human and robot performance data in real time and optimize productivity by assigning tasks tailored to individual strengths. Additionally, AI-powered robots can continuously learn from human behavior using adaptive learning systems to promote more intuitive and responsive collaboration. AI-based predictive maintenance uses sensor data to detect potential problems, ensure proactive interventions and reduce downtime. The implementation of natural language processing (NLP) enables contextual communication and therefore more seamless interaction between humans and robots. One of the biggest advantages of integrating artificial intelligence in human-robot collaboration is security monitoring. These systems play a key role by detecting threats or deviations from safety protocols and initiating interventions to ensure safe and efficient human-robot collaboration [21,23].

6. Conclusion

We can conclude that in the last ten years the number of registered and approved patents in artificial intelligence and robotics technology has been continuously growing worldwide. However, artificial intelligence has been in the first place among all technologies in recent years. As of 2000, the number of patents began to increase not only in Japan, but also the Republic of Korea and China, which is clearly visible from the diagrams presented in the paper. The basis for applying for patents in robotic technology is the development of the automotive and electrical/electronic industry, because in order for companies to be competitive on the market, they must invest in research and development in robotic technologyto achieve an increase in quality and productivity by implementing robots in their production processes. We must single out China as the leading country in the world in terms of registered and approved patents in artificial intelligence and robotic technology. Artificial intelligence is becoming crucial for the development of advanced robots, as it enables advanced robots to adapt to unpredictable situations, to learn from experience and make intelligent decisions. Robots use artificial intelligence to process sensor data, navigate, recognize objects, plan paths and interact with the environment. In short, artificial intelligence enables robots to be smart, and robotics uses artificial intelligence to create autonomous and useful devices. This symbiosis contributes to progress in many industries, from healthcare to manufacturing and transportation. Artificial intelligence (AI) and robotics are two key fields that complement each other. Advanced robotic technology is enhanced by hardware and software innovations based on the basic technologies of Industry 4.0, so that it enables devices, machines and equipment to make independent decisions and

undertake further actions independently. The infrastructure of advanced robotics is based on Cloud Computing, Deep Learning, Big Data and the Internet of Things (IoT). In order to plan and create a path, advanced robotics uses a holistic data model that includes digital representations of the product and the production system along with the life cycle. The system of controls during the performance of the task for efficient management synchronizes the integration of digital technologies and workers in the production process. Advanced robotics increases efficiency in the production process, because solutions are made through self-learning technology and artificial intelligence, and familiar tools such as robotic process automation and intelligent process automation can also be included. The implemented advanced robotic systems in production systems providemobility, perception, integrability and adaptability. There has been a greater implementation of advanced robotic systems in production processes in recent years. Industries that use robotic systems can gain a competitive advantage by increasing productivity and efficiency. The legal and regulatory framework developed around artificial intelligence requires a responsible approach to implementation and emphasizes the need for ethical considerations when integrating advanced technologies. Future directions also include exploring new applications of artificial intelligence in robotics to push the boundaries of what can be achieved beyond human expertise. The development of technologies to improve precision, machine learning algorithms and collaborative robots will contribute to the development of increasingly sophisticated and adaptive robotic systems.

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